VOLUME 1 NUMBER 3 MARCH 1964

IEEE spectrum

features

IEEE Convention

departments

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

IEEE spectrum

the cover

When cholesterol chloride is heated until it melts and then is carefully cooled, the transitional state between liquid and solid—the liquid crystal state—can be seen with the aid of polarized light microscopy. White "nematic" threads or molecular units begin building self-organizing systems on the surface of a microscopically thin crystal by addressing each other until a final state is reached. This final state as photographed by Marcel Vogel of IBM is shown by the cover illustration. Here multiple series of organized systems are visible. In the stacked layers of molecular units, information is transmitted from one layer to the other. One can develop an analogy to the modular concepts which are at present of such high interest in the semiconductor field where components are stacked on top of each other and interconnected—but once again nature has anticipated the innovation of man. Man's "modular magic" will be featured at a special evening symposium on March 24 during the IEEE Convention.

IEEE SPECTRUM is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Headquarters address: Box A, Lenox Hill Station, New York, N.Y. 10021. Cable address: ITRIPLEE. Telephone: 212—PL 2-6800. Published at 20th and Northampton Sts., Easton, Pa. **Change of address** requires thirty days notice to IEEE Headquarters. **Annual subscription:** IEEE members, first subscription included in dues, one additional subscription $13.50. College and public libraries, $13.50 in U.S.A. and Canada, $14.50 elsewhere. Others, $18.00 in U.S.A. and Canada, $19.00 elsewhere. Single copies: members, one additional copy $1.00, college and public libraries, $1.50 in U.S.A. and Canada, $1.75 elsewhere. Others, $2.00 in U.S.A. and Canada, $2.25 elsewhere. **Editorial correspondence** should be addressed to IEEE SPECTRUM at IEEE Headquarters. **Advertising correspondence** should be addressed to IEEE Advertising Department, 72 W. 45 St., New York, N.Y. 10036. Telephone: 212—MU 2-6606.

Planar arrays using either electrically large or electrically small elements have been used as adaptive antennas. This subject has received so much attention that the March 1964 issue of the IEEE Transactions on Antennas and Propagation is a special issue devoted to adaptive antennas. This month Warren White and Lorne De Size describe an adaptive feed system that can be used with a large reflector to provide adaptive capabilities.

Adaptive Techniques for Large Reflector Antennas

In recent years, there has been a growing interest in adaptive antennas that can adjust themselves to fit perturbations of the received wavefront. Such perturbations arise as a result of errors in pointing angle, inhomogeneities in the atmosphere, and mechanical deformations in the antenna structure.

All adaptive antennas use some method of dividing the incoming wavefront into multiple samples which are then made coherent by some form of phase-lock loops. Sometimes the individual elements of the antenna are small (dipoles) and wide-angle coverage is obtained by purely electronic means. In other cases, the number of elements required is sharply reduced by using large elements such as parabolic reflectors.

This latter type of system requires a combination of electronic and mechanical steering techniques to obtain wide-angle coverage. An example is the array of four 30-foot parabolic reflectors installed at Ohio State University. The electronic instrumentation for this array was supplied by AIL.[1]

A third technique, which we will discuss, uses a single large reflector with an adaptive multiple-point feed. The geometry of this antenna is shown in Figure 1. The antenna consists of a single parabolic reflector with a number of feeds located on a spherical surface centered at the focal point of the parabola.

For an undistorted plane wave arriving along the parabolic axis, the reflector converts the wave to a converging spherical wave centered on the focus. Thus, the energy intercepted by the feed system is in phase and can be easily summed. If the wave is distorted by atmospheric inhomogeneities or structural deformations, considerable compensation can be obtained by appropriate adjustment of the phase of each feed. The amount of distortion that can be successfully compensated depends on the type of distortion and the number of feed points available.

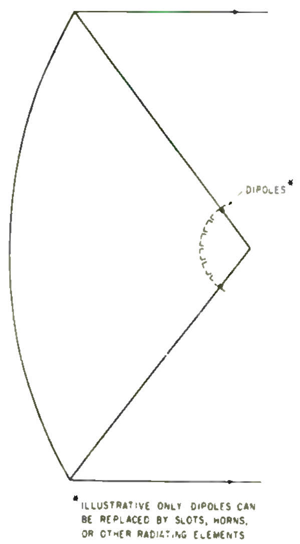


FIGURE 1. Cluster-feed antenna

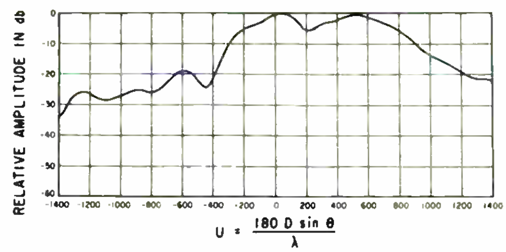


FIGURE 2. Radiation pattern from 31-feed cluster with uncorrected one-wavelength maximum linear distortion on reflector

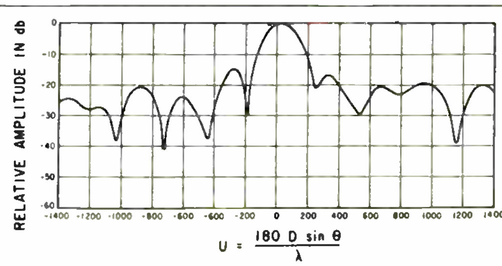


FIGURE 3. Radiation pattern from 31-feed cluster with corrected one-wavelength maximum linear distortion on reflector

The type of compensation that can be achieved is shown in Figures 2 and 3. The antenna involved is a distorted parabola with 31 feed elements. The distortion consists of a one-wavelength linear bend extending over one half of the reflector surface. Figure 2 shows the radiation pattern when the feed elements are summed in phase; Figure 3 shows the corresponding pattern when the feeds are adaptively rephased to conform to the distorted wavefront. Although the resulting pattern is not perfect, it is a vast improvement over the blob of Figure 2.

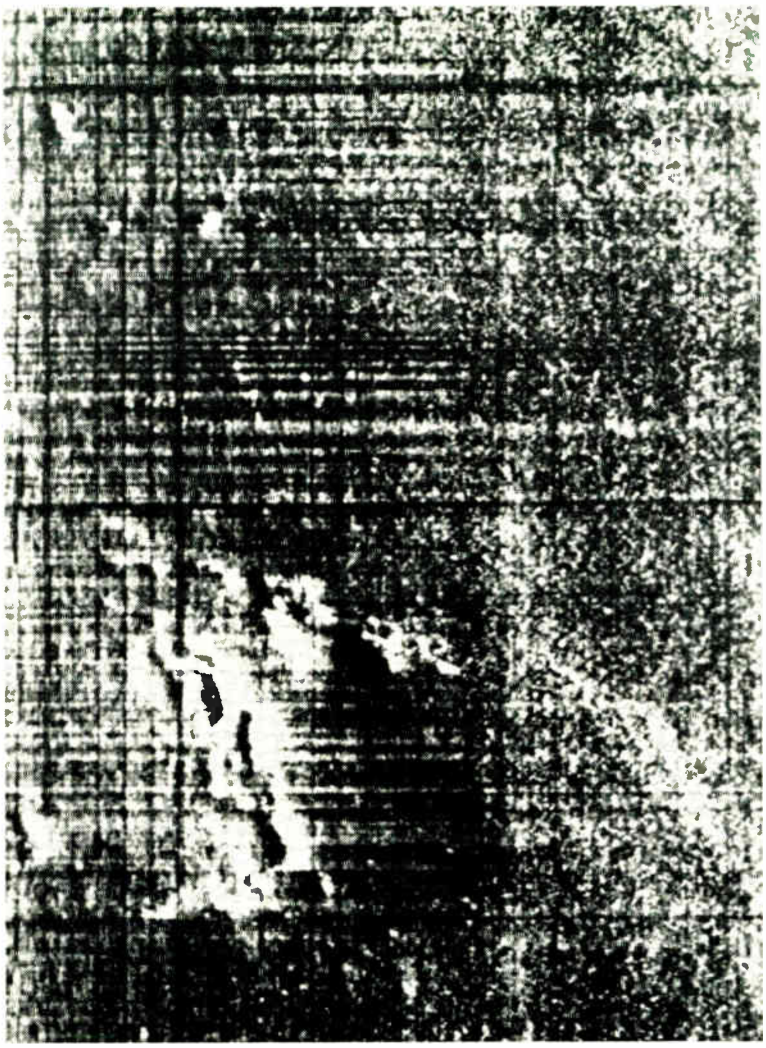
The same general technique can be applied to wavefronts arriving off-axis either adaptively or by programmed phase shifters. For the off-axis wavefronts, the optical aberrations inherent in a reflector antenna are also corrected, which improves scanning performance.

Preliminary data on this technique was reported at the PTGAP International Convention in 1963.[2] Additional work on both single and double reflector systems is now being performed under Air Force sponsorship. The work discussed here was sponsored, in part, by the Rome Air Development Center, Air Force Systems Command, under Contract AF 30 (602)-2657.

References:

1. S. W. Gery and A. E. Ruvin, "The Instrumentation of an Array of Reflectors for Passive Satellite Communications," paper presented at the Eighth National Communications Symposium, October 1962.
2. W. D. White and L. K. De Size, "Electronically Steerable Antenna Feed Techniques," paper presented at the 1963 PTGAP International Symposium, July 1963.

The ART of engineering



Ultrasonic photography made possible this view of the floor of the Atlantic Ocean 8400 feet down. The new sonar system developed by Westinghouse scientists and engineers photographs the ocean floor with ultrasonic sound at depths far too great for light to penetrate the perpetual blackness. The new system builds up a three-dimensional picture line by line, similar to the way in which a television picture is produced. Each sonar line is a strip of ocean bottom 2400 feet long and 4 feet wide, with 1000 2½-foot elements. The system thus has a resolving capability down to 2½ by 4 feet and has a search rate of about 1½ square miles per hour. The original photograph was taken from a moving strip of sensitive paper, or facsimile recorder, whose rate compressed the picture in the forward travel or vertical direction. The area of the Atlantic Ocean floor shown above is roughly ¼ mile wide and ½ mile from top to bottom.

SELECTED FOR THE MINUTEMAN PROJECT

More than 6 million El-Menco Dipped Mica Capacitors have been used in the Minuteman ground support and control equipment.

After 64,000,000 ACTUAL TEST unit-hours at 85°C with 225% of the rated DC voltage applied, no failures of any type occurred.

The accumulated 64 x 10^6 test unit-hours without any failures can be used to calculate many different failure rates depending upon the confidence level desired. However, we shall explore the meaning of the results at a 90% confidence level.

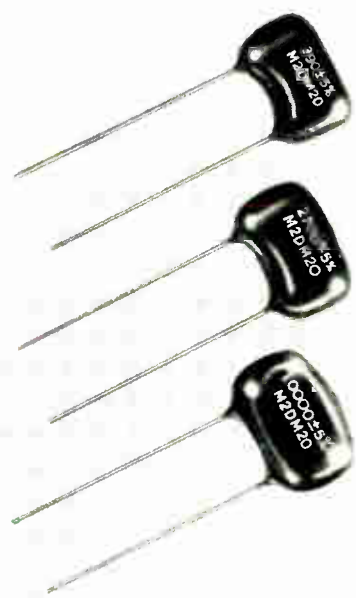
Assuming no acceleration factor for either temperature or voltage, we have verified a failure rate of less than 0.004% per 1000 hours. (Actually, there is a temperature effect and it has been found that, with the DC voltage stress remaining constant, the life decreases approximately 50% for every 10°C rise in temperature. There is also a voltage effect such that, with the temperature stress remaining constant, the life is inversely proportional to the 8th power of the applied DC voltage.)

Assuming no temperature acceleration factor and assuming the voltage acceleration exponent is such as to yield an acceleration factor as low as 100, we have nevertheless verified a failure rate of less than 0.00004% per 1000 hours.

Assuming no temperature acceleration factor and assuming the voltage acceleration factor is on the order of 250 (test results are available to confirm this) we have accumulated sufficient unit-hours to verify a failure rate of less than 0.000015% per 1000 hours!

All above failure rates are calculated at a 90% confidence level!

Write for a complete reliability study on your company letterhead.



DIPPED MICA CAPACITORS TYPE M2DM

THE ELECTRO MOTIVE MFG. CO., INC.

WILLIMANTIC, CONNECTICUT

MANUFACTURERS OF El-Menco Capacitors

Dipped Mica • Molded Mica • Silvered Mica Films • Mica Trimmers & Padders
Mylar-Paper Dipped • Paper Dipped • Mylar Dipped • Tubular Paper

ARCO ELECTRONICS, INC., Community Drive, Great Neck, L. I., New York
Exclusive Supplier to Jobbers and Distributors in the U. S. and Canada

West Coast Manufacturers Contact:
COLLINS & HYDE CO., 1020 Corporation Way Palo Alto, California
5380 Whittier Boulevard, Los Angeles, California

Reflections

75 years ago

Artificial Lighting. "Of human industries of the present day none perhaps, save those which have to do with providing the race with food, clothing, shelter and fuel, is more important to the cause of material welfare than that which deals with the production of artificial light, and he who seeks a means of measuring the material civilization reached by a nation might find an excellent criterion in the progress which it exhibits in the art of illumination.

"The problem of comparing the various methods of artificial lighting which are in vogue at the present day is one of great interest, whether we view it from the commercial standpoint, taking the cost of production as our controlling factor, or from the broader basis of relative usefulness, cost being relegated to a secondary position, or, finally, from the purely scientific point of view. From whichever side we approach this question, we are led inevitably to the consideration of certain elements which are alike of scientific, utilitarian and commercial importance.

"At first sight the attempt to determine the relative value of two sources of light would seem to be a simple matter. The number of factors, however, which enter into such a determination is surprisingly large, and many of them are of a character which makes it difficult to give them definite and complete expression. Of these the greater part are, indeed, commonly left out of account altogether, for the sake of simplicity, and we content ourselves with an antiquated and totally insufficient measure of our sources of illumination, which we call candle-power. It is to these other elements which enter into the question of the character of artificial light—such, for instance, as have to do with its *quality*—but which are, as a rule, quite lost sight of, to which I would ask your attention this evening, together with a discussion of those which are commonly made use of in photometry. If, in so doing, I am led to speak of methods which belong to the realm of pure science, I trust that you will agree with me in thinking that the results are not unimportant even to those whose interest in the problem of the production of artificial light is purely utilitarian.

"In the important question of the efficiency of a light-producing machine or process, the practice of to-day is very far from having reached that degree of exactness of expression which we demand in other cases of the transformation of energy. In electric lighting the energy expended is readily determined in absolute measure, or in that excellent practical unit, the *Watt*. In lieu of any attempt to express the useful energy obtained, however, we still content ourselves in practice with that most unscientific unit, the candle-power, based upon a source of illumination which is particularly subject to fluctuations of intensity and color. Even as used in the Bunsen photometer the shortcomings of the standard candle are sufficiently apparent; but no one who has not attempted to study it by methods which make it possible to detect changes of color as well as of brightness, can fully appreciate its fickleness." (E. L. Nichols, "The Efficiency of Methods of Artificial Illumination." *Trans. AIEE*, vol. VI, Nov. 1888–Nov. 1889, pp. 158–159.)

50 years ago

Birth of the Amplifier. The following brief news item that appeared on page 12 of the New York Herald on November 7, 1913, marked an historic event—the first public demonstration of the vacuum tube used as an amplifier. Among those present at the demonstration was the Editor of the IRE, Alfred N. Goldsmith, who had the enterprise and foresight to prepare a publication draft of the paper after the meeting and have it passed upon by de Forest. Thus it is that this memorable lecture, quoted in part in the following paragraphs, was preserved and published just 50 years ago this month.

MAY TALK TO THE PACIFIC.

Telephone Service Across Continent Believed Near by Use of Audion Amplifier.

That direct telephone service between this city and San Francisco will begin soon was the assertion of many who attended the monthly meeting of the Institute of Radio Engineers at Columbia University last Tuesday night.

Dr. Lee de Forest, inventor of the new audion amplifier, or relay, demonstrated the possibilities of his invention, and declared that through the amplification of minute electric currents results will be accomplished heretofore considered impossible.

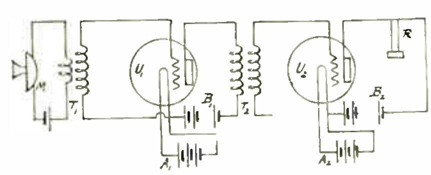
Representatives of the United States Navy who were present showed much interest in the invention as a possible aid in wireless operation.

"In a patent issued to the author in 1907 is described an arrangement whereby a grid Audion can be so connected that it acts as a relay and also amplifies minute pulsating electric impulses. Of late this amplifier has been much studied and is now being applied to a variety of purposes.

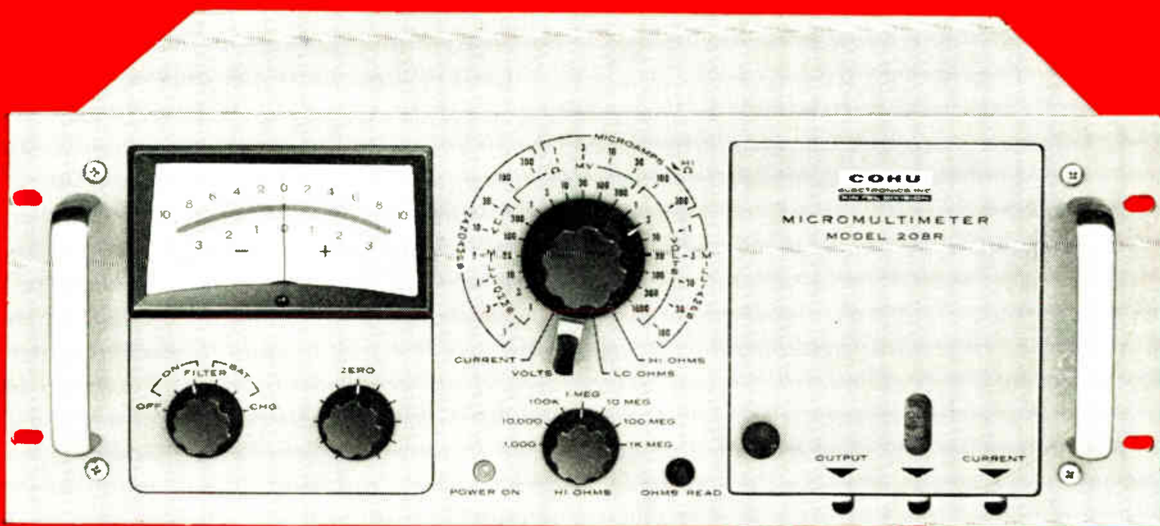
"Figure 3 shows the simplest arrangement using two amplifiers "in cascade." The source of energy to be amplified may be an Audion used as a radio-detector, a microphone, a magneto telephone receiver over a long distance line, a cable transmitter, or the like. T_1 represents a step-up transformer, which is essential if the impulses from S be of low voltage.

"For a single amplifier, T_2 will represent the indicating instrument. For a two-step amplification T_2 is a one-to-one transformer. Where the two amplifiers are supplied from separate lighting batteries T_2 may consist of one coil only. Similarly amplifier Number 2 may actuate a third, and so on; the successive

Fig. 3. Two audion amplifiers in cascade.



KIN TEL introduces FIVE precision test instruments IN ONE



Model 208R Micromultimeter

See us at the IEEE Show, March 23–26, Booth 3601

AT LESS COST, IN FAR LESS SPACE than closest equivalent instrumentation, Model 208R combines performance not previously available in one device.

HIGH RANGES AND LOW RANGES in one instrument give you the advantages of a DC microvoltmeter with ranges to 1000 volts, a microammeter, a wide range ohmmeter, an electronic galvanometer, and a narrow-band DC amplifier.

CHECK THESE FEATURES. Available for rack mounting or bench-top use, Model 208R operates from 115 or 230 volts, 50 to 400 cps, and from optional nickel-cadmium battery pack. Circuitry is solid state, chopper stabilized. Electrical output is suitable for driving a strip-chart recorder. Extra-long probes are stored on plug-in holders in a handy internal compartment, accessible from the front panel. $1495. Additional export charge.

CHECK THIS PERFORMANCE.

	VOLTAGE MEASUREMENTS	CURRENT MEASUREMENTS	RESISTANCE MEASUREMENTS
SCALES (full-scale indication)	10^{-6} to 10^{3} volts DC	10^{-10} to 10^{-1} ampere DC	10^{-3} to 10^{9} ohms
ACCURACY	1% of full scale or 10^{-7} volt, whichever is greater	1% of full scale or 10^{-11} ampere, whichever is greater	10^{-3} to 10^{8} ohms scales: 2% of full scale or 10^{-4} ohm, whichever is greater; 10^{9} ohms scale: 3% of full scale
INPUT RESISTANCE	10^{-5} to 10^{3} volt scales: $>10^{8}$ ohms; 10^{-6} and 3×10^{-6} volt scales: $>10^{7}$ and 3×10^{7} ohms	10^{-10} to 10^{-5} ampere scales: 10^{4} ohms; 3×10^{-5} and 10^{-1} ampere scales: 10^{1} ohms	N/A
DRIFT (30 minute warmup)	$<2 \times 10^{-7}$ volts	$<2 \times 10^{-11}$ amperes	$<2 \times 10^{-4}$ ohms

Send for product information or demonstration of the KIN TEL Model 208R Micromultimeter, or any of KIN TEL'S line of precision instruments. Representatives located in all major cities.

COHU ELECTRONICS, INC
KIN TEL DIVISION

5725 Kearny Villa Road, San Diego, California 92112 • Phone 277-6700 (Area Code 714) steps requiring, as a rule, larger bulbs, with larger heating areas and larger cold electrode surfaces.

"The assembled three-step amplifier is shown in Figure 5. The switches for adjusting "B" battery voltage and "A" battery circuit resistance, and for throwing the bulbs on or off are clearly visible. It will be seen that the apparatus has been arranged so that a single bulb can be used, or a two or three-step amplification as may be desired.

"By measurements made with the shunted-telephone-receiver method, a good Audion amplifier shows an amplification of 500 per cent. This general ratio holds also for the second and third steps, so that with three Audion amplifiers in cascade I have obtained an energy amplification of one hundred and twenty times, and this including losses from the three transformers in circuit.

"The strictly quantitative action above described holds for the hundred-fold, three-step amplifications as well; so that the ear at least, detects no distortion in this process. This holds unless the third amplifier is over-excited, so that the "blue arc" passes. This latter effect can always be prevented, as above explained, even while relatively large current variations are registered. To what limits of amplification this Audion principle can be carried has not yet been determined.

"The principle involved differs so radically from that of any form of telephone, microphone, or mechanical amplifying device that the Audion opens up entirely new possibilities in all lines of micro-electrics. First of all, its extraordinary sensitiveness is attended with no delicate adjustments and is absolutely nonmicrophonic. No amount of jarring or mechanical vibration disturbs its complete reliability. The ticking of a watch placed upon an ordinary microphone connected with one dry cell in a primary current can be amplified and heard thru a telephone when a coupling of less than five per cent unites the microphone circuit with the amplifier-telephone circuit; whereas from the most sensitive telephone receiver connected directly in this secondary circuit not a trace of a sound can be heard. Thus any microphone, or even an ordinary magneto receiver, with a two- or three-fold amplifier becomes a "Dictograph"—but with a delightful clearness of articulation.

Fig. 5. Audion three-step amplifier.

"If, in the radio telephone receiver, we add one or two amplifiers to the usual Audion detector, it is possible to bring up, clear and loud, articulation which, with this detector and telephone receiver alone, is too faint to understand. Similarly with the radio telegraph. The amplifier when used to relay the signals received on the Poulsen tikker at San Francisco has postponed by two hours the time of "daylight fading" from Honolulu.

"The current changes in the circuits of the second or third amplifier are sufficient to operate reliably a moderately sensitive contact relay; so that it is now possible to operate any desired form of calling device, or remote control apparatus, by any radio signals which are clearly audible, as well as to read easily signals which are quite inaudible with the ordinary detectors.

"Inasmuch as a theoretically perfect single rectifier can have an efficiency of only 50 per cent, the fact that the Audion, amplifying alternating currents of practically any frequency, shows an efficiency of from 100 to 500 per cent, should most effectively silence the old and recurrent contention that this detector is merely a sensitive and efficient rectifier, or "vacuum valve."

"In the long-distance telephone field lies the most obvious and useful application of this amplifier. The Audion used as a two-way amplifier at the middle of a metallic circuit requires, it is true, some type of the usual balanced circuits, with precautions to prevent "singing"; but the difficulties here afforded are less serious than with the microphone-telephone repeater. The relative constancy of adjustment, and especially the freedom from microphonic troubles and distor-

tion, simplify the problem. It is the writer's hope that more detailed information of exceedingly interesting work which is being done in this direction by telephone engineers may shortly be presented.

"Aside from long distance work, other applications of this telephone relay, of more radical and far-reaching significance, may be produced in the future. For example, it has been suggested that a magneto telephone receiver be used in place of the microphone at each subscriber's station, allowing once more that original clearness and fidelity of voice which was sacrificed when the microphone was made a part of every telephone equipment. No central battery energy need be supplied to the subscriber, except for calling purposes. His voice supplies the energy for driving this magneto dynamo. The minute, but correct, currents thus generated might be carried to central station over a pair of wires of such size that twice the present number of conductors could be inclosed in the standard sized cables. With these minute currents, troubles from cross-talk would be minimized, while high resistance or microphone contacts in the lines would cease to be the serious matters they are at present. The Audion, being an extremely high-resistance device, requires for a transformer a high-resistance primary, with a secondary adapted to standard telephone receivers.

"At the central stations, then, we would have banks of Audion amplifiers fed from the common storage battery. In-coming and out-going calls would operate signal devices with this central battery energy as at present, but when the talking circuit was made, the subscriber's magneto transmitter would be connected, thru an induction coil, to the grid of an idle Audion, amplified, sent out over a trunk line, re-amplified, if necessary, at the other exchange, transformed, and sent out to the receiver's station.

"The ease with which voice records are made on the fine steel wire of a Telegraphone, the fidelity of these records (when not intense enough magnetically to saturate the wire), and the practically unlimited length of a record (30 minutes or more), once appeared to give to this wonderful device possibilities which were quite beyond any to be hoped for from the cylinder or disk phonograph. However, the faintness of the reproduction has limited the commercial application of the Telegraphone to an office dictating and telephone-recording machine. All attempts reliably to amplify Telegraphone records so as to throw the sound out into a room, by the use of microphone relays, have failed. The adjustments are too delicate and transient, and the distortion excessive.

"With a three-step Audion amplifier I am able to supply a number of 'loud-speaking' telephone receivers, and to distribute music, or voice records, over a small hall in sufficient volume. From four such loud-speaking receivers nested together, a violin record on the Telegraphone has been heard at a distance of 250 feet in quiet open air. By the use of larger bulbs for the third amplification, and with two or more of these in parallel, each supplying six or more loud-speakers, any enclosed space of reasonable size can be filled.

"This amplification of Telegraphone records has revealed a number of interesting peculiarities of that instrument hitherto unrealized. Notably it has shown how imperfect and unreliable a device is the carbon microphone, voice actuated. The haphazard action of packing, friction, and the effect of the natural vibration periods of the diafram, are exasperatingly demonstrated. I am at work on these problems at the present time, investigating the best methods for recording various types of music, voice, etc., and using for this purpose both the microphone and special forms of magneto transmitters. I believe the application of the Telegraphone to the music-reproduction field now awaits a perfection of proper methods of recording.

"The problem of recording high speed radio telegraph signals has been repeatedly attacked, using photographic tape records with the Einthoyen string galvanometer and crystal rectifier detector. The multiplicity of delicate adjustments, and the obliterations which even moderate atmospheric disturbances cause in the records, convince, in time the most optimistic investigators in this field of the basic fallacy of this method.

"Attempts have been made to record radio signals by means of the Telegraphone but the fact that excessively loud signals (such as can be heard three feet from the telephone receiver) are needed to make satisfactory Telegraphone records, has kept this method inapplicable.

"Now, however, with the three-step Audion amplifier relaying the detector signals, the Telegraphone becomes a simple and surprisingly reliable rapid re corder. A tape-actuated Wheatstone transmitter, controlling by two successive relays the wave length of a 12 K.W. Poul-

FIRE EATER

...cools hot head problems for keeps!

SCOTCH® BRAND Heavy Duty Instrumentation Tape is the name. And it takes hot recorder heads in stride by resisting tape surface temperature as high as 250°F! Shrugs off the intense, localized heat that higher tape speeds and tensions build up at recording heads. Keeps the magnetic record straight by minimizing rub-off, protecting against drop-outs.

What's more, "SCOTCH" Heavy Duty Tapes, with a special high-potency oxide and binder formulation, outwear ordinary tapes *at least* 15 times. Conductivity is greater, too. 1000 times! Drains off static before it can attract dust, cause trouble. Exclusive built-in Silicone lubrication minimizes head and tape wear. 16 different heavy-duty constructions meet all requirements, even involving extremely high speeds, short wavelengths.

TECHNICAL TALK Bulletin No. 3 discusses effects of frictional heat on tape performance as well as heavy-duty oxide and binder formulations. Free. Write 3M Magnetic Products Division, Dept. MEC-34, St. Paul 19, Minn.

SEE YOU at the IEEE SHOW, New York, March 23-25, Booth 3242

Magnetic Products Division 3M COMPANY

sen arc transmitter, sends Morse signals at the rate of sixty words per minute. The received Tikker signals are amplified and recorded on a Telegraphone wire running at a rate of about eight hundred feet per minute. In reproducing the record this wire speed is reduced to approximately one-third. The pitch of the tikker signals as thus reproduced is of course very low; but with the above speed-reduction ratio these signals, even without reamplification, are still sufficiently loud to permit the use of a typewriter by the transcribing operator.

"For speeds higher than sixty words per minute it is necessary to obtain the incoming signal in the form of a high-pitched note, which, upon reduction for transcribing at 25 words per minute, has still a pitch of some 150 cycles per second. Methods for accomplishing this latter have been recently worked out by the writer.

"The Telegraphone rapid receiver has been in daily commercial use for several months at the arc stations of the Federal Telegraph Company, between San Francisco and Los Angeles. The method is not limited to arc transmitters. In fact, the musical spark stations offer certain advantages for this method of high speed recording. It is necessary only that the received signals should be 50 to 100 times "audibility" before amplification.

"While it is yet too early to speak authoritatively on the subject there appears no reason why the Audion amplifier should not also be applied with excellent advantage to submarine cable recording and relaying."

DISCUSSION

John Stone Stone: "The problem of the telephone amplifier is one of great difficulty. I became interested in it in 1892, and soon found that the question of amplifying without producing distortion was prominent. The amplifying relays which were furnished were all mechanical instruments; their parts had inertia and consequently distortion was always produced. We never had the instrument of our ambitions which, being without inertia, would amplify correctly even the weakest impulses without distortion. It is therefore with earnest scientific pleasure that I recognize that we have at last an instrument which will therefore amplify even the weakest currents.

"There is an application of this amplifier which is of great interest to me, namely to the field of 'wired wireless.' By this method of transmission it is possible to send simultaneously over the same line a great number of conversations, each being carried by its own extremely rapidly alternating current. The receiving station can be appropriately tuned to any of the frequencies used. This is an older art than radio telegraphy. Up to the present it has not materialized because the energy of the current thus transmitted was too small to enable competition with ordinary telephony. This new amplifier promises to bring the "wired wireless" telephone to a par with the usual wired telephone. There is then a prospect of a satisfactory solution of the problem of multiple telephony. As many as twenty messages might be transmitted simultaneously over the same line." (Lee De Forest, "The Audion—Detector and Amplifier," *Proc. IRE*, Mar. 1914, pp. 24–30.)

Lightning Protection. "The results Mr. DeBlois has shown are, in a large measure, explanatory of what has been my impression for years, in fact, as long as I can remember having any thought or dealings with lightning or lightning protection. While it may be true that within the path of the discharge there may be oscillatory portions, I think the main phenomenon is that of a continuous current.

"I arrived at that conclusion early in my investigations in this wise: I have been in telegraph offices when lightning struck at some place nearby, and have been near a telephone when lightning also was nearby, and I found that the relays went click, click, click. They acted as if they had received a direct current—no high frequency, pure and simple, would have induced such an effect in the relays; it would instead have jumped the relay and sparked across the terminals.

"So, also, everybody knows that during a thunderstorm a telephone bell is frequently rung—which means that a current went through the numerous turns of the electromagnet. That could not be induced by high frequency, it was induced by a steep wave front and not obliterated by the reversal of the phase of the wave, as would be the case with high-frequency effect.

"I quite agree with Mr. Creighton in the assumption that there may be in the length of a long discharge to earth some parts where there is oscillation, but if I were to picture the effect, as it occurs to me, it would be about as follows:

"I will first make the statement that I do not think it is quite the thing to consider a cloud as a charged conductor.

That statement I have made many times. It is not a conductor. It is a very poor conductor—it is a mass of fog. You cannot locate charges on it as you can on a tinfoil condenser. The cloud has plus or minus charges all through. They tend, naturally, to approach the earth which has the opposite charge.

"Somewhere in this system perhaps, where the cloud dips down a little, over an object on the earth's surface a little higher than the rest, there is a beginning of the breakdown. No doubt it begins as accumulation of a free charge and rapidly develops into a discharge. It discharges the lower part of the cloud, and as that begins to discharge, the rest of the cloud starts to feed into it, the cloud path ramifying like tree branches in all directions.

"Many photographs, even the photographs shown on the screen a short time ago, show two other discharges in the same field, fine discharges, leading down this way and that; what are they? They are the perspective projection of the more or less horizontal discharges miles away in the cloud and feeding the main discharge . . . .

"I have been asked to state why it is that barns are struck by lightning so often, especially when they have moist hay, etc., in them. They are struck pretty often when they have no hay in them, and I do not know that the moist hay has much to do with it. If they are struck by lightning while the hay is in them, they may be burned; if they are struck by lightning where there is no hay in them, they may not be burned. Of course, the combustible material takes fire very readily. That may be the difference. But let us ask—why is the barn struck primarily? Because it has one of the best grounds that can exist. The ammonia salts, the drainage from the cows and horses, soaks into the earth, and that forms a direct connection to the earth. That is why the barn is struck. Why is a barn equipped with lightning rods, which take the charge directly to the ground, struck by lightning and destroyed? Because no conducting ground outside the barn can be compared to the splendid ground which exists inside the barn. We would naturally expect the lightning to go to the best conductor, the best ground on the premises. Let me emphasize this. It will take the best ground on the premises, and that is within the barn. The moral of it is that lightning rods should be anchored where the *best ground is obtainable, in all cases*—something which is quite generally forgotten in providing lightning protection." (Elihu Thomson, *Trans. AIEE*, vol. XXXIII, Part I, 1914. pp. 539–540.)

25 years ago

A New Receiver. "A paper by G. W. Fyler and J. A. Worcester of the General Electric Company (Bridgeport), on "The New Armstrong Frequency-Modulation Receiver," was presented by Mr. Fyler. He discussed the type of receiver now being produced by the General Electric Company. This receiver had in its second detector a circuit derived from the well-known automatic-frequency-control diode circuit used in earlier receivers. The intermediate-frequency amplifier has a very linear frequency-shift versus audio-frequency amplitude response for a frequency variation of 100 kilocycles on both sides of the mean carrier frequency.

"Descriptions were then given of the radio-frequency amplifier, the converter which employs a separate oscillator, intermediate-frequency amplifier, limiting stage, frequency-discriminating audio-frequency stage, audio-frequency amplifier, and power supply. Phase variation is used in the audio-frequency system to obtain push-pull output. To improve the acoustic output of the receiver, a special-edge curvilinear cone was developed for the loud speakers used. Over-all characteristics from the studio to the receiver acoustical output were shown and the paper was concluded with a discussion of factors affecting the design of practical high-fidelity receivers.

"E. H. Armstrong, who developed the system of transmission being discussed, described the transmitters and studio equipment to be used in the demonstration which was part of the meeting. Test material was transmitted from Alpine, N.J., on a frequency of 42.8 megacycles with an output of 20 kilowatts. Recorded material was supplemented by a live-talent program relayed by Alpine, N.J., from Yonkers, N.Y. Six of the new receivers were used for reception.

"Messrs. DeMars, Doolittle, and Noble described and presented pictures of frequency-modulation transmitters and antenna installations now being constructed on several mountain tops in New England.

"January 19, 1939-E. R. Sanders, chairman, and W. R. G. Baker, sec-

retary, presiding." (From report of Connecticut Valley meeting, *Proc. IRE*, Mar. 1939, p. 229.)

Coordination of Knowledge. "It is not enough to have training in method of attack and a knowledge of principles. There must be a finite knowledge of gases, liquids, solids, organic and inorganic materials, light, heat, sounds, and electricity. There must be supplementary knowledge of mathematics, thermodynamics, metallurgy, mechanics, hydraulics, electronics, and other subjects to motivate and focus the abstract scientific knowledge. Above all, there must be a co-ordination of knowledge and principles in order that these men may work intelligently.

"The man needed by technological industry must be able to state his variables at the start of a problem, weigh their relative importance, predict their changes under changed conditions, put them together according to a planned program that is based upon a theoretical analysis and solution, and apply skill and technique to bring about a tangible answer. And, in these problems, there will be one or more variables that are impossible to evaluate by means of present knowledge; consequently, the engineer must have the ability to explore the unknown. Here again only recorded knowledge and broad principles of science are the tools available for him to use.

"It may be that this specification assumes too great a scope for engineering because it is impossible to train such a man in any reasonable time. Experience seems to indicate that specialization instead of generalization is the only practicable educational procedure and that the problems of industry are best solved by the joint actions of specialists in science and engineering. But there is doubt as to the validity of this conclusion simply because the broader and better conception has not been tried. We could well discuss this alternative as it offers a relatively easy path to the goal, but it is not so logical or so theoretically effective as the endeavor to give adequate training to each individual.

"This is the ideal specification for graduate training and, if the engineering colleges can fill it, rapid and major advances in technology can be counted upon to occur. This is an ambitious program to undertake; especially since the number of men that will be taken by industry in the near future at a premium wage will be limited and the cost to the colleges will be high. It is doubtful, moreover, that more than half a dozen colleges can get or now have the faculties, the facilities, and sufficient funds to give the training desired. But the opportunity to do this pioneering educational work is here and surely a few leaders will be found willing to try so that all may benefit by actual experience.

"It seems practicable and best to initiate this work in some universities through the co-operation of the faculties in science and engineering. Few, if any, engineering colleges are sufficiently self-contained as to teaching staff and experimental equipment to undertake such a broad and such a thorough training as is proposed.

" . . . The ideal man produced by this graduate training should be a master of the sciences, a master of mathematics, expert in technique, and skilled in the engineering approach to the solution of problems." (L. W. W. Morrow, "Graduate Training for Engineers," *Electrical Engineering*, vol. 58, Mar. 1939, p. 120.)

A New "Vu." A report was read on the adoption by the National Broadcasting Company, the Columbia Broadcasting System, and the Bell Telephone Laboratories of a new volume-level indicator and a new standard zero volume level for broadcasting. The new instrument has dynamic characteristics which differ widely from existing instruments and is more highly damped so that violent oscillations of the pointer are avoided. The zero level is based on this new instrument and results under steadystate conditions when one milliwatt is impressed across a 600-ohm circuit. A new designation "vu" numerically equivalent to the number of decibels above the new zero volume level will be adopted." (From Board of Directors Report, *Proc. IRE*, Mar. 1939, p. 228.)

Colorado River Aqueduct. "The aqueduct has its intake on the Colorado River just above the confluence of the Bill Williams River 150 miles below Boulder Dam. The Parker Dam, just below the mouth of the Bill Williams, is now being completed by the United States Bureau of Reclamation using funds furnished by the District, and will raise the water 72 feet above river level creating a reservoir of 717,000 acre-feet capacity from which the aqueduct will draw its supply. From its intake at Parker reservoir the main aqueduct

CFS-180A
1 to 2 Parts in 10^{10} per day Stability

MANSON BUILDS THE INDUSTRY'S MOST RESPECTED CRYSTAL FREQUENCY STANDARD

CFS-250A
1 to 2 Parts in 10^{11} per day Stability

...AND NOW THE MOST ADVANCED, TOO

	CFS-180A	CFS-250A
Stability (Aging Rate)	1 to 2 parts in 10^{10} per day.	1 to 2 parts in 10^{11} per day.
Output Frequencies	1 Mc and 100 Kc.	1 Mc and 100 Kc.
*Optional Output Frequencies	5 Mc and spectrally pure 5 Mc.	5 Mc and spectrally pure 5 Mc.
Input Power (Power Supply self-contained)	115 V AC, 50-400 cps.	115 V AC, 50-400 cps.
Battery Operating Time	35 hours normal operation.	24 hours normal operation.
Size (including power supply & battery pack)	3½" H x 16½" W x 16" D.	3½" H x 16½" W x 16" D.

WHERE PRECISE FREQUENCY CONTROL IS VITAL The Manson CFS-180A Crystal Frequency Standard, with an ultra-high stability of 1 to 2 parts in 10^{10} per day, has a well-earned reputation for accuracy and reliability. Mean Time Between Failure (MTBF) of this unit is well over 11,000 hours. Presently in use as the timing base for the Pacific and Atlantic Missile Ranges, and in satellite tracking, doppler navigation and many other communications, navigation, timing and laboratory applications, the CFS-180A is a natural choice for those seeking stabilities in this range.

Now, in addition to the CFS-180A, Manson offers the new CFS-250A Frequency Standard with a stability of **1 to 2 parts in 10^{11} per day.** Like the CFS-180A, the CFS-250A is ideal for systems applications, and incorporates all the engineering and design features which have made the CFS-180A such an outstanding instrument.

Among the outstanding features of these frequency standards are: self-contained power supply; integral, stand-by, emergency battery pack, automatically switched into operation in the event of line failure without loss of stability; compact solid state design (3½ inches high) and optional spectrally pure 5 Mc output for multiplication into the gigacycle frequency ranges.

Check our specification chart, then take your choice — both the CFS-180A and CFS-250A are available to meet your requirements now. Detailed engineering data is available upon request.

manson laboratories
A SUBSIDIARY OF hallicrafters
375 Fairfield Ave Stamford, Conn
At the IEEE Show: Booths 3212–3214

extends 241.7 miles to the terminal reservoir at Cajalco. This distance is covered by 92.1 miles of tunnel, 54.5 miles of cut and cover conduit, 62.8 miles of open-lined canals, 28.7 miles of inverted siphons, 1.2 miles of pump-delivery lines, 1.1 miles of open ditch, and 1.3 miles of passage through reservoirs.

"From the Cajalco reservoir, distributed conduits will deliver water to the member cities of the District. Five pumping stations lift the water from Parker reservoir at elevation 450 feet above sea level to 1,807 feet, the highest point on the aqueduct, from which point flow is by gravity to the terminal reservoir at elevation 1,405. The problem from the standpoint of the electrical and mechanical engineer was to design and build five pumping plants capable of raising 1,500 second-feet of water through a total net lift of 1,617 feet by means of power obtained principally from Boulder Dam." (J. M. Gaylord, "The Pumping System of the Colorado River Aqueduct," *Trans. AIEE*, vol. 58, 1939, pp. 112–113.)

Over 60. "Precision frequency-measuring assemblies for use in the range of 30 megacycles and lower have in the past been fully described. It is possible by some simple equipment additions, to extend the range of these assemblies to perhaps 60 megacycles. The accuracy of measurement when using a primary standard assembly may be as high as one in five million and as high as one in five hundred thousand when using a secondary assembly.

For frequencies higher than 60 megacycles it is customary to use a Lecher frame with which an accuracy of one in twenty-five hundred may be attained. Harmonics of a stable variable-frequency oscillator can also be used with an accuracy of perhaps one in ten thousand in the resulting frequency measurements.

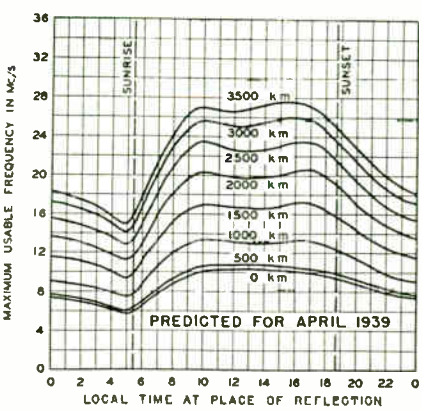
It is evident from the foregoing that frequency-measuring methods are still in a rudimentary state insofar as frequencies above 60 megacycles are concerned. There are several reasons for this, the most important being the lack of stable oscillators for fundamental operation at these high frequencies. Many transmitters at the higher frequencies use crystal control and frequency multiplication, making it a simple matter to measure the crystal frequency and then multiply it by the harmonic number in order to find the frequency of operation. Some transmitters use a form of long-line control with a stability still under that necessitating precision measuring equipment.

Another factor is that a large majority of the transmitters operating at the high frequencies are transmitting or will transmit television or facsimile which may require a band width such that a variation of the carrier frequency of several kilocycles will have a relatively little effect on the received signal. A precision means for measuring frequency is therefore not necessary.

It is not unlikely however that as further developments are made and new uses found for the ultra-high frequencies, a precision frequency-measuring system will be necessary." (Samuel Sabaroff, "An Ultra-High-Frequency Measuring Assembly," *Proc. IRE*, Mar. 1939, p. 208.)

Forecasting. "This report inaugurates a new service, the forecasting of radio transmission data for the month following the one in which this report is published. Fig. 4 gives the expected monthly average values of the maximum usable frequencies for radio communication by way of the regular layers, for April, 1939. These estimates had to be made three months in advance. They are based on the observed trends of the critical frequencies in the eleven-year solar cycle and information on diurnal and seasonal variations accumulated over a period of several years. It is believed that the estimates will be accurate within fifteen per cent, for undisturbed days." (T. R. Gilliland, S. S. Kirby, N. Smith, "Characteristics of the Ionosphere at Washington, D.C., January 1939," *Proc. IRE*, Mar. 1939, p. 227.)

Fig. 4—Predicted maximum usable frequencies for sky-wave radio transmission; average for April, 1939, for undisturbed days, for dependable transmission by the regular F and F_2 layers.



INTERNATIONAL CONVENTION

IEEE

Technical Program

From March 23 to 26, the New York Hilton Hotel and the New York Coliseum in New York City will be hosts to the IEEE International Convention. The recently completed New York Hilton is situated a convenient six blocks from the Coliseum. The theme of this year's Convention is "A Glimpse of the Future." Both the technical papers program and the exhibits have been expanded approximately 20 per cent to encompass the full scope of IEEE technical activities.

March 23-26, 1964

TECHNICAL PROGRAM

Time: 10:00 A.M., Monday, March 23 through 5:00 P.M., Thursday, March 26.

Place: New York Hilton and New York Coliseum.

A schedule of 64 technical sessions appears on page 39, followed by abstracts of all the papers to be presented.

THE IEEE SHOW

Time: 9:45 A.M. to 9 P.M., Monday through Thursday, March 23–26.

Place: New York Coliseum, Columbus Circle and New York Hilton, Avenue of Americas at 53 St.

A list of 1000 exhibitors and their products appears in "IEEE Exhibitors" beginning on page 309 of this issue.

For the convenience of visitors, the exhibits at the New York Coliseum will be grouped as follows: Floors 1 and 2—Components, Floor 3—Systems and Instruments, Floor 4—Production. Electrical equipment will be on display at the New York Hilton.

COCKTAIL PARTY

Time: 5:30–7:30 P.M., Monday, March 23.

Place: New York Hilton, East Ballroom.

IEEE ANNUAL BANQUET

Time: 6:30 P.M. Wednesday, March 25.

Place: New York Hilton, Grand Ballroom.

Principal Speaker: Charles F. Horne, President, General Dynamics/Pomona Div., and President, Electronic Industries Association.

This year's banquet will feature the presentation of the following major IEEE awards: Medal of Honor, Edison Medal, Founders Award, Lamme Medal, and Education Medal. In addition, the 118 recently elected Fellows will be recognized.

LADIES' PROGRAM

An entertaining program of tours and shows has been arranged for the wives of members, who are also invited to the cocktail party and the IEEE Annual Banquet. Ladies' Headquarters will be located in the New York Hilton, Second Floor Promenade.

INTERNATIONAL RECEPTION ROOM

Members of the Convention Reception Committee will be on hand to welcome all IEEE members from abroad in the Beekman Room on the second floor of the New York Hilton. It is hoped that this facility will help our members from abroad feel more at home during their stay in the United States.

REGISTRATION

All IEEE members attending the Convention may register any day of the Convention at either the New York Hilton or the New York Coliseum from 9 A.M. to 9 P.M. The registration fee is $1.00 for IEEE members and $3.00 for non-members.

TRANSPORTATION

The New York Coliseum and the New York Hilton Hotel are readily accessible to one another. The Coliseum is located at Columbus Circle (59th Street and Eighth Ave.) and the Hilton at Avenue of Americas (Sixth Ave.) and 53rd Street.

CONVENTION RECORD

All available Convention papers will be published in the 1964 IEEE International Convention Record which will be issued in ten parts according to subject and available in July 1964.

Order forms may be obtained from IEEE Headquarters.

General Committee

G. W. Bailey, *Chairman*
Nelson S. Hibshman, *Vice Chairman*
Emily Sirjane, *Secretary*

W. M. Baston, W. E. Braun, W. C. Copp, J. F. Craib, E. K. Gannett, F. Hamburger, Jr., J. M. Kinn, R. E. Lafferty, R. L. McFarlan, R. C. Roxberry, W. G. Vieth, Mrs. Ernst Weber

Banquet Committee

W. M. Baston, *Chairman*

Sol Abrams, J. F. Bisby, M. K. Bonner, H. L. Brownman, J. W. Kearney, W. D. Reiner

Exhibitors Advisory Committee

Robert Andrews, *Chairman*

L. Allen, W. C. Copp, R. H. Denton, K. Garrison, H. A. George, E. W. Gerlach, C. Glade, P. G. Marble, J. Parker, Lillian Petranek, S. Skilnyk, P. Wilson, J. Young

Cocktail Party Committee

R. E. Lafferty, *Chairman*

A. A. McKenzie, C. A. Meyer

Facilities Committee

R. C. Roxberry, *Chairman*

Robert Bannon, L. C. Berke, Adolph Brenner, R. H. Brook, W. J. Carroll, Robert Causin, Harvey Cohen, L. M. Davidson, C. H. Doersam, Jr., D. S. Elkort, Albert Fink, Vernon Fowler, C. J. Franks, D. E. George, Ed Gluecker, J. J. Gordon, George Gorelick, R. C. Hall, J. D. Hirsch, E. H. Katz, S. H. Katz, F. L. Katzmann, David Lovcik, Murray Marcus, Vincent Mazzola, Icarus Pyros, M. M. Rosenfeld, P. L. Ross, L. M. Salmen, Jr., Carl Schleicher, P. L. Schwartz, Stanley Seifer, Carl Sontz, M. H. Tucker, George Weinstock, Ivor Wisepart, Milton Zerkin

Special Activities Committee

J. M. Kinn, *Chairman*

J. L. Callahan, L. G. Cumming, R. M. Emberson

Hospitality Committee

W. G. Vieth, *Chairman*

Carlo Abbio, A. R. Albro, E. F. Doyle, W. D. Houghton, A. T. Lattauzeo, J. Letosky, H. L. Mayo, Norman Mills, K. E. Mullenger, Charles Roggenkamp, H. B. Rose, J. O. Schroeder, S. Wittels

International Reception Committee

R. L. McFarlan, *Chairman*

B. B. Barrow, A. B. Bereskin, J. N. Dyer, P. E. Green, Eduard Karplus, Jean Lebel, D. B. Sinclair, D. E. Thomas

Publicity Committee

E. K. Gannett, *Chairman*
L. Winner, *Vice Chairman*

R. C. Blatt, J. M. Carroll, W. C. Copp, W. R. Crone, R. W. Emerson, E. E. Grazda, H. Hechtman, R. K. Jurgen, J. M. Kinn, J. J. O'Connor, B. F. Osbahr, H. S. Renne, R. Schoonover, R. W. Sollinger, Jr., N. Sperber

Registration Committee

J. F. Craib, *Chairman*

R. L. Crane, R. M. Foley, J. R. Hefele, William Howard, A. J. Kelly, K. J. Knudsen, V. A. Kulik, Lawrence Levey, G. V. Novotny, Frank Mounts, R. S. Nelson, R. A. Peritz, M. M. Perugini, R. D. Post, Bertram Rudofsky, E. J. Smith, Elwood Schmidt, C. R. Wheeler

Finance Committee

W. E. Braun, *Chairman*

Technical Program Committee

Ferdinand Hamburger, Jr., *Chairman*

L. G. Abraham, Harold Chestnut, E. F. Cook, E. F. MacNichol, Jr., G. E. Moore, L. M. Olmsted, A. L. Samuel, Gustave Shapiro, D. B. Sinclair, R. H. Whaley

SESSION ORGANIZERS

R. J. Adams, H. M. Altschuler, E. J. Baghdady, J. G. Barry, H. P. Birmingham, J. G. Brainerd, D. E. Brinkerhoff, A. M. Casabona, I. T. Corbell, W. B. Dennen, John Durkovic, L. E. Franks, R. N. Hall, F. L. Hermach, T. J. Higgins, J. L. Jatlow, A. E. Joel, R. E. Kimball, Robert Kingston, L. K. Kirchmayer, John C. Leffel, Wilbur R. LePage, F. D. Lewis, R. S. Livingston, J. E. McLinden, R. M. Morris, L. M. Olmsted, R. W. Rochelle, M. J. Ronas, A. L. Samuel, H. W. Shaner, H. Sherman, W. H. Shirk, Jr., C. A. Steinberg, A. H. Sullivan, Jr., J. P. Van Duyne, W. G. Vieth, H. D. Voegtlen, R. H. Whaley, John Zaborsky

Ladies Activities Committee

Mrs. Ernst Weber, *Chairman*

Mrs. L. V. Berkner
Mrs. Hendley Blackmon
Mrs. W. H. Chase
Mrs. W. R. Clark
Mrs. J. W. Davis
Mrs. J. H. Enenbach
Mrs. A. N. Goldsmith
Mrs. P. E. Haggerty
Mrs. F. Hamburger, Jr.
Mrs. J. T. Henderson
Mrs. H. O. Hodson
Mrs. L. C. Holmes
Mrs. T. G. LeClair
Mrs. C. H. Linder
Mrs. J. E. McCormack
Mrs. R. L. McFarlan
Mrs. D. E. Noble
Mrs. B. M. Oliver
Mrs. W. E. Peterson
Mrs. Haraden Pratt
Mrs. Herre Rinia
Mrs. E. B. Robertson
Mrs. J. D. Ryder
Mrs. W. G. Shepherd
Mrs. E. C. Starr
Mrs. B. R. Teare, Jr.
Mrs. F. K. Willenbrock

SCHEDULE OF TECHNICAL SESSIONS

	NEW YORK HILTON					NEW YORK COLISEUM		
	Trianon Ballroom	Mercury Ballroom	Sutton Ballroom North	Sutton Ballroom South	Regent Room	Room A	Room B	Room C
MONDAY, MARCH 23 10:00 A.M. — 12:30 P.M.	SESSION 1 Wire Communication I	SESSION 2 Marine and Industrial Electrical Applications	SESSION 3 Computer Related Topics I	SESSION 4 Data Communication and Telegraph Systems I	SESSION 5 Television Systems	SESSION 6 Instrumentation I	SESSION 7 Feedback Control Systems	SESSION 8 Reliability
MONDAY, MARCH 23 2:30 — 5:00 P.M.	SESSION 9 Wire Communication II	SESSION 10 Electrical Applications In Industry	SESSION 11 Computer Related Topics II	SESSION 12 Data Communication and Telegraph Systems II	SESSION 13 Microwave Theory and Techniques	SESSION 14 Instrumentation II	SESSION 15 Is Measurements Training a Neglected Area of the Engineering Curriculum?	SESSION 16 Electromagnetic Compatibility
TUES., MARCH 24 10:00 A.M. — 12:30 P.M.	Session 17 Electrical Engineering Education	SESSION 18 Instrumentation III	SESSION 19 Space Electronics and Guidance	SESSION 20 Space System Design Techniques	SESSION 21 Switching Systems	SESSION 22 Symposium on High Energy Research and New High Energy Accelerators	SESSION 23 Nonlinear and Linear Control	SESSION 24 Electronic Technologies in Industry
TUES., MARCH 24 2:30 — 5:00 P.M.	SESSION 25 Aeronautical Electronics and Navigation	SESSION 26 Instrumentation IV		SESSION 28 Switching Systems and Techniques	SESSION 29 Information Retrieval IEEE and You	SESSION 30 Optimal and Adaptive Control	SESSION 31 Microcircuits and Processing Techniques	SESSION 32 Electrical Technologies in Industry
TUES., MARCH 24 8:00 — 10:30 P.M.	SESSION 27 MODULAR MAGIC — SPECIAL HIGHLIGHT EVENING SYMPOSIUM NEW YORK HILTON, EAST BALLROOM							
WED., MARCH 25 10:00 A.M. — 12:30 P.M.	SESSION 33 Telemetry	SESSION 34 Electron Devices	SESSION 35 Syncom II Satellite	SESSION 36 Semiconductor Devices	SESSION 37 Instrumentation V	SESSION 38 Improving Written Communications	SESSION 39 Radas	SESSION 40 Rotating Machinery
WED., MARCH 25 2:30 — 5:00 P.M.	SESSION 41 The West Ford Experiment	SESSION 42 Instrumentation VI	SESSION 43 Power Generation	SESSION 44 Circuit Theory I	SESSION 45 Radio Communication Systems	SESSION 46 Packaging and Interconnections	SESSION 47 Audio and Acoustics	SESSION 48 Systems Science
THURS., MARCH 26 10:00 A.M. — 12:30 P.M.	SESSION 49 Transmission	SESSION 50 Radio Propagation	SESSION 51 Recording and Audio Measurement	SESSION 52 Circuit Theory II	SESSION 53 Electronic Components and Materials I	SESSION 54 Antennas	SESSION 55 Human Factors	SESSION 56 Basic Sciences I — Circuits and Systems
THURS., MARCH 26 2:30 — 5:00 P.M.	SESSION 57 The Electric Power System of Tomorrow	SESSION 58 Communication and Modulation Techniques	SESSION 59 Engineering Management	SESSION 60 Symposium on Data Transmission	SESSION 61 Electronic Components and Materials II	SESSION 62 Arrays and Ionosphere	SESSION 63 Defense Systems	SESSION 64 Basic Sciences II — Fields and Systems

SESSION 1

Monday 10 A.M.–12:30 P.M.
New York Hilton, Trianon Ballroom

Wire Communication I

Chairman: John C. Leffel, Michigan Bell Telephone Co., Southfield

1.1 A High Speed, Companded, Negative Resistance PCM Encoder, Franklin Selber, *U.S. Army Electronics R & D Lab., Ft. Monmouth, N.J.*
The negative resistance encoding technique and its use in a PCM encoding system is discussed. Negative resistance encoding is accomplished by designing N circuits which have special V-I characteristics (including a negative resistance region) and connecting them in parallel. This will then generate a composite V-I characteristic with 2^N stable states and this circuit can then be used as an analog-to-digital converter. Included work on this technique is an investigation into its basic principles along with its advantages and limitations.

A unique negative-resistance circuit along with a digitally controlled companding technique was studied and the chosen procedure along with the major design problems is given. Also experimental results are included and compared with theoretical considerations.

1.2 192-Channel Time Division Multiplex PCM Communication System by Pulse Distribution Transmission, Hiroki Yoshine, *Hitachi, Ltd., Tokyo, Japan*
Because of the necessity of economical multiplexing of short-haul trunk lines, time division multiplex PCM communications of about 24 channels are being developed in a number of countries. However, these systems are being restricted from the economic point of view by the channel capacity per cable pair.

This paper points out that this problem can be solved by adopting the distribution transmission system, and an actual example of the adoption of such a system is adduced. In the first half of the paper, the application of the distribution transmission system is proposed, and various problems consequent upon the adoption of such a system are clarified. In the second half of the paper, the properties and distinctive features of a 192-channel time division multiplex PCM communication system in which this system was adopted are described. In this system, success has been attained in reducing by about 50 per cent the costs of the equipment per channel in comparison with the 24-channel time division multiplex PCM equipment of the past. Finally, the conclusion is reached that the distribution transmission system is an extremely effective system for the multiplexing of existing exchange cables.

1.3 Improvement in Pulse Transmission on Coaxial Transmission Lines by Reduction of Skin Effect, C. M. Evans, L. R. Whicker, *Purdue University, Lafayette, Ind.*
This paper is concerned with the fidelity of nanosecond pulse transmission in laminated coaxial structures. The ideal situation in which the laminated conductors exhibit a constant surface impedance is investigated, and criteria for specifying maximum allowable distortion associated with a given length of line are determined. Curves depicting the frequency variation of the surface impedance are obtained; and the effects of frequency variations of the parameters of the laminate materials are presented. It is shown that restrictions which have been imposed on such lines in the past may be relaxed without affecting the propagation characteristics of the structure. Finally, a typical line is designed, and its response to a voltage step function is evaluated.

1.4 A Phase-Locked 4 Kc/s Primary Frequency Supply, W. R. Wysocki, *Bell Telephone Labs., N. Andover, Mass.*
A transistorized phase-locked primary frequency supply has been designed to produce an accurate 4 kc/s base frequency for an L-type multiplex carrier and pilot supply. This frequency supply is phase-locked to an incoming pilot frequency. It features digital circuitry, high reliability, high free-running frequency accuracy, and a substantial size reduction over its vacuum tube predecessor. This paper reviews the operational as well as the circuit and equipment design features of this frequency source. In addition, mean time to failure and other reliability parameters are calculated. Finally, an analysis of the phase-lock loop is presented.

SESSION 2

Monday 10 A.M.–12:30 P.M.
New York Hilton, Mercury Ballroom

Marine and Industrial Electrical Applications

Chairman: W. E. Jacobsen, General Electric Co., Schenectady, N.Y.

2.1 Diesel-Electric Machinery Installation with Centralized Control for Oceanographic Survey Ship, D. W. Drews, *Westinghouse Electric Corp., East Pittsburgh, Pa.*
Two oceanographic survey ships will employ twin-screw, diesel-electric propulsion with centralized engine room control. These will be the first ships to be built in an American yard with centralized control of main and auxiliary machinery, including automatic start-up and shutdown of machinery, automatic data logging and alarm trend printing, computer programming of the fuel and ballast systems, and full pilot house control of propulsion and bow thruster. Instrumentation and controls for vital systems are centralized at a central engineering control station for monitoring and control by a single operator. The computer will be a Westinghouse PRODAC 510 with a militarized UNIVAC 1218 central processor.

2.2 A Marine Standard for Intrinsic Safety, J. M. Dorsey, *U.S. Coast Guard, Washington, D.C.*
The characteristics of new tanker cargoes and the trend toward automated cargo handling systems necessitates marine standards permitting the use of intrinsically safe equipment.

Intrinsic safety uses the concept of a minimum ignition energy below which sparks will not ignite a flammable mixture. Energy values vary with product, pressure, voltage, energy source, gap geometry, and vapor-air mixture. The new standard groups products into five classes, arranged by energy levels. A limiting energy for the class is specified which provides a safety margin of four based on energy. Minimum wiring restrictions are needed. Laboratory testing is necessary for final approval. Proposed regulations are appended.

2.3 The Contribution of Motors to a Short Circuit, D. Fabrizi, *SACE, Bergamo, Italy*
The contribution of motors to a short-circuit reaches high values especially on board ships. The phenomena can be grouped into the formulas which express the 3-phase rotating machines transient conditions.

Some simplifications allow the easy calculation of the maximum peak current at time $T/2$, but accurate values for the maximum peak value and the symmetrical component can be obtained by means of tests only. On the basis of data obtained in many laboratories and in field test, IEC have standardized some factors which allow the quick calculation of the motor contribution to a short circuit at various times. These factors have been confirmed with two series of tests carried out in the laboratory on single motors and on board a Navy ship.

2.4 A Static Inverter, Wide-Range, Adjustable Speed Drive, I. M. Macdonald, *Allis-Chalmers Mfg. Co., Milwaukee, Wis.*
The paper presents the main features of, and the performance results obtained with a 30 kVA solid-state converter of the rectifier-inverter form, used as a variable frequency power supply for 3-phase motors of the solid rotor type.

The paper deals with the measures adopted in the inverter to provide for wide-speed ranges and constant motor torque throughout the speed range. It also describes the methods used to provide good linearity of control, stability, and resolution of voltage and frequency while maintaining basically simple and efficient circuitry in the power supply.

Presented, also, are other industrial applications, particularly as frequency changers, in which the same type of circuitry has been supplied.

2.5 The New Precision Draw-Speed Controller for Paper Machine, J. Inagaki, *Tokyo Shibaura Elec. Co., Ltd., Kawasaki, Japan*
This is a precision draw-speed controller which has been developed to control with accuracy of 0.01 per cent the so-called draw-speed—i.e., the speed difference between two adjacent rolls in a sectional drive paper machine.

The sectional drive motor speed is converted through the magnetic reluctance pickup into a frequency signal proportional to the speed; and the draw-speed to be controlled is converted into a frequency difference through a frequency mixer, a frequency bridge and an integrator.

This controller is characterized by extremely high precision, compactness of construction, long service life, and very high stability to external disturbance.

In Japan this device is already applied to different paper machines such as newsprint paper machines producing a 208-inch wide web at 2000 feet per min or 226-inch Kraft paper machines. Principle, construction, performance of this controller are described in detail with reference to examples of application.

SESSION 3

Monday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom N.

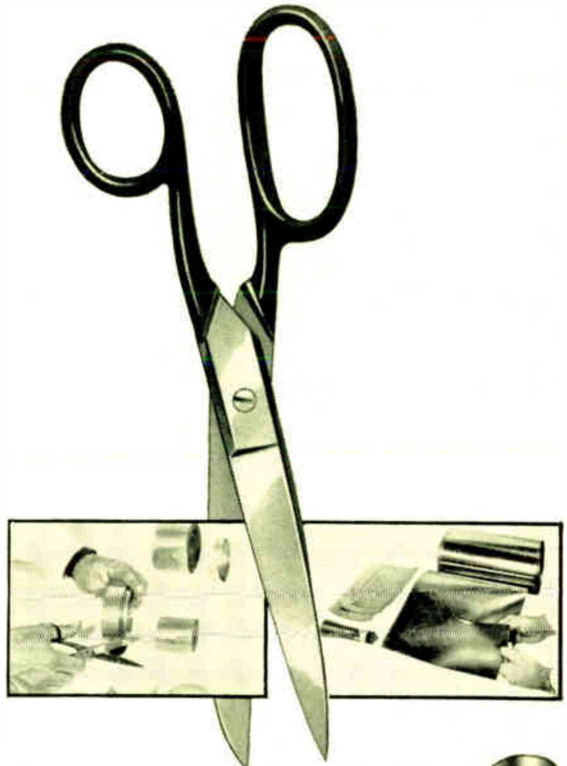
Computer Related Topics I

Chairman: D. E. Rosenheim, International Business Machines Corp., Yorktown Heights, N.Y.

3.1 Tunnel Diode Memory, M. M. Kaufman, L. Dillon, G. Ammon, *Radio Corp. of America, Camden, N.J.*
A number of tunnel-diode test memories have been built and studied at RCA during an ultra-high-speed computer development program. This paper describes the effort on the final memory subsystem designed, built and tested. The memory subsystem used a two-tunnel-device memory cell matrix and was completely compatible with a tunnel-diode logic subsystem. The memory had a full logic gate decoder and addresses were incremented by the logic subsystem. The memory stack was built as 32 words, 5 bits each, and had drive circuits with drive power capable of driving 24-bit words. The decoder was designed as a 32-word portion of a 1024-word decoder and built using the same circuits

DO-IT-YOURSELF MAGNETIC SHIELDS

from versatile Netic and Co-Netic Foils

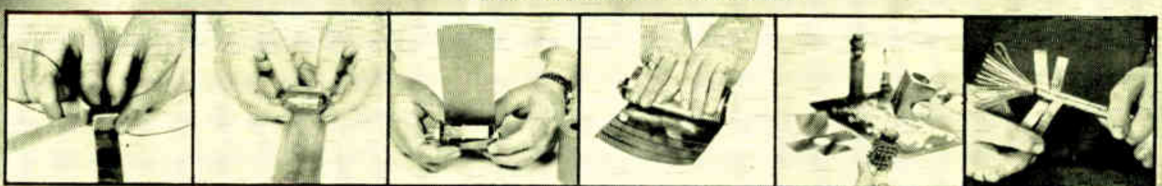


CUT IT!

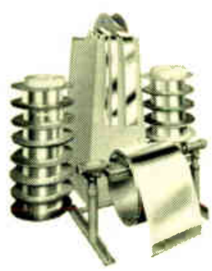
Cuts easily with an ordinary scissors to any size or outline. Flexible foils are stocked in thicknesses from .002″ and in continuous lengths 4″, 15″ and 19-3/8″ wide.

WRAP IT!

Your component is quickly wrapped and protected—within seconds—regardless of its contour or location. Foil takes minimum space. Typical applications illustrated.



Audio Transformer — Vacuum Tube — Relay — CRT — Printed Circuit Module — Cable Shielding



Co-Netic and Netic magnetic shieldings are ideal for initial laboratory or experimental evaluation. They are also available for production applications or to fit automated operations (illustrated at left). Component performance may be dramatically enhanced because Co-Netic and Netic alloys stop degradation from unpredictable magnetic fields. When grounded, they effectively shield electrostatic as well as magnetic fields over a wide range of intensities. The alloys are not significantly affected by dropping, vibration or shock and do not require periodic annealing.

Every satellite and virtually all guidance devices increase reliability with Netic and Co-Netic magnetic shielding alloys. Use these highly adaptable foils to save valuable space, weight, time and money.

Prevent Magnetic Tape Degradation with Netic and Co-Netic containers during shipment or storage. Available in single or multiple reel capacities in round or rectangular containers and large storage vaults. Particularly valuable in maintaining original fidelity of recorded data on programming tapes, telemetering, broadcast, video and hi-fi tapes. Low residual magnetism.

PHONE YOUR NEAREST SALES OFFICE TODAY:

Meriden, Conn.........BE 7-9232	Greensboro, N.C........272-6149	Albuquerque, N.M....AM 8-6797
Union City, N.J.......UN 4-9577	St. Petersburg, Fla......391-9735	Phoenix, Ariz.........AM 4-4934
Riverton, N.J...........829-5237	Maitland, Fla...........647-7830	San Diego, Cal........BR 8-6230
Syracuse, N.Y.........GR 1-8650	Dallas, Tex............FL 7-9213	Los Angeles, Cal......WE 1-1041
Baltimore, Md..........467-3766	Morrison, Colo.........985-4810	Mt. View, Cal..........961-2070
Huntsville, Ala.........534-2073	Salt Lake City, Utah....328-0921	Seattle, Wash.........PA 5-2700
Philadelphia, Pa......LO 3-3990		

Canada: Montreal, WE 7-1167; Winnipeg, SP 4-1991

MAGNETIC SHIELD DIVISION

Perfection Mica Company / EVerglade 4-2122

1322 N. ELSTON AVENUE
CHICAGO 22, ILLINOIS

ORIGINATORS OF PERMANENTLY EFFECTIVE NETIC CO-NETIC MAGNETIC SHIELDING as in the logic subsystem with a worst case decode time of 35 nanoseconds. Using the same logic circuits to decode only to one out of 32 words, a 13.8-nanosecond decode time results and the access time is then 23.8 nanoseconds. The limitation on storage capacities, estimated at 256 words of 24 bits, is also discussed.

3.2 A Ferrite Parity-Determining Device Capable of Performing Coding Operations in Parallel, E. N. Belland, *Lockheed Missiles and Space Co., Sunnyvale, Calif.*

A ferrite device capable of doing the "exclusive or" function, or parity determination, on twelve variables has been constructed and operated. At the same time the parity of any contiguous subgroup of bits can also be determined. The device is a hollow ferrite cylinder into which slots have been cut. The input variables control windings threading these slots. Flux injected at one end of the cylinder is "steered" along a path determined by the input variables. This device is discussed in connection with a Hamming code, a Reed-Muller code, and a low-density code; being used for encoding and error correction information.

3.3 High Speed Threshold Logic A/D Converter with Error Correction, D. S. Schover, Mark Stein, *The Hallicrafters Co., Chicago, Ill.*

High performance analog-to-digital conversion has been achieved by the use of threshold logic with unique error correction and time-sharing features. The system as described in the paper is capable of quantitizing analog signal information into a 12-bit binary coded decimal word having a conversion speed and accuracy of 200 kc/s and 0.1 per cent respectively. The technique applied to the detection and correction of encoding errors has led to a practical system implementation having 0.1 per cent accuracy while utilizing threshold elements limited to 1 per cent accuracy. In order to realize a high overall conversion rate, a novel time-sharing feature has been employed enabling an analog quantity to be processed and read out at a speed three times faster than the basic encoder rate.

3.4 Hybrid Computation—A Means to Study Predictive Control System Behavior, O. I. Elgerd, *University of Florida, Gainesville*

Fast-Model Repetitive Predictor Systems (FMRPS) are suggested as very promising candidates for time optimal control. These systems are utilizing a fast model of the controlled plant and this model is continually being subject to exploratory or experimental control in order to verify best control strategy in the real time system.

Serious difficulties are associated with the design of FMRPS in the area of logic choice. This paper presents a method of utilizing hybrid computers that suit themselves very well for this type of work.

The method is demonstrated on a second order plant where one future switching is enough for achievement of time optimality. The method can be extended to several future switchings.

3.5 Single Chip NAND Gate, Norman Levy, *General Instrument Corp., Hicksville, N.Y.*

The multitransistor single-chip microelectronic NAND gate is the subject of this article. Many different integrated circuit configurations have been developed and are currently being manufactured. All of these represent a compromise between circuit requirements and fabrication methods. We are herein offering still another circuit configuration. We believe that this configuration has many advantages over its predecessors.

The circuit is essentially a blocking type NAND gate which supplies power to its driving nodes. Two types of operation, clamped and unclamped, are available in a single device. The unit operates over a temperature range of −55°C to +125°C and is capable of driving six similar units at speeds that are in excess of 1 Mc/s.

Basically there are two types of NAND logic blocks; the type that takes power from the preceding stage to operate its inverter and the type that supplies its own power to operate its inverter. In the first type we drive each succeeding building block with a preceding building block. In the second type, a blocking action occurs which in effect disconnects the succeeding from the preceding block when the preceding block is operating in its high output impedance mode.

3.6 Ferroelectric–Photoconductive Image Storage, S. C. Requa, *Molectro Corp., Santa Clara, Calif.,* J. M. N. Hanlet, *Pacific Palisades, Calif.*

This report describes work directed toward fabrication of a new device capable of image storage by exclusively solid-state means. The device described is based upon two distinct solid-state effects: photoconductivity and ferroelectricity.

The basic device is a sandwich of ferroelectric and photoconductive films between two continuous outer electrodes, of which one is transparent.

A stored optical image is represented by an electric charge pattern in the ferroelectric film where the conversion from optical image to charge has been accomplished by means of the photoconductive film. Utilization of the photoconductive effect enables a high quantum efficiency in contrast to photoemmisive storage devices, further, an infrared image capability is possible.

Retrieval can be accomplished, for example, by sequential optical scanning of the memory.

SESSION 4

Monday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom S.

Data Communication and Telegraph Systems I

Chairman: F. E. Froelich, Bell Telephone Labs., Holmdel, N.J.

4.1 Correlative Digital Communication Techniques, Adam Lender, *Lenkurt Electric Co., Inc., San Carlos, Calif.*

A concept of transmitting intelligence by means of a signal having certain correlation properties has been evolved, and the theoretical and practical aspects of this research are presented. An important advantage of these techniques is that for a fixed performance criteria, considerably higher speeds are possible compared to the presently known methods. In addition, the implementation is simple and straightforward. An unusual property of these techniques is the capability of error detection without introducing redundancy into the original data.

Expressions for spectral distributions, error performance as well as practical implementation, including the error detection process, are presented.

4.2 New Regulator Circuits for Wide-Band Data Transmission, R. E. Powers, *Bell Telephone Labs., N. Andover, Mass.*

This paper discusses design considerations pertinent to the development of new pilot controlled regulator circuits for L-Multiplex group and supergroup transmission bands. The regulators operate under control of 104.08 kc/s and 315.92 kc/s edge-of-band pilot frequencies, the new Bell System standard pilots for long distance message as well as wide-band data service. It is shown in the paper, by means of a mathematical model, that regulator control circuit expansion, pilot filter bandwidth, and envelope gain enhancement limit the speed of regulator response to 2–3 seconds. Other design considerations, including the need for initial operation without controlling pilot, are also described. Laboratory models of the new regulators are now performing satisfactorily at the American Telephone and Telegraph Co. Long Lines Office at Wayne, Pa.

4.3 Cumulative Codes as Variable Redundancy Codes, J. K. Wolf, *New York University, New York, N. Y.*

A cumulative decision feedback system is considered whereby the digits are decoded on the basis of all the digits in all of the repeated blocks. If an (n,k) binary group code is repeated $(N\text{-}1)$ times, the resultant digits are considered as nN-tuples derived from an (nN,k) code. The parity check matrix, minimum distance and generator polynomial (for cyclic codes) are determined for the (Nn,k) codes in terms of the respective quantities for the (n,k) code.

A method for partitioning the error detection and correction capabilities of the (Nn,k) code is suggested on the basis of a constant fail-safe probability criterion.

4.4 An Error-Correcting Data Transmission System with Block-by-Block Synchronous Operation over Telephone Channels, F. Schreiber, E. Lukas, P. Bocker, *Siemens & Halske AG, Munich, Germany*

A data transmission system is described in which the information is divided into blocks and transmitted at a rate of preferably 600 to 3000 bauds. After each block, the transmission is interrupted and a feedback signal returned, according to which either the next block is transmitted or the previous one repeated. Transmission takes place in a synchronous process in which, with the aid of a heading signal preceding each block, a "block synchronism" is established instead of the usual character synchronism. Independent of this, bit synchronism is continuously derived from the received element transitions.

Each block is protected by a group code after Bose-Chaudhuri. Coding and decoding is effected with the aid of a multiple feedback shift register. The transmission process is further protected by the inclusion in each block of a sequence number and service bits for ensuring the correct transmission sequence of the blocks in the transmission process as a whole. A flow diagram is employed to demonstrate that, through the highly reliable block protection and the appropriate design of the feedback signal and sequence number, the remaining error probability in the data sink is in the order of 10^{-10}.

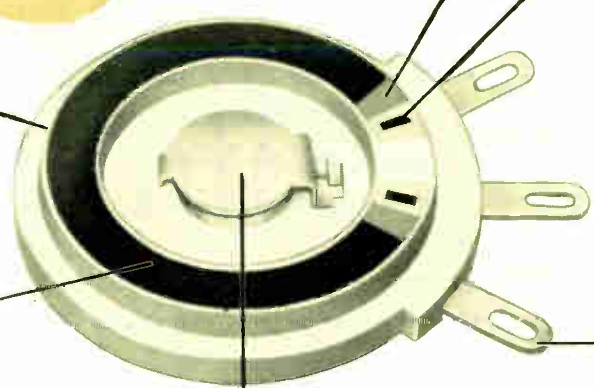
The system can be adapted for operation with different terminal equipment; the interface between the data terminal and the modern corresponds to the proposals for recommendations of the CCITT. The division of the system into functional units permits, in addition to operation in telephone networks, adaptation to half- or full-duplex operation over telegraph or data transmission channels.

4.5 Results of a Medium Speed Parallel Data Transmission Test, R. C. Anderson, T. L. DeFreese, J. H. Soderberg, *Bell Telephone Labs, Holmdel, N.J.;* R. Brooke, H. A. Goldman, *Minneapolis-Honeywell, Needham Heights, Mass.*

This paper presents the results of a data transmission test in which a data set generating nine frequency-shift channels within the voice band was employed. The tests were conducted over a cross section of the various types of facilities found in the switched telephone network.

Relationships between error performance and transmission characteristics were investi-

NAL ?



In five years of volume production

our Cermet Element (fired at more than 650°C) has more than withstood application challenges requiring:

- extreme stability and reliability under severe environmental conditions
- temperature extremes
- high loads
- resolution approaching infinity
- radiation exposure

Here, point by point, is why:

[1] **Cermet Resistance Element** is fired to ceramic base.

[2] **Ceramic Base** serves as built-in heat sink.

[3] **Gold Termination Pad** diffuses with cermet resistor, becomes part of substrate after firing.

[4] **Terminals Electrically Bonded** to fired on termination pad with high temperature conductor.

[5] **Gold Plated Nickle Silver Terminals** rigidly anchored to ceramic substrate.

[6] **Collector Ring** for contactor is integrally connected to center terminal to avoid series connections.

Elements can't separate from subtrate during varying environmental conditions. Thermally bonded cermet resistors are a virtually indestructible combination of a matrix of inorganic material and precious metal alloys after firing.

gated. Also correlation between errors and noise impulses was examined on a real time basis. Results include a statistical analysis of: a distribution of error probability among calls, distribution of errors among the channels, error density distribution within characters, number of error free characters between successive errors, probability of error free transmission, and expected character transmission rate as a function of block size.

SESSION 5

Monday 10 A.M.–12:30 P.M.
New York Hilton, Regent Room

Television Systems

Chairman: O. L. Prestholdt, CBS Radio, New York, N.Y.

5.1 A Slow-Scan TV System Using the Permachon for Scan-Conversion, Copthorne MacDonald, *Westinghouse Electric Corp., Elmira, N.Y.*

A system was developed for the U. S. Weather Bureau which uses a slow-scan vidicon to convert the optical image of a PPI weather radar display to a narrow-band television signal suitable for transmission over conventional facsimile grade telephone circuits. Scan conversion equipment utilizing the Permachon storage vidicon converts the received slow-scan TV image to a bright 625-line TV display. In normal operation, the 2-minute frame time slow-scan information continuously updates the monitor display; however, the receiver switches to a long storage mode if the transmission is stopped. Advantages over microwave systems, equipment features, and performance details are discussed.

5.2 A Progress Report on Airborne Educational Television, F. G. Mullins, *Westinghouse Electric Corp., Baltimore, Md.*

More than 2000 schools in six midwestern states are participating in airborne educational television, now in its third year. Experience has dispelled skepticism regarding aircraft and equipment reliability. Experience also has confirmed the system operating parameters that were chosen.

The F.C.C. has now been asked to make the service permanent and to allow the transmission of six rather than two channels to fulfill additional educational needs. Studies disclose that 33 airborne stations can provide the United States with more educational services than 900 ground stations at less than half the cost. Further economy could be achieved by adapting the system to other government purposes.

5.3 Video Facilities for the 1964–1965 New York World's Fair, G. L. Mignola, R. E. LaBlanc, *New York Telephone Co., Jackson Heights*

The video facilities for the 1964–1965 New York World's Fair reflects the efforts of the New York Telephone Company's World's Fair engineers, expanded over a two-year period of time.

A video cable network has been installed which has 372 pair terminations at 55 locations throughout the Fair grounds. These locations are in TV van areas and exhibit buildings designated as subcenters. Also threaded throughout the Fair grounds is a coaxial cable network for closed-circuit TV programming. Access into the cable system is realized through the use of Western Electric A2A type terminal equipment in specially designed portable cabinets and video subcenter patching.

The video cable connects to a Television Operating Center (T.O.C.) in the Bell System Exhibit which acts as the nerve center for the Fair's TV. The T.O.C. boasts some 50 bays of equalizing, amplifying, and switching equipment as well as a display testing and monitoring console. From the T.O.C. up to 30 video channels are picked for simultaneous transmission between the Fair and the Pan American Building in Manhattan 7 miles away via a specially designed microwave tower. The 140 foot tower is part of the Bell System Exhibit and is equipped with new W.E. 11 Gc/s transistorized transmitters and receivers and portable 6 Gc/s transmitters.

5.4 Design of Video Security Systems for Pay-TV, Ira Kamen, *Teleglobe Pay-TV System, Inc., New York, N.Y.*

This paper describes the requirements for developing video security systems for the new Pay-TV entertainment medium. It points out in depth how the designer copes with some specific basic requirements necessary to comply with the FCC Standards and Bell System Practices. Techniques of how the picture and/or sound are held secure so that the entertainment offered will be available only to those customers willing to pay; methods for reliable, periodic centralized metering for entertainment; and determining accurately how many subscribers purchased each program will be presented. The design of advanced solid-state centralized metering equipment and a novel approach to multiplexing encoded signals will be outlined and embellished with full mathematical treatment.

SESSION 6

Monday 10 A.M.–12:30 P.M.
New York Coliseum, Room A

Instrumentation I

Chairman: Frank D. Lewis, General Radio Co., West Concord, Mass.

6.1 An Active Bessel-Butterworth Filter, K. D. Smith, *Phillips Petroleum Co., Idaho Falls, Idaho*

Implementation of a special purpose analog-to-digital system for the Special Power Excursion Reactor Tests (SPERT) Reactor Complex at the National Reactor Testing Station required the design of a unique low-pass filter. Such a filter is required in order to recover an analog input signal from a sampled signal. Some signals require a constant amplitude characteristic while others require a constant time delay. These characteristics are approximated by use of Bessel and Butterworth polynomials and synthesized by use of operational amplifiers and *R-C* networks. The design procedure is given in detail and measured characteristics are compared with theoretical values. Use of the filter is demonstrated by means of two examples.

6.2 The Design of Linear Thermistor Networks, M. Sapoff, R. M. Oppenheim, *Victory Engineering Corp., Springfield, N.J.*

Thermistor voltage divider, ohmmeter, bridge, and temperature compensator networks are illustrated and practical techniques for linearizing their output functions with temperature are developed. Output functions discussed are voltage, current, frequency, resistance and mechanical shaft rotation. The techniques, as presented, are both graphical and analytical. In all cases, the output functions are transformed to a standard, normalized form to permit the use of universal design charts and equations. The analytical techniques shown may be used to interpolate design curves or as a means of bypassing the graphical techniques in favor of a purely mathematical approach to the problem of linearization.

Where applicable, other transformation equations are presented for the purpose of converting networks employing "design center" thermistors to networks in which "standard value" thermistors may be used.

6.3 Bendix Star Tracker Multiplier Phototube D. Ceckowski, *The Bendix Corp., Southfield, Mich.;* W. Polye, *The Bendix Corp., Teterboro, N. J.;* W. Wilcock, *Imperial College, London, England*

The design, development, and performance analysis of an image dissector multiplier phototube using the Bendix Continuous Resistance Channel Electron Multiplier are discussed. The channel multiplier which replaces a discreet dynode electron multiplier structure offers significant advantages in reduction of weight, volume, and power consumption while retaining the sensitivity of larger tubes. The tube elements are: the photocathode, sensitive to visible radiation; the electrostatic lens, which images the photocathode onto an image plane containing a single aperature; and the channel multiplier located at the aperature. Magnetic deflection is used to scan the cathode scene over the aperture.

This tube was developed for star tracker guidance systems, however, it can be used in many applications where high resolution image dissection is required.

6.4 Measurement of Phase Stability of Quartz Crystal Oscillators for Airborne Radar Applications, J. R. Buck, D. J. Healy, III, M. Meiseles, *Westinghouse Electric Corp., Baltimore, Md.*

Coherent radar systems for airborne applications place stringent requirements on the extreme short-term phase stability of the carrier frequency generator. When the carrier frequency is controlled by a quartz crystal unit in an oscillator circuit, serious difficulty can be encountered with phase modulation of the carrier frequency resulting from the vehicular environment. Typical requirements are that the phase modulation index be smaller than 10^{-4} radians at the carrier frequency. At the oscillator frequency the requirement for a phase modulation index is typically less than 10^{-7} radians. A method for making measurements of modulation indices of this magnitude has been developed which permits measurement directly at the oscillator output without requiring prior frequency multiplication to the SHF range. This method involves the use of a band-pass crystal filter, low-noise intermediate frequency amplifier, limiter and phase demodulator.

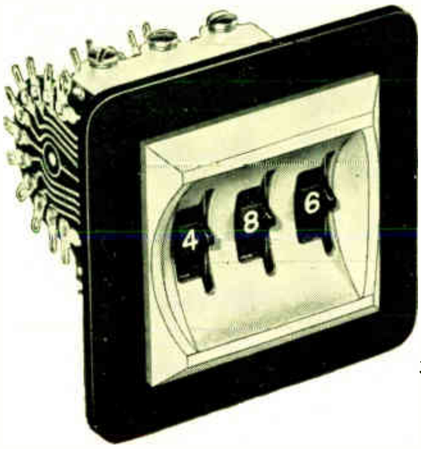
This technique and its limitations are described in detail. Results of the evaluation of crystal units developed by the Bell Telephone Laboratories for a severe environment are given.

6.5 Atomic Clock Using Microwave Pulse-Coherent Techniques, M. Arditi, *ITT Federal Labs., Nutley, N.J.;* T. R. Carver, *Princeton University, N.J.*

In order to increase the stability of gas cell atomic clocks using optical pumping of the alkali atoms, the line-width of the 0–0 hyperfine transition has been artificially narrowed by subjecting the atoms in the cell to two phase-coherent microwave pulses. In this case the resonance line has a width characteristic of the pulse repetition frequency which can be made several times smaller than the natural line-width in the cell. The detection of the microwave stimulated emission is used as a correction signal to lock a crystal oscillator to the atomic transition. Proper timing of the sequence of microwave pulses and light pulses for optical pumping is necessary to conserve phase-coherence and to obtain a well-defined Ramsey pattern.

Results of a laboratory model employing Rubidium 87 show an improvement of the short-time stability of the crystal oscillator by one order of magnitude and the elimination of the light shifts associated with the optical pumping.

C·D·I THUMBWHEEL C·D·I SWITCH MODULES



NEW EXTRUDED BEZEL

(No Screws Exposed)

3-module assembly.
Pat. 3010101.

Equally accurate for gloved or barehand operation. Convenient tabs are especially useful when manual settings are changed often. Large, clear numbers. High legibility because only selected number is visible. Can be furnished in 8, 10 or 12 positions with single or multi-wafer construction in lug type printed circuit wafers. Digital, binary, multiples of each, or multiples of both available with or without internal lighting in standard or MIL types. Ask for technical details today.

C·D·I C·D·I

Patent No. 3104299
Other Patents Pending

Impervious

The sealed front panel portions of **Series PSB binary and decimal rotary push button switches** are completely impervious to dust and liquids. Ten-positions. Ideal for limited space—require only 1" panel space per module. Simply press button to operate. Data sheets available.

THUMBWHEEL SWITCHES

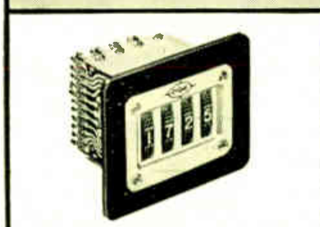
TABET U.S. Patent 2,841,660

Binary & Digital. **Meet MIL-S-22710** C·D·I

- **For Critical Reliability Applications.**
- **Available with internal lighting MIL-L-25467A.**

Permanent wafer type, Series TSD-P. Only ½" panel space needed per module. Also available in multi-deck series TM.

Removable wafer type, Series TSD-R. For continuous operation applications where interruptions must be held to an absolute minimum.



Permanent wafer type, Series TSB-P. Available in 8, 10, 12 or 16 positions, up to 36 switches per assembly.

Removable wafer type, Series TSB-R. For applications where maintenance time is valuable and rapid servicing a necessity.

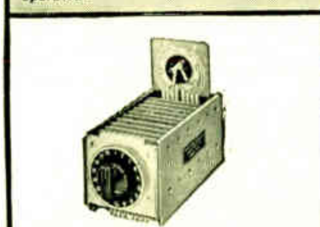
C·D·I ROTARY SWITCHES

TABET U.S. Patent 2,841,660

- **For Critical Reliability Applications. Meet MIL-S-22710**
- **Quick changing of programs, configurations, circuits.**
- **Maintenance problems completely eliminated by unique 5-second wafer replacement models.**

1¾" x 1½" Rotary Selector Switch, Series RS15. Manually (illustrated), motor or solenoid operated.

2⅛" x 2⅜" Rotary Selector Switch, Series RS21. Solenoid, manually or motor operated.



3" x 2⅞" Rotary Selector Switch, Series RS30. Manually (illustrated), solenoid or motor operated.

4" x 4" Rotary Selector Switch, Series RS40. Motor, manually or solenoid operated.

California, Burbank......Weightman & Associates
California, Menlo Park...Weightman & Associates
Colorado, Denver............Franklin Sales Co.
Florida, Orlando......William R. Lehmann & Co.
Illinois, Chicago.............Bauman & Bluzat
Indiana, Indianapolis..........Delta Sales, Inc.
Massachusetts, Needham.........Abett & Hustis
Michigan, Detroit...........S. Sterling Company
Minnesota, Minneapolis......Mel Foster Co., Inc.
Missouri, St. Louis...........Harris-Hanson Co.
New Jersey, Cherry Hill......John Billis Sales Co.
New York, Jamaica...........S.A.M. Associates
New York, Syracuse......Midstate Research Sales
No. Carolina, Charlotte & Winston-Salem..........................Dula Associates
Ohio, Cleveland & Dayton....S. Sterling Company
Ontario, Ottawa..........Whittaker Supply, Ltd.
Texas, Dallas & Houston...Edward F. Aymond Co.
Washington, Seattle...........N. R. Schultz Co.

EXPORT: Minthorne International, Inc., New York, N. Y.

C·D·I CHICAGO DYNAMIC INDUSTRIES, INC.

PRECISION PRODUCTS DIVISION 1725 Diversey Blvd., Chicago 14, Illinois Phone: WEllington 5-4600

SESSION 7

Monday 10 A.M.–12:30 P.M.
New York Coliseum, Room B

Feedback Control Systems

Chairman: Paul P. Fischer, General Electric Co., Valley Forge, Pa.

7.1 Automatic Analog Solution of Algebraic Equations and Plotting of Root Loci by Generalized Mitrović's Method, P. Kokotovic, *Inst. "Milhailo Pupin," Belgrade, Yugoslavia;* D. D. Siljak, *University of Belgrade, Yugoslavia*

Numerous methods for the analog solution of algebraic equations and the plotting of root loci have been developed. The methods presented in the computer literature, can be divided essentially into two categories: Methods which employ special-purpose computers and methods which employ general-purpose computers. The application of the former techniques is significantly limited because electromechanical devices usually not available in the standard analog computing equipment are required. Therefore, the methods utilizing general-purpose computers have attracted greater attention in common engineering design. However, the disadvantage of such methods developed so far, is in that they require considerable participation of the computer operator in the solution process whereby relatively complex schemes are employed in trial-and-error procedures.

The purpose of this paper is to present a procedure which applies the generalized Mitrović's method and the steepest descent approach to the automatic solution of algebraic equations and the plotting of root loci. The significance of the new procedure consists in its simplicity and its use of the general purpose analog computing equipment, such as potentiometers, summers and servomultipliers. Moreover, the corresponding computer circuit can be realized on extremely small-size analog facilities.

7.2 The Response of Multichannel Adaptive Systems, J. L. Douce, K. C. Ng, *The Queen's University of Belfast, Ireland*

This paper examines the behavior of two-channel adaptive control systems. It is shown that, contrary to elementary considerations, adjustment will not, in general, proceed along the line of steepest descent. Design criteria for multichannel adaptive systems are discussed, and it is concluded that simultaneous adjustment of six variables is practicable.

7.3 The Transformer Analogue Servo Analyzer Cum Synthesizer (TASAS), P. V. Rao, B. Ramaswami, *Indian Institute of Technology, Madras, India*

Both the frequency response method and the transient response method have been extensively used for the study of problems in feedback control systems. The conversion of one type of data into the other is of extraordinary interest to control system engineers both from the analysis and synthesis points of view. In the past, several graphical and analytical techniques have been suggested for this purpose. A number of special-purpose computers have also been built to obviate the tedium of the numerical computation.

The transformer analogue principle first suggested by Blackburn can be advantageously applied for developing a compact and accurate special-purpose computer for carrying out the basic operations involved in harmonic analysis and synthesis. In the transformer analogue servo analyzer cum synthesizer (TASAS) described in this paper, ideal transformers are provided with secondaries tapped at values corresponding to the sines of the angles in the first quadrant of the Argand diagram. With the aid of multiganged switches the secondaries can be suitably interconnected for obtaining the frequency response from transient response data. With suitable switching scheme it is also possible to obtain the transient response from frequency response data and this is one of the remarkable features of this computer.

The TASAS can also be used for determining the transfer function coefficients of a system from the experimental data pertaining to its complex frequency response.

7.4 The Application of Z-Transform Theory to the Analysis of Switched-Type Nonlinear Systems, E. S. McVey, G. S. Nurre, *University of Virginia, Charlottesville*

The stability of certain discontinuous feedback systems is analyzed by the use of z-transform theory. It is shown that there can be found in the z-plane a system which is equivalent to the nonlinear system under steady-state conditions. The existence of any limit cycle can be found together with the frequency at which it occurs. An intuitive argument for the stability of a limit cycle is also presented. Several examples are worked and the results compared with those obtained by other methods. The z-transform method is exact and is not restricted by the order of the system.

7.5 On the Statistical Equivalent Gain of Memory Type Nonlinearities, A. K. Mahalanabis, A. K. Nath, *Institute of Radio Physics and Electronics, University College of Technology, Calcutta, India*

The statistical equivalent gain of a nonlinear element has been variously defined: Booton defined it as the parameter which, when multiplied by the input signal, yields an output signal that approximates the actual output signal in the minimum rms error sense. Smith prefers to define it as the cross-power operator (i.e., the cross-power spectrum is obtained by multiplying the input power spectrum by the equivalent gain) while West defines the equivalent gain as the parameter which on multiplication by the input signal yields the correlated component of the output signal. Axelby on the other hand, finds the equivalent gain as the ratio of the rms value of the output to that of the input. All of these definitions, while conveniently producing the same result for the equivalent gain of a zero-memory nonlinearity, lead to extreme mathematical complications when applied to the evaluation of the equivalent gain of a memory type nonlinearity.

In the present paper, two procedures are outlined for obtaining the equivalent gain of some memory-type nonlinearities for band-limited random signal inputs. Justification for considering such signals is not hard to find, particularly in cases where the linear part of the system has low effective damping.

7.6 Characteristic Errors of a Loaded Synchro Transmitter, Sivy Farhi, *Hughes Aircraft Co., Culver City, Calif.*

This paper accurately describes the characteristic error of a synchro transmitter that results from loading the secondary windings. The second harmonic error due to unbalanced loads has long been apparent to synchro manufacturers and users, and has been described in a published paper. The secondary slot harmonic error considered in this present paper was predicted by the author while employed at the Eclipse-Pioneer Div. of the Bendix Corp. The existence of this error is not generally known and a description of it has not been previously published.

SESSION 8

Monday 10 A.M.–12:30 P.M.
New York Coliseum, Room C

Reliability

Chairman: Harvey R. Barton, RCA Service Co., Cherry Hill, N.J.

8.1 Selecting Most Reliable Electronic Components, Irwin Nathan, *General Precision Aerospace, Inc., Little Falls, N.J.*

The advertised failure rates of electronic components designed for aerospace applications are generally low. Unfortunately, these failure rate estimates are not precise, partially because test samples are small. This results in confidence-band spreads of several orders of magnitude. Furthermore, these failure rate estimates are not made under operational conditions. The designer is thus faced with the following dilemma: Selecting unproven components to achieve performance requirements may endanger mission reliability, while selecting proven components will bolster reliability confidence, but may degrade mission performance.

In this paper we present one method of obtaining useful data and analyzing the results to permit intelligent design trade-offs.

8.2 Failure Predestination, R. Hilow, J. Klion, *Rome Air Development Center, Griffiss AFB, N.Y.*

It is the purpose of this paper to outline an overall concept of component part life based on the premise of thresholds of failure. It shows the relationship of this concept to different modes of failure and to the enigma of families of parts which have been observed to have constant as well as time dependent failure rates. The paper discusses the advantages which result from identifying such thresholds, progress to date in their identification, the various tests which may be utilized in their detection, the test costs, efficiencies, and experimental results to date.

8.3 Reliability Screening Using Infrared Radiation, A. Feduccia, *Rome Air Development Center, Griffiss AFB, N.Y.*

The infrared radiation emitted by all electronic component parts may possibly be used to (1) identify short-life or faulty parts and (2) predict the degradation or drift of part parameters. It has been shown that parts emitting abnormal amounts of infrared radiation under the same stress conditions tend to experience early failures. This paper will deal with the investigations leading to the development of a nondestructive infrared test which can ferret out potential early part failures before the parts are used in a circuit. Investigations into the use of radiometric techniques combined with high-resolution scanning to form thermal images in reliability analysis, will also be included.

8.4 Reliability Prediction of Electromechanical Functions—Estimate or Guesstimate, D. Fulton, *Rome Air Development Center, Griffiss AFB, N.Y.;* G. Chernowitz, *American Power Jet Co., Ridgefield, N.J.*

This paper contains a discussion of the present state of electromechanical reliability prediction. It takes the position that our present knowledge is at the "black box" level and that our efforts must be devoted to developing knowledge and data at the "curcuit level." By way of example, the effect on electronic reliability is considered as if knowledge was limited to the "black box."

Examples are presented of the inapplicability of generic "black box" failure rates and of the differences in failure rates which can be related to a system function, i.e., radar, communication, etc.

The "data gap" resulting from deficiencies in failure reporting systems and what must be done to update data collection and analysis is discussed.

SESSION 9

Monday 2:30–5 P.M.
New York Hilton, Trianon Ballroom

Wire Communication II

Chairman; H. W. Shaner, General Telephone Co. of Pennsylvania, Erie

9.1 A Non-Interfering Cable Pair Identification System, D. W. Gilbo, *Michigan Bell Telephone Co., Southfield*
A telephone cable pair identifying system is described. A cable pair may be energized with an audio-frequency signal in such a way as to not interfere with telephone service being provided by the cable pair. The system uses passive elements (except for a conventional oscillator and amplifier) and is simple to operate and maintain.

The total cost of the components is less than ten dollars. Field trials have been completely successful.

9.2 The Detection and Location of Transmission Impairments in Telephone Cables by the Use of an Artificial Line, D. W. Gilbo, *Michigan Bell Telephone Co., Southfield*
A method of detecting and locating telephone cable transmission impairments by the use of an artificial line in a bridge circuit is described. The distant end of the cable pair being tested is left open i.e.,unterminated. The pair is then connected to a unity ratio bridge with an artificial line in the balancing arm of the bridge. The artificial line is also unterminated and is built up to the engineer's specification for the particular cable pair under test. The bridge balance is then noted over the frequency range for the type of cable pair—e.g., 200 to 3000 c/s for voice frequency loaded pairs. The degree of balance is a measure of the similarity in propagation constant of the artificial line and the cable pair thus disclosing structural differences immediately. The location of any defects may be readily accomplished by one or two simple methods: 1. Manipulating the artificial line until a high degree of balance is obtained thus building a "model" of the defective cable pair. 2. Examining the bridge balance frequency function for identity with previously made samples of transmission impairments.

9.3 New Loop Around Systems, E. H. B. Bartelink, D. L. Knight, *Northeast Electronics Corp., Concord, N.H.*
This system establishes the circuits needed for centralized two-way transmission measurements on one-way or two-way dial trunks from a remote to a control office or between remote offices. It is operated by one-man or automatic equipment at the control office. The remote equipment is connected to a subscriber number or a test number. After seizing the remote equipment, the control office transmits multiple tone control and dial signals to select the desired trunk, dial through on it, apply milliwatt signals or test termination, or busy out defective trunks. Automatic transfer to loop or E & M operation and to 2-wire or 4-wire operation is provided.

9.4 Effectiveness of Different Loading Systems in Exchange Plant, J. N. Petrie, *Automatic Electric Co., Northlake,Ill.*
The current trend is to place even the longest rural telephone circuits in buried cable. This implies the application of "loading," together with a judicious control of "bridged taps" beyond the last loading coil.

Three sets of tests were made on 24 ga., 22 ga., and 19 ga. artificial telephone cable pairs loaded to the H-88, D-88 and D-66 systems with varying lengths of bridged tap:

1. White noise measured with 3-A NMS (3 kc/s "flat" weighting).
2. White noise measured with a 3-A NMS ("C" MSG weighting).
3. White noise measured with a true rms voltmeter (600-ohm termination).

The tests show that some of the theoretical "advantages" of the new loading schemes are not being realized.

9.5 The Steady-State Magnetic Field of a Twisted Pair, H. Adelaar, *Bell Telephone Mfg. Co., Antwerp, Belgium*
In the application of switchboard cabling, particularly to the time division switch exchanges where it is necessary to reduce crosstalk coupling to an absolute minimum, the extensive use of a length of screened cables is employed. These cables would be awkward to handle and tend to make the task of cabling a switchboard a rather time-consuming job. This paper shows the results of an investigation to determine the effectiveness of a twisted pair in reducing interference, as well as its suitability for replacement of screened or coaxial cables.

In problems connected with crosstalk due to magnetic induction between neighboring pairs it is important to be able to compute the magnetic field of a twisted pair.

In computing the steady-state magnetic field set up in the space surrounding a pair of straight parallel conductors of circular cross section and infinite length, as a result of a steady or slowly varying current flowing in opposite directions through said conductors, the difficulty of determining the distribution of the current density over the cross-section area may be circumvented by assuming that all current is concentrated in a determined point of the cross section.

Under the assumption that this law is at least approximately valid even for a twisted pair, an integral expression is derived for the components of the magnetic vector potential A, which is related to the magnetic field vector H by the expression $H = \text{curl } A$. This integral can be solved by development of the integrand into a power series and integration in part.

The resulting expression gives a good approximation of the vector potential in all points at a sufficient distance from the twisted conductors; it shows that as this distance increases, there is a rapid more-than-exponential decay of the magnetic field strength.

SESSION 10

Monday 2:30–5 P.M
New York Hilton, Mercury Ballroom

Electrical Applications in Industry

Chairman: H. G. Frostick, U. S. Steel Corp., Chicago, Ill.

10.1 Power Distribution Systems for High Speed Computers, J. W. Martin, *Simpson Electric Co., Chicago, Ill.*
In many cases in the past, the task of specifying dc power supplies for computer use has been delegated to "power supply specialists." Logic circuit designers give little, if any, consideration to the problems of providing and distributing the well regulated dc power.

However, the new generation of computers with nanosecond speeds must incorporate new approaches to the problems of dc power distribution if adequate system performance is to be achieved. At such speeds, every wire is a distributed constant transmission line and the whole machine is essentially one circuit with a high degree of complexity.

This paper describes a multiple output, well regulated dc power supply with output voltages from 5 to 48 V and output currents up to 400 A. The total output power is approximately 12.5 kW. Although the unit described was specifically designed for use with a large scale digital computer, the systems employed are applicable to any application where large amounts of precisely regulated dc power are required.

10.2 Time Division Multiplex Numerical Controller for Machine Tools, Y. Oya, *Senden-bu Hitachi Ltd., Tokyo, Japan*
This paper reports an equipment which fulfills low cost and stability, which are the most urgent necessities for present numerical controllers, with reduced number of components, based on the time division multiplexing technique.

A pulse-delaying device has been developed using capacitor temporary memories and multiphase synchronous pulses. In addition, other techniques such as electromagnetic delaying and magnetostrictive delaying are possibilities. But electromagnetic delaying is not practical because of the length required unless the repetition frequency exceeds 1 Mc/s. Magnetostrictive delaying is inefficient and uneconomical for the temporary memory of 10 to 20 bits or less required in the digital control.

10.3 High-Voltage Transistor SCR DC Power Switches, John Rosa, R. A. Colclaser, *Westinghouse Electric Corp., Pittsburgh, Pa.*
Two novel circuits are described which make use of power transistors and silicon controlled rectifiers to provide many of the characteristics of high-voltage, high-current transistors and a high-voltage, high-current turn-off silicon controlled rectifier. Design equations are derived for all of the components. An example is presented in each of the two cases of the switch used as a chopper at 60 pulses per second supplying 4.5 kW to a resistive load from a 300 V supply. The resistive-inductive load case is also considered.

10.4 Reverse Generator Voltage with Unidirectional Trinistor Control Rectifier, S. J. Asseo, *Westinghouse Electric Corp., Buffalo, N. Y.*
Most metal mill drives use separate dc generators for accurate speed control. Generator voltage and motor speed are controlled by a unidirectional trinistor control rectifier supplying excitation to the generator main field. To reverse the drive, generator voltage must be reversed. This is accomplished by using a bias field or by connecting the trinistor in buck-boost across the single machine field. In either case, the ac nature of trinistor voltage tends to wipe out reverse ampere-turns and prevent reversal of the drive motor. An external reactor in series with one machine field absorbs the alternating voltage and allows reversal of the drive motor. The size and inductance of the external reactor is to be determined from expressions and methods developed in this paper.

10.5 Dial Impulse for Remote Setting of a Predetermined-Counter with Provisions for Digital In-Line Readout of Counter Setting and Counting Progress, P. P. Corso, *Staten Island, N. Y.*
Industry often employs predetermined counters for indicating when a preset amount of material has been counted such as controlling the amount of material winding onto a reel. Pulses, representing a unit length of material, are counted by a predetermined counter which has been set to actuate a cutoff device at the count that corresponds to the desired amount of material.

The system described is frequently used, but particular manufacturing industries, require that the predetermined counter be of the explosion-proof type. However, with this type of equipment, operators experience difficulty when setting the counter, and this equipment also lacks the means for continuously monitoring counting progress.

A telephone dial issued to set the desired count into a predetermined counter; a digital "in-line" readout device is used to visually indicate the desired count; and the counts progress is continuously monitored.

SESSION 11

Monday 2:30–5 P.M.
New York Hilton, Sutton Ballroom N.

Computer Related Topics II

Chairman: Arthur L. Samuel, International Business Machines Corp., Yorktown Height, N.Y.

11.1 Sufficient Conditions for Achieving Minimum Distortion in a Quantizer, P. E. Fleischer, *Bell Telephone Labs., Murray Hill, N.J.*

A quantizer is said to be optimum when the intervals to be represented by a single value, as well as the representative values, are chosen to produce minimum error power. Necessary conditions for a quantizer to be optimum have previously been obtained. The required computations are iterative and necessitate the use of a digital computer for all but the most trivial problems. The answer so obtained, however, may really correspond to a maximum or a saddle point of the error power curve.

In this paper a very simple sufficient condition for checking the minimality of a quantizer structure is derived. A strengthened form of this condition lends considerable insight into the existence of unique optimum quantizers. Thus, it is shown that signals having Gaussian, Laplacian, or Rayleigh probability densities admit unique optimum quantizers.

11.2 Design of a Digital Waveform Identifier, E. J. Farrell, R. R. Lachenmayer, G. F. Marette, *UNIVAC, St. Paul, Minn.*

In this paper we will discuss the design of a digital waveform identifier. The device performs the following function. Given a set of reference waveforms, it analyzes a long segment of an input waveform to determine which reference waveform is "contained" in the segment. The identifier uses digital techniques. In other words, the waveforms are sampled at a fixed rate and identification is based on these samples. The way in which one obtains the reference waveforms depends on the type of identification problem.

To simplify and to clarify the discussion of the design, a particular application is considered; i.e., underwater object classification using sonar. Many of the results and techniques for sonar can be used directly in other applications.

In the first section, methods of waveform identification are analyzed and compared from a statistical viewpoint and a hardware viewpoint. A method is selected that has several desirable statistical properties.

In the second section, the selected identification procedure is implemented. The parameters affecting speed and required hardware are varied, and a design of a set of parameters is presented.

11.3 On the Optimum Quantization of Stationary Signals, James D. Bruce, *Massachusetts Institute of Technology, Cambridge*

Quantization occurs whenever it is necessary to represent physical quantities numerically. In this paper the exact expression for the quantization error as a function of the parameters that define the quantizer is presented, and an algorithm for determining the specific values of these quantizer parameters that define the absolute minimum of the error surface within the region of variation is developed. This algorithm, which is based on a modified form of dynamic programming, is valid for a wide class of error criteria. Examples are presented to compare the performance of the optimum quantizer with that of quantizers currently in use.

11.4 Procedures for Recognizing Patterns Subject to Unknown Transformations, K. B. Gray, *Hughes Research Labs., Malibu, Calif.*

The problem is that of distinguishing two classes of gray scale patterns defined on a region S in the plane. It is assumed that observations $X(u) = p(T_\alpha u, \theta) + N(u)$ are made at all points u in S, where $N(u)$ is a noise process superimposed on the observations of the pattern value $p(T_\alpha u, \theta)$. Here, $T\alpha$: u — T_αu is a random transformation with known probability distribution, and θ is a parameter indexing the various patterns. The a priori probability distribution of the parameter θ is assumed to be known. Optimum Bayesian recognition procedures, that take account of the available knowledge concerning the distribution of the random transformation $T\alpha$, are given. In addition a linear threshold recognition procedure is investigated.

11.5 Punctured Systematic Cyclic Coder, G. Solomon, J. J. Stiffler, *Jet Propulsion Lab., California Institute of Technology, Pasadena*

It is shown that all optimal error correcting (n, k) codes for fixed k and $k < n < 2^k - 1$ can be considered as codes "punctured" from a parent maximal length shift register code of length $2^k - 1$. Thus there is a great impetus given to the search for an efficient decoding procedure for the $(2^k - 1, k)$ code which is inherited by the punctured codes with a minimum of technical alterations. With such a decoding procedure, a single machine for all rates and fixed k encoder-decoder with full error correcting capabilities becomes technically feasible and desirable. The decoding procedure presented here fulfills these requirements for small k.

11.6 The Application of Electro-Optical Filtering to Object Recognition, George Revesz, D. W. C. Shen, *University of Pennsylvania, Philadelphia*

Optical data in pattern recognition problems are pre-processed by techniques of spatial frequency analysis, which is a two-dimensional generalization of the frequency analysis technique of electrical networks. This analog preprocessing method enables a simplification of the subsequent electrical decision making networks.

It is shown in the paper that problems such as unsharp focusing of images can be remedied by electro-optical networks derived from the above analysis.

It is also shown how signal to noise ratios of optical data can be improved. As an example the light intensity distribution function of a rectangular object in a noisy background is analyzed and an optimal aperture is found using the generalized Wiener-Hopf equation. The optimal aperture is approximated by several realizable apertures.

SESSION 12

Monday 2:30–5 P.M.
New York Hilton, Sutton Ballroom S.

Data Communication and Telegraph Systems II

Chairman: J. B. Booth, Short Hills, N.J.

12.1 A Time Domain Method for Estimating the Error Performance of Data Sets in the Presence of Line Distortion and Impulse Noise, G. R. Schwarz, *Bell Telephone Labs., Holmdel, N.J.*

There is need for a simple, inexpensive method to estimate the performance of data sets over data transmission lines which have distortion and impulse noise impairment. Error runs are time consuming and require the use of data sets, word generators, and error detectors. "Eye" patterns evaluation takes less time than error runs, but cannot be applied to all data sets and requires considerable skill to obtain accurate estimates.

This paper describes a procedure which uses the ratio of average to peak voltages of a periodic impulse response of data transmission lines to estimate the performance of data sets over these lines. The method evolved from data set performance studies using frequency domain line characteristics.

A companion paper by T. C. Anderson describes a similar technique using the ratio of peak to average voltages of the line impulse response. This method is an outgrowth of "eye" pattern studies.

12.2 The PAR Meter, T. C. Anderson, *Bell Telephone Labs., Murray Hill, N.J.*

The object of the PAR meter is to provide a single number rating of the fidelity of a channel for the transmission of digital signals. This rating is a weighted measure of the total gain and phase distortion in the channel. This is a time domain set. The letters PAR stand for Peak to (full-wave) Average Ratio. The PAR meter measures the ratio of the peak and full-wave, rectified average value of a low duty-cycle pulse signal. The test signal spectrum used for this measurement can be tailored to produce desired distortion sensitivities at various frequencies or to match the spectrum of the expected data signal.

This paper describes an exploratory design of this type of test equipment for use on Bell System voice-band circuits.

12.3 Intercontinental Telex Traffic, Ehrhard Rosenberg, *Seimens & Halske AG, Munich, Germany*

Intercontinental traffic from subscriber to subscriber has within 13 years developed to be a very important factor in the world's Telex service. Technical development and future possibilities are discussed as well as economical questions.

12.4 Advances in Printing Telegraphy in 1963, W. Y. Lang, *Bell Telephone Labs., New York, N.Y.*

This paper gives a description of approximately 20 new developments in the printing telegraphy art from Germany and Switzerland.

12.5 Advances in the Facsimile Art in 1963, W. H. Bliss, *Radio Corp. of America, Princeton, N.J.*

This is the eighth consecutive year for the preparation and presentation of a general facsimile report. As previously the main purpose of the paper is to present new features and development in the facsimile field which do not warrant full length papers.

The objective is to furnish an outlet and listing of some of the recent improvements and advancements in the art. Material for this year's paper has been received from six organizations scattered over the world. Because of the nature and scope of the information collected, the logical presentation consists of a series of individual reports.

Descriptions are given on new equipment developed and manufactured by the A. B. Dick Co., the Fairchild Camera and Instrument Corp., Dr. -Ing. Rudolf Hell, Muirhead and Company Ltd., the Nippon Electric Company Ltd., and the Western Union Telegraph Co. This includes a railroad car reporting system, a unit for automatic selection of index of cooperation and drum speed, the latest newspaper page facsimile equipment, recorders for weather satellite pictures, and other new services as well as the newest models of facsimile scanners and recorders.

SESSION 13

Monday 2:30–5 P.M.
New York Hilton, Regent Room

Microwave Theory and Techniques

Chairman: Leonard Swern, Sperry Gyroscope Co., Great Neck, N.Y.

13.1 A Microwave Technique for the Determination of Nonlinearities in Bulk Materials, A. K. Kamal, W. L. Adams, *Purdue University, West Lafayette, Ind.*

An experimental technique is developed for the comparison of the nonlinear component

of conductivity of materials at microwave frequencies with the nonlinear conductivity at low frequencies or dc. The technique called the dc interaction method compares only the nonlinear component of the conductivity and is not affected by large linear conductivity in "shunt." Various samples composed of aggregates of silicon-carbide crystals are examined to determine the nature of the nonlinear component of conductivity at 3 Gc/s. All of the samples tested exhibited essentially the same nonlinear conductivity at 3 Gc/s as they did at dc. Silicon-carbide aggregates, however, exhibited a large linear conductivity at microwave frequencies which masks the nonlinear effects as far as most practical applications are concerned. The aggregate approach to obtaining bulk nonlinearities may, however, show promise when it is used with aggregates of other materials.

13.2 Experiments in the Transportation of Energy by Microwave Beam, W. C. Brown, *Raytheon Co., Burlington, Mass.*

Several hundred watts of power have recently been transmitted over a distance of 25 feet by means of a microwave beam with an overall efficiency of 25 per cent, including both transmission and rectification losses. State of the art of the components involved, including microwave power generation, antenna technology, and microwave rectification are such that both the power level and distance could be increased more than a thousandfold. These component areas are reviewed in detail as well as the transmission experiments.

13.3 Multiple Quantum Frequency Conversion, D. J. Scalapino, *University of Pennsylvania, Philadelphia;* A. Vassiliadis, *Stanford Research Institute, Menlo Park, Calif.;* R. N. Wilson, *Kane Engineering Labs., Palo Alto, Calif.*

A molecular system having two energy levels and coupled to an electromagnetic field by a transition dipole moment will resonantly absorb energy at odd subharmonics of energy level separation $\omega \approx \Omega$, $\Omega/3$, $\Omega/5$ .... These correspond to 1, 3, 5, ... quantum absorption processes. Part of this absorbed energy is emitted back into the field at harmonics of ω and part is dissipated into the lattice degrees of freedom. It is thus possible to drive the molecular system with a field of frequency $\omega \approx \Omega/n$ (n odd), and obtain radiation at a frequency $m\omega \approx \Omega$. Here we present results of a theoretical and experimental study of these resonant multiquantum conversion processes.

13.4 A Fast Switching High Power C Band Ferrite Circulator, L. Silber, A. Weiss, *Polytechnic Institute of Brooklyn, N. Y.*

A differential phase shift circulator has been developed which will switch powers up to 550 kW peak, 200 W average in 20 ns. It utilizes nonreciprocal transverse field ferrite elements of novel configuration. The use of a ferrite tube permanently magnetized to remanence by a current pulse in an axial wire eliminates the usual external magnet and allows the circulator to switch. Using this configuration a device was built that operated over a frequency range 4.9 to 5.6 Gc/s. The loss between coupled ports was less than 1.3 dB and the isolation between uncoupled ports was greater than 20 dB.

13.5 Phase Equalization for Phased-Array Transmitter, S. I. Rambo, M. G. Gray, J. J. Barbagallo, *Westinghouse Electric Corp., Baltimore, Md.*

Current radar systems employing programmed multiple antenna feeds to orient the antenna beam electronically require large numbers of parallel channels operating simultaneously with identical (within close tolerances) phase-delay characteristics. In the prototype radar under consideration, these channels include over 1000 microwave amplifier tubes for which phase-delay, as well as gain and power output, must be identical in order to accomplish high pointing accuracy and power addition.

The transmitter module includes a state-of-the-art, high power, grid-controlled traveling-wave-tube amplifier having a unknown phase-frequency characteristic. It is desired to refer the phase curves of all modules to an absolute reference and obtain the best mean square fit to an average. Single frequency compensation is introduced to optimize wide-band phase tracking errors. This paper discusses the problem of determining these errors and the method of optimizing the module phase curves for zero average deviation.

A precision phase measuring system operating in a swept frequency, pulsed mode with automatic readout is described. Theory, operation, calibration and error analysis are discussed.

SESSION 14

Monday 2:30–5 P.M.
New York Coliseum, Room A

Instrumentation II

Chairman: Robert Kingston, Massachusetts Institute of Technology, Lexington

14.1 Detection and Measurement of Low-Intensity Nuclear Radiation, D. E. Engstrom, *University of Washington, Seattle*

To minimize statistical error in low-intensity radiation measurements, background counting rates must be minimized while maintaining good detection efficiency. Background counting rates are reduced by employing radiation shielding, reducing detector size and density and by constructing detectors from radionuclide-free materials. Special electronic circuits are also used. The applications of these methods are governed by the individual requirements of the system with regard to maintaining a good efficiency for the radiation being measured. Systems using solid scintillants, liquid scintillants, geiger tubes and solid-state detectors all require a different combination of these methods. Proper preparation and location of the radiation source is also a primary requisite.

14.2 In-Vessel Instrumentation for the Borax V Nuclear Reactor, E. J. Brooks, *Argonne National Lab., Idaho Falls, Idaho*

The Borax V reactor, designed and operated by Argonne National Laboratory, is a boiling water reactor with integral nuclear steam superheater, and is currently undergoing tests at the National Reactor Testing Station near Idaho Falls, Idaho.

This paper presents some of the design characteristics of the reactor, and describes in detail some of the in-vessel and in-core instruments and measurements carried out to date and planned for the future. Description of special instruments or applications of standard equipment to the task, occupy the bulk of the paper. Special techniques used in transducer installation are covered, and a section on development work on high temperature thermocouples is included. Experimental results will be presented, where applicable.

14.3 Hall Generators, What, Why and How Much, Sherwin Rubin, *National Bureau of Standards, Washington, D.C.*

A brief tutorial introduction to the Galvanomagnetic effects, the Hall effect and the magnetoresistive effect is presented.

The characteristics of the Hall effect of interest in engineering applications are outlined. Standards of terminology and measuring methods being evolved, both internationally under the auspices of the IEC, TC 47, and nationally under the auspices of the Department of the Navy, Bureau of Naval Weapons, are noted. Brief mention is made of the concept of linearity error as a percentage of its value at a point on a curve of Hall voltage vs. magnetic induction, as opposed to the definition of linearity error as a per cent of full-scale value. Two additional sensitivity indexes for Hall generators are introduced. Their derivations are outlined and they are defined both for the static and the small signal case. These new definitions differ from the commonly used one in that one is a function of magnetic induction only and the other is a function of control current only. The relationship between these indexes and the product sensitivity index is demonstrated.

14.4 Noise in Hall-Effect Sensors, Max Epstein, *IIT Research Institute, Chicago, Ill.*

The results of an analytical and experimental study of noise at the output terminals of a Hall-effect magnetic-field detector are reported. The experimental results are obtained for Hall-effect sensors made of intrinsic germanium. In the analytical model, the specimen is assumed to consist of mutually uncorrelated elements of resistance fluctuation and the mean-square potential fluctuations at the Hall terminals, due to the individual elements, are calculated. By comparison with measured values the size of the mutually uncorrelated elements is found to be approximately equal to four times the diffusion length of excess carriers in the semiconductor. Good agreement is obtained for samples of different size. Utilizing the analytical model, an optimum shape of the Hall-effect sensor is obtained which provides the highest signal-to-noise ratio. Considerations in the design of Hall-effect magnetometers and other Hall-effect devices is discussed.

14.5 The Multiplying Action of the Magnetoresistance Effect in Semiconductor and its Application to the Power Measurement, Shoei Kataoka, *Electrotechnical Laboratory, Tokyo, Japan*

This paper describes a new method of power measurement applicable to a wide range of frequency. The technique employs the magnetoresistance effect in an intermetallic semiconductor.

A theory has been developed on the multiplying action of the magnetoresistance effect in comparison with that of the Hall effect.

Experiments were made on the multiplying characteristics with InAs and InSb polycrystals and a satisfactory agreement with the theory was obtained. Applications to the power measurement were demonstrated at dc, ac, and microwave frequencies, and the temperature dependence, influences of power factor and so on were also investigated. Results of the experiments have shown excellent performance, with several advantages over the Hall-effect wattmeters.

SESSION 15

Monday 2:30–5 P.M.
New York Coliseum, Room B

PANEL: Is Measurements Training a Neglected Area of the Engineering Curriculum?

Chairman: George Yabroudy, American Bosch Arma Corp., Garden City, N.Y.

Bureau of Standards Viewpoint, Alvin McNish, *National Bureau of Standards, Washington, D.C.*

Educational School Viewpoint, Y. T. Li, *Massachusetts Institute of Technology, Cambridge*

Industrial Viewpoint, Ernest Goetz, *American Bosch Arma Corp., Garden City, N. Y.*

SESSION 16

Monday 2:30–5 P.M.
New York Coliseum, Room C

Electromagnetic Compatibility

Chairman: Herman Garlan, Federal Communications Commission, Washington, D.C.

16.1 Trends in Radio Frequency Interference Measurements, H.W. Ervin, R. J. Jacobi, *White Electromagnetics, Inc., Bethesda, Md.*
Within the last decade there has been a great emphasis on the automation of test and checkout equipments. These efforts resulted in the development of such items as RACE, GEE, MEE and DATITICO. The reasons, which led to the development of these equipments, have now been accepted by the RFI/EMC Community and actions are being taken to automatize RFI/EMC specification measurement instrumentation. This is particularly evidenced by the requirements of the new MIL-STD-826. This automation of RFI/EMC instrumentation will have to be achieved in at least two discrete steps: (1) modification of existing instrumentation to achieve semiautomatic or automatic operation and (2) development of entirely new, completely automatized instrumentation. This paper reviews the reasons leading to the establishment of the requirement for automatized RFI instrumentation and discusses interim and proposed techniques to be utilized in achieving the interim and long-term automation of RFI measurement.

16.2 Instrumentation and Measurement Techniques for Electromagnetic Compatibility, D. R. J. White, R. J. Jacobi, *White Electromagnetics Inc., Bethesda, Md.*
Recently the awareness within the RFI/EMC community, that new instrumentation and measurement techniques are needed to meet the changing and expanding RFI/EMC test requirements has moved to an action status. The RFI/EMC community is taking steps to determine test instrument design requirements preparatory to developing the required instrumentation. This undertaking implies a large and costly development effort unless the RFI/EMC communities can take advantage of applicable developments completed in other areas. In this respect, both the state-of-the-art and instrumentation and measurement techniques used by the Electromagnetic Warfare Community and Intelligence Community are years ahead of the EMC community's progress primarily because of the large government sponsored research on development support given to the aforementioned groups.

This paper treats the problems of requirements, state-of-the-art, and corrective measures that should be considered by the RFI/EMC Community to satisfy the present instrumentation and measurement technique void. The areas covered in the paper are: (1) Definition of instrumentation and measurement techniques, (2) Problems resulting from poor or inadequate IMT, (3) State-of-the-art and, (4) Future courses of action.

16.3 Methods for Predicting Interference Effects in Tracking Radars, M. D. Aasen, *ITT Research Institute, Annapolis, Md.*
Presently, modeling techniques have been established for radio frequency interference prediction in search radars. Modeling techniques for the special group of radars, classified as tracking radars, are relatively new and require further development before an adequate prediction model can be realized. The nature and aspect of a tracking radar prediction model depends upon the various forms of degradation that the system experiences in the presence of an interference environment. This degradation is dependent upon the functional mode of operation; search, acquisition, and track. The corresponding prediction techniques are also dependent upon these functional modes.

This paper presents the results of an analysis to determine the effects of interference on tracking radars and to derive methods for designing mathematical models that can be used for predicting the effects.

16.4 A Method for Deriving Estimates of the Total Spurious Response Characteristics of a Receiver from the Results of a Few Measurements, R. M. Cowgill, *Bell Aerosystems Co., Tucson, Ariz.*
The majority of the work on the measurement of spurious responses in receivers done up to now is based upon the measurement of the sensitivity of all spurious responses for each of a few (usually three) tuned frequencies within the tuning range of any one receiver or major radio-frequency head.

These responses generally have been identified as being products of the nonlinear mixing of the incoming and local oscillator signals, most often in the mixer. Very little has been said about how the sensitivity of these responses varies with tuned frequency expect to assume that the worst response of a kind found applies for all such responses. This paper examines the mechanisms involved in their generation and defines the factors upon which their sensitivity depends. These are basically the coefficients of the nonlinear equation representing the characteristics of the mixer and the radio frequency selectivity preceding the mixer. By use of selective testing method, these two factors can be separated. Once this has been done, the total spurious response characteristic of the receiver is implied and the whole tuned frequency-spurious response frequency matrix can be filled in with reasonable accuracy. This selective testing method is certainly more productive of information per unit test than the method which is the present standard for such tests. However, the proposed method has not been adequately tested as yet and it is hoped that this paper will result in such tests.

16.5 ELF and VLF Shielding Effectiveness of High-Permeability Materials, R. B. Schulz, *The Boeing Co., Renton, Wash.*
Very-low-frequency shielding theory is derived and is shown to be in excellent agreement with experimental results.

By use of a loop-to-loop technique a number of measurements were performed on the following materials given in order of effectiveness: copper-clad AMPB-65, AMPB-65, HyMu 80, Conetic AA, galvannealed steel, MuMetal, honeycomb metal sandwiches. Investigations were conducted chiefly on AMPB-65 to determine the effects of double layers, perforations of various sizes and densities, depth of overlap, and lineal density of fastening screws at overlaps. Corresponding measurement data are presented.

SESSION 17

Tuesday 10 A.M.–12:30 P.M.
New York Hilton, Trianon Ballroom

PANEL: Electrical Engineering Education

Chairman: Wilbur R. LePage, Syracuse University, N.Y.

Devices, Systems or both in Electrical Engineering Education, Peter Elias, *Massachusetts Institute of Technology, Cambridge*

Honors Programs in Engineering, A. G. Schillinger, *Polytechnic Institute of Brooklyn, N.Y.*

The Status of the Humanities in Engineering Education, S. R. Warren, Jr., *University of Pennsylvania, Philadelphia*

Status of Programmed Learning in Electrical Engineering, E. M. Williams, *Carnegie Institute of Technology, Pittsburgh, Pa.*

Retraining for EE Employees in Industry, E. H. Freiburghouse, *General Electric Company, Schenectady, N.Y.*

SESSION 18

Tuesday 10 A.M.–12:30 P.M.
New York Hilton, Mercury Ballroom

Instrumentation III

Chairman: Charles A. Steinberg, Ampex Corp., Redwood City, Calif.

18.1 Block Diagram Study of Digital Feedback Counter Systems, Q. C. Turtle, *B-I-F Industries, Providence, R.I.*
A method of analyzing and synthesizing digital system feedback counters by means of block diagram algebra is discussed. The method is made possible by means of an analogy made between voltage and frequency in the same manner that the RLC circuit-spring, mass, dashpot analogy is often made. Continuous systems and general discrete data systems are very briefly mentioned in order to establish a reference with which we may compare a feedback counter system. Rules are derived enabling the systems engineer to provide any rational scale factor less than unity by designing the appropriate counter. Numerical examples are given to illustrate and substantiate the theory.

18.2 A Single Transistor Flipflop Circuit, Carl Isborn, *Beckman Instruments, Inc., Richmond, Calif.*
This paper describes a novel flipflop circuit which utilizes only one ordinary bipolar junction type transistor instead of the usual two. One of the two stable states is oscillatory and conductive while the other is a cutoff, nonoscillatory condition.

The *O*scillatory, *N*on-*O*scillatory *F*lip*F*lop (ON-OFF)can be triggered alternately on and off by a stream of unipolarity pulses applied to a common input. Methods of cascading these flipflop circuits in carry type binary counters are described wherein a scale of 2^n is provided with only n active elements instead of the usual $2n$.

The principles of operation of the bistable circuit are analyzed and modifications of the basic circuit are described which allow its application in ring counters, shift registers, Schmitt trigger circuits and latching indicator lamp drivers with both ac and dc outputs.

18.3 A Prototype Model 13-Digit Sequential Size 11 Optical Encoder, J. W. Brean, *D. H. Baldwin Co., Cincinnati, Ohio*
The development and design of a prototype model of a high-resolution subminiature shaft-position encoder is described. The encoder operates on optical principles and is housed in a size 11 synchro package (1 inch diameter, 2 inches long). The encoder has a 13-digit resolution in one revolution and operates in the sequantial mode at bit rates up to 1 Mc/s. The electronics for sequential interrogation are included in the package. Thus the encoder has only five connecting wires. This encoder has approximately 0.1 of the volume of currently available encoders with equivalent capabilities and was developed to withstand typical aeronautical environments.

18.4 Simple Submicrosecond Transient Sampling Technique, D. N. Bray, H. J. Jensen, *Sandia Corp., Livermore, Calif.*
Application of a technique is considered which

allows samples to be taken as often as every 10 ns with sample apertures on the order of 2 to 5 ns, allowing the reconstruction of a pulse approximately 1 μs-long. Samples may be accurate to 1 per cent or more in amplitude, and sample times known within tenths of nanoseconds. Use of active electronic gating and timing circuitry is avoided. Output is maintained in an infinite time constant memory which can be interrogated at leisure to reconstruct the unknown envelope. Some practical considerations are discussed in order to allow the reader to evaluate the applicability to special cases.

18.5 A Pulse Modulator That Can Be Used as an Amplifier, a Multiplier, or a Divider, J. A. Rosenthal, *University of California, Berkeley*

A pulse modulator of very simple construction is introduced. In terms of components it consists of a relay (or regenerative switch) a capacitor, and a few resistors. The device has many uses, which include amplification, multiplication and division. Since the output of the modulator is a pulse train, it can be an efficient amplifier that is well suited to control either proportional or on-off systems. Some other advantages of the device are that it responds without sampling delay to a change in the input signal and that its output pulse has a non-zero minimum width.

SESSION 19

Tuesday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom N.

Space Electronics and Guidance

Chairman: Warren Hundley, General Precision Inc., Pleasantville, N.Y.

19.1 Experimental Investigation of Simulated Space Particulate Radiation Effects on Microelectronics, Emanuel Rind, F. R. Bryant, *NASA Langley Research Center, Hampton, Va.*

Microelectronics, like their more conventional solid-state counter-parts, are adversely affected by particulate radiation environments as found in space. These environments are briefly summarized. Experimental irradiation data obtained with 22, 40, 128, and 440 MeV protons are presented for representative macroelectronic components and compared with similarly irradiated discrete and integrated circuit type of microcomponents. Damage varies inversely with energy and directly with integrated flux. Threshold integrated fluxes of approximately 10^{11} protons/cm^2 are needed before the radiation effects become noticeable. Integrated microelectronic circuits appear to be slightly more resistant to radiation effects. However, this result may not have a great deal of statistical significance.

A Space Radiation Effects Laboratory which is being built near the Langley Research Center of the National Aeronautics and Space Administration is described. It will make available protons from 100 to 600 MeV, electrons from 500 keV to 10 MeV, as well as X-rays, neutrons and other particles. This facility is to be used in irradiation experiments which simulate the particulate space environment.

19.2 Incorporation of Scientific Instruments into Deep Space Probes, W. G. Fawcett, F. L. Schutz, *Jet Propulsion Lab., Pasadena, Calif.*

The design of a spacecraft for an unmanned scientific fly-by mission to the vicinity of one of the near planets, Venus or Mars, places severe requirements on the system design. The integration of scientific instruments into this spacecraft places some additional constraints on the design because of the developmental nature of the instruments themselves, their data requirements, the power and weight available, and the physical constraints imposed by communicating reliably over vast distances. This paper discusses a method for resolving the conflicts between spacecraft and instruments without sacrificing either reliability or weight and power.

These measures are taken in order that the maximum amount of useful data can be obtained from a given scientific system. An indication of the expansion capability of the system is presented.

19.3 Post-Detection in the Navy Space Surveillance System, M. G. Kaufman, *U.S. Naval Research Lab., Washington, D.C.*

The Naval Space Surveillance System is a multistatic CW radar system using the principle of the radio interferometer. Satellites are located in space by measuring the direction cosines of the reflected radio energy and triangulating from two or more receiving sites. Since the direction cosines are determined by electronically measuring the electrical phase difference between signals from pairs of antennas, it is required to maintain phase coherency between all differential phase shifts throughout the post-detection circuits.

Characteristics of post-detection filters and phase measuring circuits are discussed in the light of the undesirable incidental phase changes in the system and those caused by phase-rate (the latter being a function of the satellite's relative speed with respect to the surveillance fence). The compromise between system sensitivity and system error is examined as the phase signals are traced through wide and narrow band post-detection filters. In conclusion, some work on the affect of "phase jump" on the system is also considered as simple circuits are stimulated by a sudden change in phase.

19.4 Optimization of Malfunction Sending and Decision Systems for Space Vehicles, E. S. Joline, R. L. Smith, *Sperry Gyroscope Co., Great Neck, N. Y.*

A concept is defined for an electronic system that will sense malfunctions of space vehicles subsystems and initiate remedial action. The optimum design of such a system is shown to depend on many factors such as the probability of the malfunctions, the availability of remedial actions, the consequence of the malfunction with and without the remedial action, and the effective cost and reliability of the sensing system.

A design approach is described that results in the selection of sensed variables, signal processing, and redundancy to optimize a given performance index. A typical application to the rocket propulsion system of a launch vehicle indicates that the utilization of this type of system can substantially reduce the mission risk.

19.5 A Comparative Study of Aerodynamic Load Reduction Techniques for Elastic Launch Vehicles, H. H. Burke, *Martin Marietta Corp., Baltimore, Md.*; A. D. Storms, *Moog Servocontrols, Inc., East Aurora, N. Y.*

An investigation is described which determines the autopilot parameters required to stabilize an elastic launch vehicle with a winged payload and simultaneously provide aerodynamic load reduction in the presence of arbitrary wind disturbances.

Six autopilot control laws are investigated, using frequency response and trajectory techniques. The two methods of analysis are complementary, permitting stability margins and aerodynamic load reduction trends to be obtained.

Quantitative correlations are shown, relating aerodynamic loads and autopilot feedback control laws. A quantitative discussion of aerodynamic load reduction using the six autopilot control laws is included.

SESSION 20

Tuesday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom S.

Space System Design Techniques

Chairman: A. G. Kandoian, ITT Federal Labs., Nutley, N.J.

20.1 Communications System Design for Orbiting Repeaters, W. R. Wood, G. A. Myers, *Philco Corp., Palo Alto, Calif.*

A world-wide medium altitude multiple access communications satellite concept is discussed. The orbiting repeaters are capable of simultaneous multiple access with provisions for a trade-off of channel capacity for transmission security. A model of the communications system, generalized link equations, and a specific set of power (link) calculations are presented. Ground-based modulation and demodulation techniques and circuits are considered in determining the system voice transmission capacity as a function of signal-to-noise ratios for the secure as well as the nonsecure mode. Calculations are made for a specific system and this calculated performance is compared with that of other satellite communication systems.

20.2 Effects of Rain on Transmission Performance of a Satellite Communications System, D. Gibble, *Bell Telephone Labs., Murray Hill, N.J.*

Results of measurements of sky noise during rain and snow are given. Measurements were made at Whippany, N. J., at 5350 Mc/s. Results are given as distribution curves of noise values for eight specific elevation angles.

A method of estimating the thickness of the water layer on a radome during rainfall and the resulting increases in attenuation and apparent sky noise is given. Comparison with experimental results is made.

The probability distribution of the received carrier to noise ratio of the earth station has been calculated for several typical satellite communication systems that use 6000 mile orbit, gravity gradient attitude controlled satellites. It is shown how this distribution curve can be used in designing a system so as to just meet noise and breaking objectives.

20.3 Coded Division Multiplex System, A. B. Glenn, *Radio Corp. of America, Moorestown, N.J.*

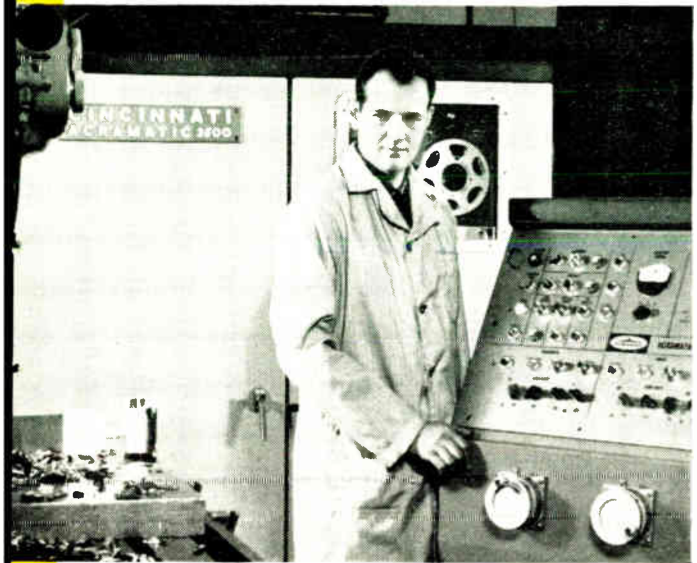
A system which separates the signals by coding is called a Coded Division Multiplex (CDM) System. Such a system requires the use of spread spectrum signal processing.

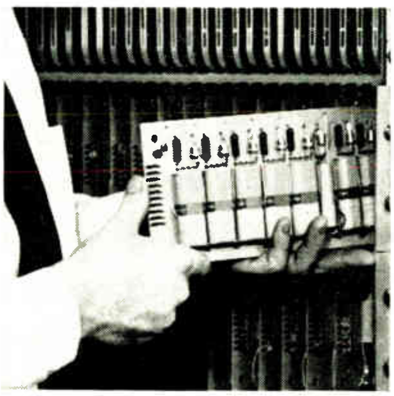
In a military environment, the use of anything but a CDM type system can result in complete electronic disaster. This paper analyzes the information symbol error probability performance as a function of the many system parameters, such as processing gain, channel capacity, jamming to desired power ratio, hard limiting, transmitted bandwidth, etc. The CDM system problems, such as traffic handling, station address, signal coding and equipment requirements are also discussed. Experimental investigation has proven the feasibility of such a system.

20.4 The Optimum Allocation of Mass in Dispersed Space-Borne Reflector Clusters. N. S. Potter, *Radio Corp. of America, Moorestown, N.J.*

In many space-oriented systems, such as orbital communication satellite or ballistic weapons systems, groups of reflectors may be launched that are subject to a constraint upon their total mass. A broadly applicable analysis is conducted of the problem of determining the partition of the specified total mass into segments such that the resultant group of geometrically similar reflectors is optimum in some sense. A generalized theory of detection/communication system performance is developed and ap-

Cincinnati Acramatic 3500 Contouring and Positioning Control Director (rear) houses the logic, memory, interpolation, tape reading and circuit-checking units. Operator's console houses hand controls and a sequence number readout.





Clareed Control Modules are combinations of glass encapsulated Clareed switches assembled on plug-in printed circuit boards.

Punched tape provides digital input data to the director unit, where the dimensional data is stored. Then, through linear or parabolic interpolation, the data is converted into analog form for transfer to the machine's hydraulic servo control system.

In transferring the digital data from the code converters to temporary storage and then to permanent storage, the bi-quinary number system is used. With Clareed flux logic, a 100 per cent check is made on the codes to make certain that the two and five code numbers are both present and correct.

Acramatic storage systems utilize Clareed double-wound Control Modules as single-mode memory matrices, with each cross-point handling one digit. These same modules also provide the digital output switching capabilities required of the system.

From permanent storage, Clareed Selection Modules (serving as scanning devices) feed the digital data into a multi-tap toroidal transformer for conversion to ratio analog information. (Here, complete isolation between input and output is required. Solid-state circuitry does not have this switching capability). Clareed flux logic then switches the command data from the converter to the servo positioning control equipment which controls the machine tool.

The positive off-on characteristics provided by isolated Clareed contacts assure accurate machine tool response. Also, the system is virtually immune to inadverent operation caused by transient noises and voltage fluctuations. These factors are combined with circuit simplicity, more than adequate switching speed, flexibility of application, and lower costs (compared with solid-state circuits).

Built-in status light on each permanent store module (driven directly from the contacts of the selection module cross-points) tells instantly whether its information channel is operating properly. Plug-in modular design simplifies maintenance, makes trouble shooting easier and greatly increases the overall reliability of the system.

The Acramatic system is another example of the capabilities of Clareed Control to provide reliable, easy-to-maintain control systems with practical switching speeds...and at lower costs.

CLAREED CONTROL DESIGN CONSIDERATIONS

If you work with control systems, take a look at these Clareed advantages. You'll find the plus features you need for your system:

- multiple input and output capabilities, making possible logic at both input and output.
- switching capabilities from low level up to 15va, ac, or dc.
- complete isolation between input and output. The output is the contact closure.
- data handling speeds up to 250 bits per second.
- modular printed circuit board construction compatible with modern electronic assembly techniques ...meets the requirement of almost any application or environment.

Standard Clareed Control Modules offer versatile, reliable, simplified means of performing these functions:

In counting: Three basic flip-flops which can be used in ring counters, bi-directional counters and shift registers for binary, binary-coded decimal, decimal, and radix$^{(N)}$ counters.

In selection: A variety of selection systems, using a single-mode matrix, a single-mode memory matrix, or a two-mode matrix (Mode 1: all crosspoints normally open; Mode 2: all crosspoints normally closed.)

In logic: AND, inclusive OR, NOR, NAND, exclusive OR, exclusive NOR as well as more complex logic in a single module.

Want to know more about the versatile Clareed approach to modern control system assembly techniques? Just give us a call and ask for Manual 400. We'll answer promptly. Address: C. P. CLARE & CO., Group 3M4, 3101 Pratt Boulevard, Chicago, Illinois 60645

CLARE®

relays and control components

plied to the analysis of hollow (Class A) reflector groups, each of fixed shell thickness, and the important class B of non-empty reflectors that are characterized by fixed packing densities.

SESSION 21

Tuesday 10 A.M.–12:30 P.M.
New York Hilton, Regent Room

Switching Systems

Chairman: W. B. Groth, International Business Machines Corp., Poughkeepsie, N.Y.

21.1 A High-Speed Data-Line Switching Terminal for On-Line, Real-Time Systems, G. E. Beltz, F. Furman, *The Teleregister Corp., Stamford, Conn.*
The new high-speed data-line switching terminal for on-line, real-time data-processing systems permits connection of one of a large number of input/output devices to the central terminal at the processor site over leased voice-grade lines within 200 ms, a marked reduction from that achievable with currently available equipment. The new terminal, operable in January 1964, provides also an excellent means of expansion of existing systems avoiding, due to its trunking technique, a costly major redesign of off-the-shelf terminal equipment. The modular terminal construction permits the connection of 30 conventional remote concentrators to 10 central line terminal units.

21.2 The IBM 7740 Communication Control System, E. A. Daley, A. E. Scott, *International Business Machines Corp., Poughkeepsie, N.Y.*
The IBM 7740 Communication Control System is the latest development in IBM's search for the most efficient method of joining remote data processing locations by common carrier facilities. Providing complete control for a communication network, the IBM 7740 is a center not only for communication control but also for message accounting, logging, traffic reporting, error handling and allied procedures. It performs operations such as remote data collection, in which batched input records are stored on its disk files for later processing, while already updated records are available for immediate retrieval by remote terminals.

This paper describes the characteristics of the system, variations in its internal make-up, possible communication line configurations, data processing systems to which it may attach, some suggested applications and real time program procedures.

21.3 The IBM 7741—A Communications-Oriented Computer, J. E. Drescher, C. A. Zito, *International Business Machines Corp., Poughkeepsie, N.Y.*
The IBM 7741 contains many features which make it uniquely suited to real time processing. Novel internal organization and utilization of new techniques have allowed construction of a powerful communications-oriented computer with resultant economies in both money and space.

This paper discusses the basic engineering concepts of the 7741. Building on these ideas, such features as automatic block allocation, mode changing, line speed conversion, code insensitivity, high reliability, interval timer, the instruction set, internal checking and others are described. A message switching example is given, showing the interaction of program and hardware functions.

21.4 Communications Switching and Telephone Charging of a Hotel Accounting System, J. C. Sieglinger, *New York Telephone Co., N.Y.*
The need for a simple automatic system for counting message unit registrations on local telephone calls is discussed. This system is used in a step-by-step private branch exchange (PBX) such as hotels, hospitals, colleges, etc. that provide automatic billing for local telephone calls. A description is given for the method used in identification of the calling station, the storing of message units on initial and overtime periods and the passing of this information to a business machine punch card or a teletypewriter tape output. An example of the system is now in use at the New York Hilton Hotel in New York City.

21.5 Data Processing Features of a Hotel Accounting System, W. Wilson, *International Business Machines Corp., New York, N.Y.*
The New York Hilton provides the optimum in guest service. A prime example in this area is an IBM 1401/1405 Data Processing System handling the guest account functions. With the help of an IBM 357 Data Collection System, each guest's bill is always current and available from the 1403 High Speed Printer upon demand.

All charges incurred by guests in remote hotel locations are promptly transmitted to the front office for inclusion in the guests record located in RAMAC storage. Even each local telephone charge will be punched into a card immediately upon completion of the guest's call.

SESSION 22

Tuesday 10 A.M.–12:30 P.M.
New York Coliseum, Room A

PANEL: Symposium on High Energy Research and New High Energy Accelerators

Chairman: Robert S. Livingston, Oak Ridge National Lab., Oak Ridge, Tenn.

Future Research with High Energy Accelerators, Melvin Schwartz, *Columbia University, New York, N.Y.*

High Energy Electron Accelerators, M. S. Livingston, *Massachusetts Institute of Technology, Cambridge*

High Intensity Accelerators Below 1 GeV, J. R. Richardson, *University of California, Los Angeles*

High Intensity Multi-GeV Proton Accelerators, Lee Teng, *Argonne National Lab., Ill.*

Super Energy Accelerators, Lloyd Smith, *University of California, Berkeley*

SESSION 23

Tuesday 10 A.M.–12:30 P.M.
New York Coliseum, Room B

Nonlinear and Linear Control

Chairman: Louis F. Kazda, University of Michigan, Ann Arbor

23.1 Information Theoretic Aspects of Feedback Control Systems, J. L. Barnes, *University of California, Los Angeles*
Viewed as an information system, a feedback control system is composed of information (and noise) generators, information transporters, information stores, information processors, and (actuators, i.e.,) information sinks. The basic bounds on the performance of a control system are derivable from the corresponding bounds on the information theoretic aspects of its elements and their connection as well as on the mass-energy aspects. The physical-mathematical origin and practical consequences for servos of these information theoretic bounds are presented.

23.2 Stability and Design of Nonlinear Control Systems via Liapunov's Criterion, Y. H. Ku, Ralph Mekel, C. C. Su, *University of Pennsylvania, Philadelphia*
Part I of this two-part paper presents a matrix method for finding the Liapunov functions of high-order nonlinear systems. The given system is characterized by the matrix relation $\dot{\mathbf{x}} = \mathbf{A}(\mathbf{x})\mathbf{x}$, where the column matrix **x** denotes the state variables in the phase space, $\dot{\mathbf{x}} = d\mathbf{x}/dt$, and $\mathbf{A}(\mathbf{x})$ is a square matrix containing the elements 0, 1, constants, and functions of the state variables, such as $f(x_1)/x_1$, etc. The Liapunov function V is given by $\mathbf{x}'\mathbf{S}\mathbf{x}$, where $\mathbf{x}'$ denotes the transpose of **x**, and **S** is a symmetric matrix whose elements contain constants k_{ij}, as well as functions of the state variables. Its time derivative $\dot{\mathbf{V}}$ is given by $\mathbf{x}'\mathbf{T}\mathbf{x}$, where **T** is a matrix whose elements α_{ij} are closely related to the elements β_{ij} of **S** as well as the elements of the $\mathbf{A}(\mathbf{x})$ matrix. Specifically, $\mathbf{T} = (\mathbf{A}'\mathbf{S} + \mathbf{S}\mathbf{A} + \dot{\mathbf{S}})$, where $\dot{\mathbf{S}} = d\mathbf{S}/dt$. The **T** matrix is also derived as $\mathbf{T} = \mathbf{B}'\mathbf{A}$, where the new matrix **B** is obtained from $\nabla \mathbf{V} = \mathbf{B}\mathbf{x}$. Part II considers several examples of third-order nonlinear systems with more than one nonlinearity. Phase-space trajectories are given to represent the stable and unstable cases and the limit cycles. These results can be correlated to the Liapunov criterion to facilitate the choice of nonlinear functions and constants (gains) in the design of nonlinear control systems.

23.3 Superposition in a Class of Nonlinear Systems, A. V. Oppenheim, *Massachusetts Institute of Technology, Cambridge*
The ease of analysis and characterization of linear systems stems primarily from the fact that they satisfy the principle of superposition. In this paper, a generalization of the principle of superposition is presented and the class of nonlinear systems that satisfy this generalized principle is discussed. In particular, this class is shown to include all invertible systems.

A canonical form for systems in the class is derived. This form consists of a cascade of three systems, the first and last of which are dependent only upon a general property of the system inputs and outputs, respectively. The second system in the canonical representation is a linear system. Necessary and sufficient conditions are presented under which all of the memory in the system can be concentrated in the linear portion. Applications of the theory are considered for various types of nonlinear feedback systems.

23.4 Stability Domains for Linear, Stationary Control Systems Via the Direct Method of Liapunov, G. W. Johnson, *International Business Machines Corp., Huntsville, Ala.*
Many definitions have been offered to characterize the stability of linear systems, all of which fall under one or more of the many modifications of the stability theory of Liapunov. In this paper the "direct method" of Liapunov is used to obtain relatively loose but simple estimates of the stability domain of linear systems in the space of multiparameter uncertainties. The limitations of the classical theory in this area represents one of the major deficiencies of linear control theory at the present time. The inability to define the effects of simultaneous multiparameter uncertainties has contributed to the possible overemphasis upon the design aspects of "adaptive" control systems.

23.5 An Extension of Oppelt's Stability Criterion Based on the Method of Two Hodo-

graphs, C. F. Chen, I. J. Haas, *Christian Brothers College, Memphis, Tenn.*
The paper describes a stability criterion for feedback control systems which is based on the separation of the hodographs of an open loop system into two separate hodographs. It may be applied to nonlinear, as well as linear, systems.

Kochenburger's two-loci comparison does not give the relative stability information. Oppelt's two-hodograph method does not show the phase margin, or any information about the cross-over frequency.

The extension herein described, is based on Oppelt's two hodographs with the addition of an auxiliary circle from which the phase margin etc. can be determined directly. This eliminates the necessity of drawing the conventional "resulting locus" for compensated feedback systems in linear system design; and offers more information for nonlinear system analysis.

SESSION 24

Tuesday 10 A.M.–12:30 P.M.
New York Coliseum, Room C

Electronic Technologies in Industry

Chairman: E. A. Roberts, Lincolnwood, Ill.

24.1 The Classification of Silicon Controlled Rectifier Inverter Circuits, Neville Mapham, *General Electric Co., Auburn, N.Y.*
There are a great many combinations of circuit configurations and commutation methods which produce a multitude of SCR inverter circuits. This paper proposes a method of classification based on the properties that the circuits exhibit. The classification consists of: Division into six methods of commutation; subdivision into two paths for the flow of reverse recovery current; and further subdivision into six circuit configurations such as choppers, bridge circuits, etc. This classification yields the information as to which circuits are capable of regulation, which are load sensitive and what the requirements are regarding voltage and current rating and the number of SCRs needed.

24.2 Commutation Behavior of Diffused High Current Rectifier Diodes, E. E. Von Zastrow, J. H. Galloway, *General Electric Co., Auburn, N.Y.*
Commutation behavior of power rectifier diodes is important inasmuch as it affects performance and reliability, particularly when diodes are connected in parallel as in large rectifier installations. The commutation interval of a power diode is analysed and the important circuit and device parameters are identified. Previous work by others had concerned itself with alloy devices. This paper deals with large area diffused, and large area controlled avalanche diodes. As a reference, test data are presented on some typical large area alloy devices. Critical values of rate of change of reverse current (di/dt) are identified. Beyond the critical value of di/dt device failures may occur. Failure mechanisms are discussed and analyzed. A method is presented for the selection of proper protective circuitry based on analysis and measured test data.

24.3 The Future for Semiconductor Business in Automobiles, D. I. Van Blois, L. J. Giacoletto, *Michigan State University, East Lansing*
The automotive industry has become a significant user of semiconductors. The growth rate has been spectacular due, in great measure, to the recent reductions in prices of semiconductor devices. The reduced prices, together with greater reliability, and in most cases, improved operating properties has accelerated the switch from heretofore standard to new manufacturing. The various segments of the semiconductor uses in automobiles, radios, alternators, regulators, ignition systems, and miscellaneous applications, have been examined individually in terms of past and present dollar volumes. Their performances are then totaled and extrapolated into the future with suitable weightings for probable prices, probable percentage adoption, and probable total automobile sales. The resulting total growth curve shows a very steep rise for the next five years with a volume of $100 million by 1965 and a likely volume of $300 million by 1970.

24.4 The Control of Battery Powered DC Motors Using SCRs in the Jones Circuit, Neville Mapham, J. C. Hey, *General Electric Co., Auburn, N.Y.*
The Jones chopper using SCRs in a time-ratio control circuit is operating very successfully as a means of controlling the speed of battery driven dc motors. The most common application is in vehicle drives. The advantage of the SCR control is in the smoothness of the speed control and the high efficiency with which the circuit operates. The advantages of the Jones circuit lie in the ease and reliability with which the chopper starts to operate and the small size of the commutating capacitor due to the step up transformer. Design equations are given as well as measured results in actual equipment.

SESSION 25

Tuesday 2:30–5 P.M.
New York Hilton, Trianon Ballroom

Aeronautical Electronics and Navigation

Chairman: Sven H. Dodington, ITT Federal Labs., Nutley, N.J.

25.1 The Precision VOR System, A. B. Winick, *Federal Aviation Agency, Washington, D.C.;* E. R. Hollm, *Airborne Instruments Lab., Deer Park, N.Y.*
Azimuth bearing requirements for the Federal Aviation Agency's National Airspace System are discussed. The proposed system, which retains compatability with the existing VOR system, is described. Photographs of the ground and airborne equipment are included with flight check recordings and station error curves measured at the test site.

25.2 Waveguide Glide Slope—Theory and Flight Test, E. R. Hollm, A. D. Mehall, *Airborne Instruments Lab., Deer Park, N.Y.*
The Waveguide Glide Slope theory of operation as an equi-signal and null-reference system is described. Flight test data gathered at two different locations are included to show the improvement in course quality compared to conventional glide slope systems. Monitoring and proposed additional tests are discussed.

25.3 Optimization of a Hybrid Inertial Solar-Tracker Navigation System, R. C. Brown, *Iowa State University, Ames;* D. T. Friest, *Autonetics, Anaheim, Calif.*
A combined inertial solar-tracker navigation system has obvious advantages in marine applications where an all-weather, secure system is desired. The problem of optimizing the use of all measured information in such a system has not been solved previously. This paper first shows that there is a fundamental limitation on any inertial system which tracks only one celestial body if it is operated in the usual damped-inertial mode. Next, a mode of operation which circumvents this limitation is described along with an optimization technique for this mode. Finally, a more general solution to the problem based on Kalman's state-variable approach is given.

25.4 Microcircuit Digital Techniques Applied to the Loran-C Receiver, J. Meranda, *Sperry Gyroscope Co., Great Neck, N.Y.*
A typical electromechanical navigation system has been reduced from a complex instrument composed of servo motors, resolvers, relays, choppers, gear trains, and an oscilloscope to a completely solid-state device. It is rebuilt around a single family of standard integrated digital circuits. The system design consisted of finding the digital or binary counterparts of each of the diverse elements and of combining these counterparts into a self contained system. Methods are described which indicate the feasibility of achieving simplified digital control and data processing. These methods should be of immediate interest to the designer of avionics systems where the computational requirements can be satisfied with a differential analyzer and where statistical design concepts are applicable.

25.5 TV Mosaic Radar Generator Techniques, H. H. Naidich, *ITT Federal Labs., Nutley, N.J.*
The TV Mosaic Generator has been scheduled first in a series of six progressive implementation stages in the master plan for the development of an Air Traffic Control System which has been issued by the Systems Research and Development Service of the Federal Aviation Agency. At last year's IEEE International Convention, a complete ATC system was presented, based on the use of the TV Mosaic Generator. This paper discusses the techniques used to generate a TV mosaic composed of adjacent geographical areas covered by a complex of radar systems. Each of many TV displays which use the TV mosaic is capable of being independently positioned to select a portion of the total area covered by the multiple radars. A controller at the display can follow an aircraft through a chain of radars if he so desires.

SESSION 26

Tuesday 2:30–5 P.M.
New York Hilton, Mercury Ballroom

Instrumentation IV

Chairman: John P. Van Duyne, Boonton Radio Co., Rockaway, N.J.

26.1 A Data Storage System for Obtaining Missile Reentry Heating Data, T. B. Ballard, *NASA, Langley Research Center, Hampton, Va.*
A miniature data storage system used to obtain missile reentry heating data is described. The system does not employ a radio link. Instead, digital information is stored in a 360-bit nondestructive readout ferrite memory which is interrogated after recovery of the instrument package. The stored digital information is a series of times at which predetermined nose cap temperatures were reached.

Included in the paper are system design considerations and details of a novel circuit for determining temperature time histories in ablative materials.

26.2 A Stochastic Approach to the Problem of Allowable Magnetic Moments in a Space Vehicle, A. W. Green, Jr., J. J. Burch, *Texas Instruments Inc., Dallas*
In space vehicles containing magnetometer experiments, care must be taken that the magnetic sensor is not disturbed by magnetic fields due to other electronic or mechanical components within the spacecraft.

The problem of placement of a few simple components of known magnetic moments is fairly straightforward. The problem of design-

ing a complex electronic assembly that *must* be placed within a certain distance of the sensor and yet be magnetically acceptable is more difficult. The designer must assemble hundreds of items, which are probably magnetic, and guarantee that their net effect at the sensor will not exceed some prescribed limit.

It is to the problem of establishing *initial* component selection and configuration guidelines and checks that the stochastic or probabilistic approach is directed. This approach will permit the designer to ascertain with some confidence the probable magnetic effect at the sensor of N magnetic moments whose amplitudes, locations, and directions are described by probability density functions. Conversely, given a set of probabilistic limits on the allowable magnetic field at some distance from the unit to be designed, he may ascertain the permissible distribution function of the magnetic moments.

The statistical approach frees the designer from making a precise field calculation for each component and each possible configuration. In return for this unburdening, he must accept more general answers—answers which are statistical rather than precise.

26.3 The Application of Magnetometers to the Dynamic Simulation and Control of the Geomagnetic Environment, Norman Wolff, *Vickers Inc., St. Louis, Mo.*

A magnetic field is completely described by a magnitude and direction. For simulation and control of a magnetic field in space, a three-axis coil system based upon rectangular coordinates is used. The field is then resolved into three orthogonal components and the total field can now be simulated by the control of three magnitudes only. A three-axis fluxgate magnetometer probe is placed inside the coil system to measure the field near the working space and with external amplifiers, controls and power supply, is used to control the current to the coils. Magnetometers, coil systems, and programming techniques are discussed and test results on one such system are given.

26.4 A Cosmic Noise Radio Astronomy Experiment for the S-48 Satellite, M. Chome, S. Gross, *Airborne Instruments Lab., Deer Park, N.Y.;* R. Stone, *NASA, Washington, D.C.*

Due to the shielding effect of the earth's ionosphere, it is difficult to measure cosmic noise radiation from the surface of the earth at frequencies much below 10 Mc/s. Low-frequency cosmic noise temperature data are necessary to study the atmosphere of the sun and planets as well as the interplanetary plasma. Similarly, observations of the spectral and spatial distribution of cosmic radio waves at less than 10 Mc/s are important if we are to understand more clearly the origin and composition of galactic and intergalactic matter.

The Topside Satellite (S-48) has as its primary mission the sounding of the topside of the ionosphere. This will be done at six frequencies. A "radar" like plot of the ionosphere will be the result. In addition to the primary mission, the cosmic noise level at these six frequencies will be measured.

The paper will discuss the experiment, the calibration techniques and the anticipated accuracy and some of the data analysis techniques.

26.5 Experiences with the Impedance Probe on Satellites, O. C. Haycock, K. D. Baker, *University of Utah, Salt Lake City;* J. C. Ulwick, *Air Force Cambridge Research Labs., Bedford, Mass.*

A system is presented for measuring the impedance of a dipole antenna on a satellite orbiting in the ionosphere. These impedance variations are used to determine the electron density of the ionosphere. Details of the instrumentation are given. Experimental results from many satellite flights are given in the form of antenna impedance to aid in antenna engineering. Electron density profiles are also presented. The density data show interesting spatial and temporal variations and of particular note are the day to day variations. Discussion is made of the effects of the vehicle wake on the electron density.

SESSION 27

Tuesday 8 P.M.–10:30 P.M.
New York Hilton, East Ballroom

Modular Magic—Special Highlight Evening Symposium
(See page 80)

SESSION 28

Tuesday 2:30–5 P.M.
New York Hilton, Sutton Ballroom S.

Switching Systems and Techniques

Chairman: T. P. Miller, ITT-Kellogg Telecommunications, Chicago, Ill.

28.1 Terminal Area Communication System—To Accelerate Message and Data Traffic Flow, Curtis M. Jansky, *ITT Communication Systems, Inc., Paramus, N.M.*

This paper describes a method for materially reducing present message and data delays which are attributable to manual handling procedures in the terminal area (an Air Force Base, an Army Fort, a Navy Base, or other Military Installation). Studies have shown that from 70 to 85 per cent of the excessive delays can be eliminated by the automation of message flow within the terminal area. This paper describes the concept and design criteria for a terminal area communication system to automate the flow of both message and data traffic from the typewriter at the originating offices through out the terminal area and into and out of long-haul networks.

The following three papers will cover three fundamental technological subsystems essential to the successful instrumentation and operation of this system.

28.2 Error Control in a Terminal Area Communication System, W. J. Gluchoski, *ITT Communication Systems, Inc., Paramus, N.J.*

This paper describes a particular approach to providing error control for handling data with a terminal area communication system. Requirements for error control in digital transmission and some applicable techniques to satisfy these requirements shall be covered. Then the primary factors governing the selection of a specific encoding/decoding technology for the terminal area communication system will be discussed. This paper will continue with an analysis of undetected error rate performance and of digital transmission efficiency, and will conclude with an evaluation of the complexity of error control electronics for terminal equipments.

28.3 Terminal Area Communication System—Signalling and Supervision, L. M. Small, *ITT Communication Systems, Inc., Paramus, N.J.*

This paper describes the concept, structure, and proposed code set for signalling and supervision within the terminal area communication system. This approach to signalling and supervision provides high performance and high communication line efficiency to effect reliable control of the terminal area switch within the framework of a totally synchronous, error controlled, digital communication system. An analysis of signalling error rate performance as well as terminal electronic equipment complexity shall be discussed.

28.4 Time Division Switch for the Terminal Area Communication System, R. D. Banks, *ITT Communication Systems, Inc., Paramus, N.J.*

This paper describes a digital synchronous time division switch uniquely applicable in the digital terminal area communication system. The operating mode and structure of the digital bit stream to and from digital message and data terminals shall first be described. Then the conceptual design of the internal structure of the switch "matrix" shall be presented. A short discussion of the function of the switch control director shall be followed by a resume of the performance factors and projected complexity of the switch. In particular, emphasis shall be placed on the techniques by which this switch is nonblocking, by which this switch can provide message broadcast with error control, and by which the required equipment complexity shall grow approximately as a linear function of the number of lines, instead of as the square of the number of lines as in the case of a nonblocking space division switch.

28.5 Optimal Routing Procedures in Distributed Switching Networks, Yen-sun Fu, *ITT-Kellogg, Chicago, Ill.*

A study is conducted to provide optimum routing procedures in a trunk-distributed switching network, that is, a scheme of choosing the shortest available path (time-wise) to connect, on demand, the originating switching point with the destination point before communication takes place. In more mathematical language, the objective is to select an optimal path in a distributed switching network consisting of nodes and links that connect the originating node with the destination node.

This paper is chiefly concerned with work on the mathematical formulation for the computational method that constitutes a useful tool not only to achieve real-time operation, but also to establish quickly a new routing pattern even if some major changes occur in the network. Updated information about the network is assumed to be available to the computer for the purposes of computation. An illustrative example, together with a table of computation results, is presented.

28.6 A Low Speed Magnetic Memory Device, Weichien Chow, *ITT-Kellogg, Chicago, Ill.*

Computer and switching/control systems in use today typically require some type of memory for system operation. The memory, or data store for the system, serves to hold data in storage until it is needed by a cycle of system operation. Relays, flip-flops, punched cards, magnetic tapes, disks, and drums, ferrite cores and matrices represent some of the devices available for this purpose. This paper describes a new magnetic drum memory that has been developed as a low-cost storage device which does not require ancillary amplification for either input or output functions for switching and control systems. This memory device has some features that are characteristic of a digital computer memory, but it does not have the latter's high cost. The new memory device can be used either as a general purpose bit store, or as the main storage device in switching/control systems.

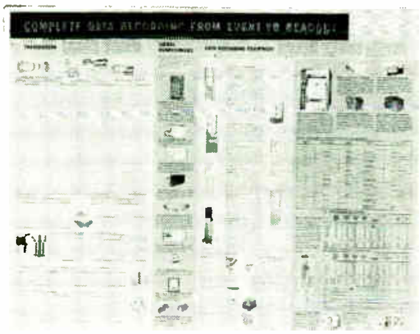
SESSION 29

Tuesday 2:30–5 P.M.
New York Hilton, Regent Room

Information Retrieval, IEEE and You

Chairman: Morris Rubinoff, University of Pennsylvania, Philadelphia

A new "must" for engineers



Measuring 21″ x 27″, and schematically arranged, the new CEC chart covers in detail each instrument in the four categories shown below. This includes basic specifications, cross-reference tables to aid in selection of instrumentation, and information on how to use *combinations* of the various instruments to meet specific needs. In addition, the chart describes the finest support equipment for dynamic measuring and recording in industrial and military applications.

Sensors and Pickups

Chart shows the 43 available for pressure, vibration, acceleration.

Signal Conditioners

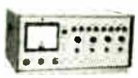


Chart shows 11 basic types and where they may be required.

Magnetic Tape

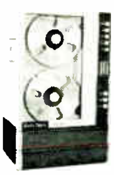


Chart shows 8 analog and digital recorder/reproducers with support equipment.

Direct Readout

Chart shows 5 recording oscillographs, 33 galvanometers and where they can be used. Also support equipment.

Please write today while sufficient copies are still available. Ask for CEC Chart DM-37-X11.

CEC

CONSOLIDATED ELECTRODYNAMICS

A SUBSIDIARY OF **BELL & HOWELL**/PASADENA, CALIF. 91109
INTERNATIONAL SUBSIDIARIES: WOKING, SURREY, ENGLAND AND FRANKFURT/MAIN, GERMANY

Users of Our

Coil Winding Machines

Profit from...

Design Leadership

Technical Know-how

Performance Guarantees

Visit us at the Show
to see this equipment
or
write us about your needs

COIL WINDING EQUIPMENT CO.

OYSTER BAY, L.I., NEW YORK
WAlnut 2-5660
(Area Code 516)

COWECO

BOOTH 4426 IN COLISEUM — BOOTH 165 IN N.Y. HILTON

29.1 The Government Role in Information Retrieval, J. H. Kelley, *Office of Science and Technology, Office of the President of the United States, Washington, D.C.*
With the increasingly large role that the Federal Government plays in the sponsorship of research and development, it assumes a greater responsibility for seeing that the results of the government programs are made accessible to those people who need it. The Government has taken several important measures to improve the methods of communicating the results of research and development. The solutions are not easy because the problems are not simple. The problems in scientific communication can be divided into the government aspect and the national aspect. They can be again divided into scientific and technical information for management purposes and for research purposes. Also, scientific and technical communications can be divided by the different nature of the information content. Scientist-to-scientist information is quite different from scientist-to-engineer or engineer-to-engineer communications.

The very nature of the American system rules out any non-democratic centralized information retrieval system sponsored by the government. However, the government is keenly aware that communication among scientists and engineers must be kept viable to insure scientific and technical progress of the nation. Thus, the Government is attempting to provide improvements which are consistent with our pluralistic nature of society.

29.2 Information Systems for Engineers, W. M. Carlson, *Dept. of Defense, Washington, D.C.*
The engineering profession has taken the leadership in determining a direction for the effective development of modern technical information systems. Programs initiated by the Engineers Joint Council in 1962 are being implemented by the engineering societies, including IEEE. The basis for the EJC activity is a vital concern for serving the individual engineer within the framework of a system that covers all engineering literature of interest to him. Progress and future plans for the EJC approach will be explored and evaluated.

29.3 The IEEE Program for Improvement in the Use of Information, C. N. Mooers, *Rockford Research Institute, Inc., Cambridge, Mass.*
Easier and quicker access to engineering and scientific information and data by members of the IEEE is the goal of the IEEE information program under preparation by the IEEE Information Retrieval Committee. Emphasis is upon the application of modern information retrieval techniques for ease of discovery of information or data wherever located, and for promptly securing low cost copies. The program takes as its base the publications of the Institute and the information retrieval program launched by the Engineers Joint Council with which IEEE is affiliated. The program aims to knit together modern information retrieval techniques, micro-image storage techniques, teletypewriter inquiry and service features, computer techniques, several evolutionary innovations in publications, and in due time the development of specialized information and data service centers. The paper will describe the objectives of the IEEE program.

29.4 Information Dissemination and the Professional Technical Groups, C. B. Hensley, *International Business Machines Corp., Yorktown Heights, N.Y.*
This paper will relate fundamental principals of selective dissemination to the organizational problem of serving the information needs of the IEEE membership.

The Professional Technical Group structure of the IEEE is a simple but effective form of selective dissemination of specialized technical information. By joining one or more Groups a member can increase the number of papers he receives relevant to his area of interest without being swamped with non-relevant material. However, this has introduced the problem of trying to provide the right Groups to satisfy this need without creating so many that the available support is unduly diluted. The paper will describe other possible methods for improving IEEE selective dissemination procedures.

29.5 Information Retrieval Implementation Activities, L. B. Wilson, *Sperry Gyroscope Co., Great Neck, N.Y.*
The initial implementation phase of the IEEE information retrieval program consists of a series of trial runs for publication of special catalog card information along with articles in several PTG Transactions. This is a special type of catalog card information intended to facilitate indexing and retrieval of PTG Transaction articles by using subject-indicating terms for indexing, by having indexing done at the source by the author and/or the editorial staff, and by making abstracts be as informative as possible.

This paper will discuss instructions which are being prepared to assist in the establishment and use of index terms by PTG Transactions editorial staffs, by IEEE members, and by libraries and technical information centers. Brief suggestions will be given about various ways in which the catalog card information can be used with specific types of retrieval systems.

SESSION 30

Tuesday 2:30–5 P.M.
New York Coliseum, Room A

Optimal and Adaptive Control

Chairman: Eric R. Behn, American Bosch Arma Corp., Garden City, N.Y.

30.1 A Computer-Simulated Learning Control System, M. D. Waltz, K. S. Fu, *Purdue University, Lafayette, Ind.*
This paper describes a learning control system and its simulation on a hybrid computer. The controller is capable of controlling a plant that may be nonlinear and non-stationary. The only a priori information required by the controller is the order of the plant. The approach is to classify the measurement space (the measurements represent the state of the plant and environmental parameters) into sets called control situations and then to learn the best control choice for each control situation. The learning is accomplished by reinforcement of the probability of choosing a particular control choice for a given control situation.

The controller was simulated on a digital computer which was interconnected to an analog computer that was used to simulate the various plants. Detailed experimental results obtained from this hybrid simulation are presented.

30.2 The Cost Function and Its Minimization for a General Class of Self-Adaptive Systems, H. J. Perlis, *Rutgers, the State University, New Brunswick, N.J.*
This paper presents a detailed analysis of a general class of self-adaptive systems under realistic conditions. The particular set of systems considered are those in which the following conditions exist: the nominal transmittance of the time-varying primary system is known, there are k varying parameters and $2Q$ adjustable parameters, output transducer noise is not negligible, and the spectral densities of the parameter variations and of the measurement noise are known. The auxiliary systems are closed-loop and employ perturbation-correlation identification techniques. An over-all system, quadratic cost function expression is developed. This is shown to be a function of the variance of the system transmittance which, in turn, is a function of the spectral properties of the parameter variations and the measurement noise. Optimization techniques are presented to minimize the cost function for the over-all, self-adaptive system.

30.3 Application of Dynamic Programming to Stochastic Minimal Time Control, Milton Ash, *System Development Corp., Santa Monica, Calif.*
In order to cope with highly nonlinear control problems of the minimum time variety using modern control theory, two complementary methodologies have appeared. These are Pontryagin's maximum principle and Bellman's principle of optimality of dynamic programming. For such control problems in which the control element appears linearly, both the maximum principle and the optimality principle assert that the optimal control is bang bang. However, when a stochastic element is manifest, the principle of optimality redefines the problem in terms of minimum expected time in a very natural way. This results in a partial differential equation whose solutions yield the optimal isochrones in the phase space. An illustrative problem is presented.

30.4 Recursive Linear Regression Theory, Optimal Filter Theory, and Error Analyses of Optimal Systems, S. L. Fagin, *Sperry Gyroscope Co., Great Neck, N.Y.*
A review is presented of the little known recursive least squares fit method. This method's main feature is its avoidance of matrix inversion when additional pieces of data are to be included. In a similar manner recursive regression formulae are found for the case where the data is multidimensional and its components are correlated. A matrix inversion is required, but it need be no greater than the dimension of the additional piece of data. With minor modification, the recursive linear regression formulae are applied to the derivation of a somewhat more general version of the Kalman optimal filter. This provides the link between optimal filter theory and classical linear regression theory.

Short cuts in the preliminary evaluation of the accuracy potential of candidate systems are demonstrated through the exploitation of optimal filter theory.

30.5 Final Value Control Systems, N. E. Nahi, J. R. Smith, *University of Southern California, Los Angeles*
In many control problems, it is not possible to transfer the system from an arbitrary initial state to an arbitrary terminal state. In such cases, it is still possible to determine control algorithms which will minimize the terminal error. This paper provides a method for determining the optimal control vector which minimizes the terminal error for systems which can be represented by a linear differential equation. It is assumed that the integral of the square of the norm of the control vector is bounded.

The procedure consists of determining the set of points which are reachable from an arbitrary initial state, and then determining the point of this set which minimizes the terminal error. The terminal error which is minimized is either the euclidean norm of the error, or a particular coordinate of the error.

30.6 Adaptive Pattern Recognition and Signal Detection Without Supervision, P. W. Cooper, *Sylvania Applied Research Lab., Waltham, Mass.;* D. B. Cooper, *Columbia University, New York, N.Y.*
Adaptive pattern recognition and signal detection can be viewed as a variation of the classical problem in statistical classification wherein the partitioning of an n-dimensional sample space into category (signal) regions is determined

through estimation from a set of samples from the categories. When the correct association of the samples is known, the problem is the commonly treated *supervised* one. This paper, examining the *nonsupervised* case wherein the correct association of the sequence of samples is unknown, demonstrates that it is possible under extremely general conditions to achieve effective adaptation without supervision. With particular emphasis on a two-category (binary detection) model, general conditions are described under which nonsupervised adaptation is possible, and specific simple yet rapidly convergent techniques are presented under varying degrees of prior knowledge of the statistical properties of the data.

SESSION 31

Tuesday 2:30–5 P.M.
New York Coliseum, Room B

Microcircuits and Processing Techniques

Chairman: David A. Hill, Hughes Aircraft Co., Los Angeles, Calif.

31.1 Projection Photolithographic Technique for Use in the Fabrication of Microcircuits, W. B. Glendinning, Sidney Marshall, Albert Mark, T. F. Brooks, *U.S. Army Electronics R & D Lab., Ft. Monmouth, N.J.*
The new projection technique makes use of conventional photographic emulsions, registration through use of a ground-glass screen or binocular viewer, and very high ultraviolet light concentrations. Exposure time intervals of less than one second duration of time have produced useful window geometries of various shapes. Photomask pattern size reductions have been controlled through a range of 2:1 to 22:1. Line resolutions of several microns have been obtained.

The technique has been used: to prepare process masks for use in the selective deposition of evaporated materials and the selective etching of materials; for the preparation of photomasks utilizing the synthesis of images produced from several simple metal photo-mask patterns such as a square, a circle, and an elongated rectangle. Photo-mask patterns similar to those used in current microcircuit fabrication have been made.

31.2 A General-Purpose Ceramic-Base Thin-Film Microcircuit Amplifier, Manfred Kahn, *Sprague Electric Co., N. Adams, Mass.*
A complementary, four-transistor, direct-coupled amplifier is described, that has a low component count, and employs negative feedback to define its mode of operation. Minor changes in the feedback loop, allow the amplifier to handle a wide range of gains and bandwidths. A microcircuit implementation of this amplifier has been built on 1 × 0.4 inch large ceramic substrate. Each amplifier utilizes two such substrates; one carries the transistors, the input and the biasing networks and the second carries the resistors, capacitors and diodes for the various feedback configurations. The substrates are packaged together and interconnections of external leads adapt the amplifier to the required function.

31.3 Dielectric Formulations for Use in Processing Screened Ceramic Microcircuit Substrates, R. L. Stermer, Jr., *NASA, Langley Research Center, Hampton, Va.*
This is a report of two principle dielectric types for use in the screened thin-film process. The first dielectric material is for use in the fabrication of minimum stray capacitance conductor crossovers. The second material is designed for application in high *Q*, high capacitance devices which are within the geometrical constraints of the substrate surface. Material formulation, processing and firing techniques are discussed. Pertinent electrical characteristics of the materials are presented. These materials have been used in the fabrication of practical circuits and the advantage of their application is discussed.

31.4 A Universal Logic Function Wafer, E. F. Uber, A. J. Domenico, *Lockheed Missiles and Space Co., Palo Alto, Calif.*
A production process utilizing titanium thin-film circuitry together with a layered interconnection matrix is described which yields a single function wafer capable of many diverse logic functions. The titanium thin-film circuitry, forming NAND/NOR logic elements, was selected due to the high yield and high uniformity of the components insuring that mass production techniques may be applied successfully. An added feature of the techniques is that the total volume occupied by the logic network, including interconnections, may be significantly reduced.

The essential feature of the universal logic function wafer is the layered interconnection matrix which permits a connection to be made between any pair of appropriate component terminals after the initial wafer fabrication. With a function wafer consisting of eight NAND/NOR logic elements, any of the 254 nontrivial functions of three variables may be formed in a total volume of less than 0.1 cubic inch. This work was supported by LMSC Independent Research and Development Program.

SESSION 32

Tuesday 2:30–5 P.M.
New York Coliseum, Room C

Electrical Technologies in Industry

Chairman: L. W. Birch, Ohio Brass Co., Mansfield

32.1 The Polyphase Induction Motor Controlled by Firing Angle Adjustment of Silicon Controlled Rectifiers, W. Shepherd, J. Stanway, *Royal Military College of Science, Swindon, Wilts, England*
The delta connection with back-to-back SCR pairs in the delta legs is found to be the best connection for stepless control of a balanced three-phase load. The effects of delta-delta and delta-wye transformer connections are studied by means of oscillograms.

Continuous, stepless control of an induction motor applied voltages is possible by the firing angle control of three SCR pairs. Measured and calculated torque-speed characteristics have fair agreement. Theory suggests that accurate and economic speed control can be achieved by the use of SCR pairs shunted across rotor resistors.

Performance characteristics, waveform oscillograms, measured harmonic analysis and mathematical analysis are given for both the series and the shunt control of single-phase, resistance-inductance loads by use of the back-to-back SCR pairs. Control of the firing-angles simulates the action of a nonlinear resistance with infinitely smooth adjustment and practically no dissipation comared with a conventional wire resistor. The shunt SCR controller has a smaller operating range than the series SCR controller but has a better waveform. The effects of various single-phase transformer connections, combined with the SCR pair, are studied by means of oscillograms.

32.2 Some Effects of Large Particles in Electrostatic Precipitation, G. W. Penney, G. W. Seman, *Carnegie Institute of Technology, Pittsburgh, Pa.*: R. E. Probst, *Laurel, Md.*
Conventional theory for efficiency of electrostatic precipitation which assumes that particles adhere perfectly to the collecting electrode predicts that large particles will be precipitated much more efficiently than small particles. Measurements of actual performance show that the reverse is often true. Studies show that adhesion of large particles is poor so that they do not adhere as assumed in the theory. Photomicrographs of the surface of dust as collected by precipitation show large particles may not only leave the collecting electrode but also carry off fine particles leaving craters in the dust surface. The precipitation of large particles and the erosion and partial reprecipitation of fine particles has been measured for various air velocities, current densities, and electric field strengths.

32.3 Development of Practical High Efficiency Lamps Employing Metal-Iodide Arcs, J. M. Harris, *Sylvania Electric Products, Inc., Salem, Mass.*
Commercial mercury lamps have been developed to a high degree. They have long life, good reliability and good lumen maintenance. A modified mercury lamp containing metal iodides increases the red rendition and broadens the visible spectrum, a quality of which present-day mercury lamps are wanting. With these additions, the percentage of energy radiated in the visible can be increased from the conventional 17 to 37 per cent thereby increasing the overall efficiency of the lamp consistent with luminosity curve corrections. Such improvements are attained by using metal iodides instead of metals per se. The metal iodides have a higher vapor pressure than the metals themselves and are stable at the lamp operating temperature. Iodides of sodium, thallium, thorium and mercury contribute broad emission lines plus a forest of lines through the spectrum. Additional starting problems have been overcome by use of novel starting circuits and altered lamp design.

32.4 A Study of Brushwear and Undercutting Tool Wear with Mica Segments, H. C. Lauroesch, *General Electric Co., Schenectady, N.Y.*
A significant item in the manufacturing costs of small commutators is the undercutting of the mica segments. And, to reduce this cost, the industry has historically turned to amber mica. This investigation was undertaken to determine where the reconstituted mica papers fit into the overall picture and further what is the effect of type of binder. The data obtained include brushwear on high speed portable appliance motors with flush commutators and simulated undercutting tool wear using commercial undercutting saws with commercial grades of mica segment plate materials.

32.5 A New Technique of Roadway Underpass Lighting, Norman Falk, *Holophane Co., Inc., New York, N.Y.*
This paper studies a new technique of roadway underpass lighting, utilizing wall-mounted, prismatically controlled, mercury vapor lamp equipment, in terms of: 1. Recommended standard practice of levels of illumination, required for vehicular and pedestrian safety. 2. Economic analysis comparison to other standard systems including an examination of the effects of varying certain parameters in the cost analysis. 3. A qualitative and quantitative evaluation of uniformity, visibility, fatigue, and comfort factors involved in underpass illumination solutions. 4. A consideration of field experience, employing this new method of underpass lighting. 5. An evaluation of the impact of future lamp and luminaire developments on underpass lighting techniques.

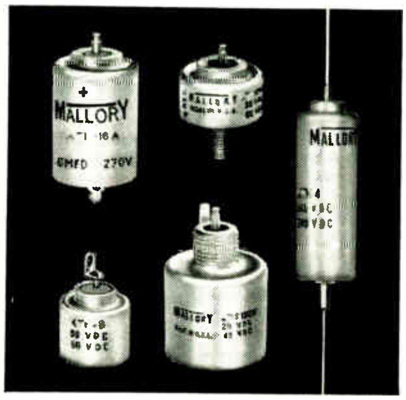
SESSION 27

Tuesday 8 P.M.–10:30 P.M.
New York Hilton, East Ballroom

DESIGNER'S FILE

Radiation-proof tantalum capacitors

The new XTG line of Mallory wet slug tantalum capacitors is designed to resist the effects of radiation. A group of sample capacitors recently passed a series of radiation exposure tests in the Ground Test Reactor of Lockheed Missiles and Space Company, Sunnyvale, California.



Capacitors were subjected to both gamma ray and neutron bombardment at 75°F. During 6744 minutes of reactor build-up time, the following dosage levels were reached:

Fast neutron bombardment: 6.579 x 10^{13} neutrons/cm^2, at energy level greater than 0.1 Mev.

Gamma radiation: 79.56 x 10^6 gamma rad. (C) from carbon source.

Capacitance, dissipation factor and DC leakage were measured for each capacitor at 120, 400 and 800 cps, both before and at the end of the dosage period. No detrimental changes in electrical characteristics occurred.

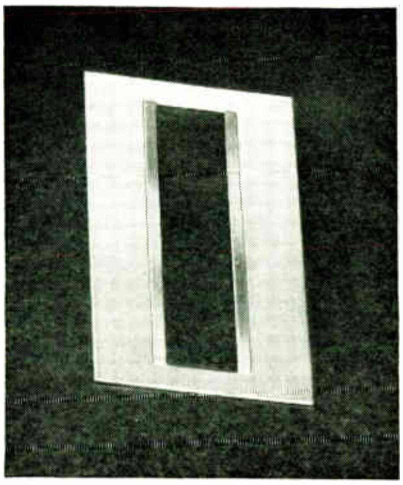
The XTG line uses special materials and construction to achieve radiation resistance. Temperature range is —55°C to +85°C. The line includes the same capacitance and voltage ratings as standard MIL-type Mallory wet slug tantalum capacitors, in all MIL terminal configurations.

FOR DATA USE READER SERVICE CARD

High-precision cutting of "difficult" materials

How would you cut the molybdenum wave guide aperture shown here to highly accurate dimensions?

An excellent answer is EDM—



electrical discharge machining. And where you need to maintain exceptionally close tolerances and accurate reproduction of complex contours, the electrode material to use is Elkonite® 10W3. On the part shown here, for instance, an Elkonite 10W3 electrode made it possible to hold slot width tolerances of 0.0001".

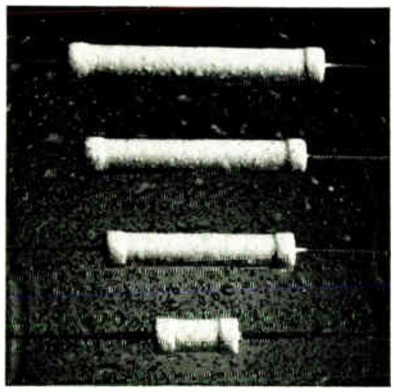
Any time you have a forming job that's difficult enough to warrant electrical discharge machining, it pays to consider Elkonite electrodes. Their ability to machine sharp corners and intricate contours in fine detail . . . their far longer service on the EDM machine . . . their ability to cut to extreme tolerances . . . will speed your production and reduce total machining costs.

FOR DATA USE READER SERVICE CARD

Mallory Film Resistors stay stable in high humidity

A recent series of humidity exposure tests demonstrate the ability of Mallory Type MOL metal oxide film resistors to hold stable values of resistance when subjected to extreme moisture.

The tests were run on a group of 33,000-ohm, 3-watt MOL resistors with nominal 10% tolerance. First, the resistors were exposed to 95% relative humidity at 40°C for 100 hours at no load. Result: average change in resistance was +0.37% . . . maximum change was +0.51%.



Next, the resistors were held for 1000 hours in this same atmosphere, with full rated wattage applied. Result: average change in resistance was in the band from —0.7% to +0.62%; maximum changes were —1.2% and +1.6%.

Through all this high humidity test Mallory MOL resistors remained at resistance values well within their stated tolerances. On long-term load life tests—10,000 hours—they show equally fine stability, with resistance holding within 1% of initial values.

The MOL series comes in 2, 3, 4, 5 and 7 watt ratings, with resistance values ranging from 30 ohms minimum on the 2 watt to a maximum of 125K ohms for the 7 watt unit. Standard tolerance is 10%; other tolerances can be supplied.

FOR DATA USE READER SERVICE CARD

Modular Magic—Special Highlight Evening Symposium

A panel of outstanding authorities will forecast the impact of the revolutionary processes and techniques for fabricating microelectronic integrated devices and circuits now emerging from our laboratories. Principles of design, methods of assembly, potential performance, practical applications, and the economic outlook will be discussed in a session that will be of unusual and timely interest to all IEEE members.

Moderator: Patrick Haggerty, *President, Texas Instruments Inc., Dallas*

Robert N. Noyce, *General Manager, Semiconductor Div., Fairchild Camera and Instrument Corp., Mountain View, Calif.*

C. Lester Hogan, *General Manager, Semiconductor Products Div., Motorola, Inc., Phoenix, Ariz.*

Leonard C. Maier, *General Manager, Semiconductor Div., General Electric Co., Syracuse, N.Y.*

Harry Knowles, *Manager, Molecular Electronics Div., Westinghouse Electric Corp., Elk Ridge, Md.*

J. E. Brown, *Vice President, Engineering, Zenith Radio Corp., Chicago, Ill.*

SESSION 33

Wednesday 10 A.M.–12:30 P.M.
New York Hilton, Trianon Ballroom

Telemetry

Chairman: James E. Scobey, Jr., NASA, Goddard Space Flight Center, Greenbelt, Md.

33.1 The Design of Signals for Space Communications and Tracking, E. J. Baghdady, K. W. Kruse, ADCOM, Inc., *Cambridge, Mass.*
Space communications and tracking requirements are outlined with emphasis on unique problems encountered with the space transmission channel, particularly when implementing the precision tracking function. Important signal design considerations are discussed. The fundamental principles of tracking are presented and tracking systems are classified in a convenient manner. Tracking signals are classified as harmonic and non-harmonic. These tracking signals are then analyzed in terms of their range measurement capabilities with particular emphasis of the properties of the signal autocorrelation functions. Criteria for comparing tracking signals are established and representative tracking signals of each type are compared. A third class of signals is defined which combines the desirable features of both types.

33.2 Design of an Instrumentation System for a Large Booster, V. V. Patton, R. W. Sjostrom, Wm. E. Smull, *The Martin Co., Denver, Colo.*
This paper presents an overall description of the instrumentation and telemetry system used for evaluating the performance of the Titan II ICBM during the development flights. Emphasis is placed on the wiring, grounding, shielding and impedance balancing techniques used to carry low millivolt signals for distances of a hundred feet or more in a hostile electromagnetic environment. The use of standardized transducer outputs with reduced calibration and checkout adjustments is also stressed.

33.3 Digital Command System—A Spacial Communicator, G. H. Carothers, Jr., *Radiation, Inc., Melbourne, Fla.*
Presented in this paper is the purpose, implementation, design criteria and the operational functions of the NASA Digital Command System, which is a part of the Gemini/Agena Telemetry Command Link. A description of the general block diagram is developed in light of the "command capability" desired by the ground based flight controllers. System characteristics are depicted in tabular form. Philosophies and mechanizations of operations such as inputting, reviewing, and transmission of command information are delineated. Operational relationships with Flight Control are detailed, as well as the "self qualification" features for insuring that only legitimate command content is transmitted. This being a life support system, an enumeration of the control devices implemented to facilitate minimum "down time" for maintenance is presented.

33.4 Telemetry Encoder for International Satellite S-52/UK-2, J. W. Adolphsen, A. B. Malinowski, *NASA, Goddard Space Flight Center, Greenbelt, Md.*
The S-52/UK-2 satellite is the latest in a series of satellites to utilize pulse frequency modulation. This paper documents design aspects of the S-52 encoder on a functional block basis and discusses in detail some new circuitry which is a significant improvement over instrumentation of earlier PFM encoders. Desired results were an increase in reliability, a reduction in power dissipation, and simplification of instrumentation circuitry wherever possible, while maintaining or improving system capabilities and performance. In achieving desired design aims the solution of attendant generated problems yielded much useful information, particularly in the area of high reliability semiconductors, and some of these details are discussed.

SESSION 34

Wednesday 10 A. M.–12:30 P.M.
New York Hilton, Mercury Ballroom

Electron Devices

Chairman: R. L. Watters, General Electric Research Lab., Schenectady, N.Y.

34.1 Transmitter for Coherent Light Communication System, Michiaki Ito, *Nippon Electric Co., Ltd., Kawasaki, Japan*
A series of experiments has been carried out with a transmitter for possible application to a practical light communication system. Design and performance of a dc excited helium-neon gas laser and sensitive wide-band modulator, alignment, and focusing procedures are discussed.

34.2 Network Theory of Semiconductor Hall Plate Circuits, J. M. Garg, *Wayne State University, Detroit, Mich.;* H. J. Carlin, *Polytechnic Institute of Brooklyn, N.Y.*
The paper deals with purely electrical realizations of the network element, the Gyrator at low frequencies. It discusses the utilization of Hall effect in semiconductors and the properties of nonreciprocal devices based on this effect.

A systematic study of the Hall plate, the best that can be expected from it, and the conditions under which the best performance can be expected are established; and some new theoretical and practical schemes are suggested which permit better understanding of device performance and yield better devices.

The Hall devices are nonreciprocal, passive and stable but dissipative. They permit the extension of frequency range from dc to several megacycles over which the nonreciprocal device can be used. In this sense they are complementary to the microwave Faraday-effect devices such as isolators and circulators. These will permit greater flexibility and choice of elements for complex circuit designs, if the loss can be tolerated. This paper presents basic limitations, from an insertion loss standpoint, on the performance of Hall plate circuits embedded in resistance or reactance networks.

34.3 Non-Reciprocal Parametic Amplifiers: Theory and Instrumentation, H. B. Henning, *LFE Electronics, Boston, Mass.*
The advantages of a non-reciprocal parametric amplifier over conventional types are manifest. Perturbations in signal source characteristics no longer degrade stability and power gain. For this reason, conventional paramps require circulators. But circulators are noisy, temperature sensitive, and complicate any attempts to cool the paramp cryogenically.

To overcome these difficulties, this paper discusses the theory of non-reciprocity and applies it to two single-varactor paramps. One paramp operates in a CW mode, the other is superregenerative. Both units (a) will provide down-conversion at very low noise figures and (b) will accommodate signal frequencies which exceed the nominal value of the pump. Design constraints and performance characteristics are discussed.

34.4 Ultrasonic Amplification Characteristics and Nonlinearity in CdS, Tatsuo Ishiguro, Ichizo Uchida, Tatsuo Suzuki, *Nippon Electric Co., Ltd., Kawasaki, Japan*
Studies on the gain (loss) and the nonlinear characteristics of ultrasonic amplification in solids are carried out in the frequency range 15–135 Mc/s by using CdS crystals. A gain of 94 dB at 135 Mc/s is obtained. Generation of higher harmonics up to 405 Mc/s is observed.

The observed relation between the gain and the drift field is nonsymmetric and the plots of the maximum gain versus frequency do not agree with the theory developed by White. When the conductivity of the crystal is low, these disagreements become considerable. Taking into account the effects of phase shift between the space charges formed by conduction electrons and by trapped electrons, we develop a modified expression for the gain. Agreements between the theory and the experiments are satisfactory.

34.5 An Experimental Study of 1/f Noise in Transistors, M. J. Wiggins, *The Martin Co., Orlando, Fla.*
Mathematical models of thermal and shot noise characteristics of transistors are adequate for the determination of the optimum operating point and source impedance. However, in the case of $1/f$ noise which occurs at low frequencies and has a spectral distribution proportional to $1/f^n$, models presently available do not describe the phenomenon sufficiently for practical design purposes.

This paper describes an experimental approach to the determination of optimum operating point and source impedance for transistor circuits in applications where $1/f$ noise predominates. Results of a number of tests which measure the noise spectrum as a function of operating point and source impedance are described. Results of such tests are presented as parametric plots of noise factor versus frequency, and conclusions are drawn as to the choice of parameters for optimum noise performance at low frequencies. A description of the special measurement techniques is included. A procedure is developed for rapid determination of the entire noise spectrum of a transistor for practical design purposes.

SESSION 35

Wednesday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom N.

Syncom II Satellite

Chairman: Arnold Levine, ITT Federal Labs., Nutley, N.J.

35.1 Communication Operations with Syncom

GOT A **COCK-EYED SWITCHING PROBLEM?**

Bring it to us at Booth E-164, IEEE Show, New York Hilton Hotel.

Our engineers will be in constant attendance, ready to show what our rotary multipole switches, slip-rings, and brush-holder assemblies can do for you.

We've solved hundreds of complex switching problems and we'll gladly tackle yours.

P.S. If you're not going to the show, write or telephone us anytime.

ELECTRO SWITCH
ELECTRO SWITCH CORP.
167 King Ave., Weymouth (Boston), Massachusetts 02188
Telephone: 335-5200, Area Code 617

TOPS IN KNOBS

EXCLUSIVE DESIGNS FROM STOCK MOLDS

AVAILABLE ONLY FROM ROGAN

Visit Booth 4110 IEEE Show

Choose from wide variety of knobs that meet requirements of modern industrial development...match progress of military - electronic advancement.

Save tooling costs... get faster deliveries . . . get details on complete line of Rogan stock molded knobs. Write on business letterhead for new catalog.

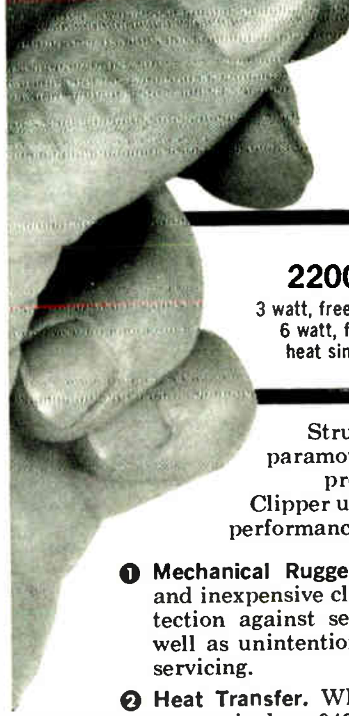
ROGAN BROTHERS, INC. 8025 N. Monticello Ave. Skokie, Illinois 60076

Specializing In Stock Molded Knobs Since 1939

NOW from SAGE

Two new Smaller Sizes in METAL SLEEVED TYPE C

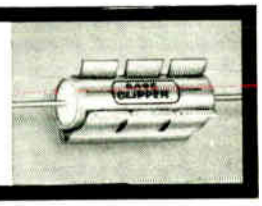
Clipper RESISTORS



2200C and 2250C miniature—precision wirewound POWER RESISTORS

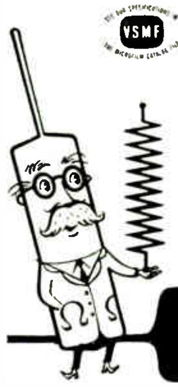
(Shown actual size)

2200C
3 watt, free air
6 watt, fully heat sinked



Structural simplification has been paramount in the course of improving product designs at Sage. Type C Clipper units thus provide unsurpassed performance in these important features:

1. **Mechanical Ruggedness.** Brass sleeve housing and inexpensive clip mount assure absolute protection against severe vibration and shock as well as unintentional roughness in assembly or servicing.
2. **Heat Transfer.** When fully heat sinked on 1.5 square inches .040" aluminum per watt, power rating is increased 2 for 1 over the free air rating.
3. **Reliability.** Construction is fully welded; IMPERVOHM® insulation rated for 350° C operation and 1000 volt rms dielectric strength.



STYLE	POWER RATING		RESISTANCE .05 Ω to
	Free Air	Body Mounted	
*2200C	3	6	20 K Ω
*2250C	3	6	40 K Ω
2400C	3.5	7	42 K Ω
2550C	5.5	11	88 K Ω
2600C	7	14	114 K Ω
2650C	8	16	170 K Ω
2750C	10	20	257 K Ω

*new

Ask for Catalog R-62 giving full details

SAGE
SAGE ELECTRONICS CORP.
Country Club Road • East Rochester, N. Y.

II, T. R. Gleason, W. T. Tobias, R. G. Keyes, *U.S. Army Satellite Communications Agency, Ft. Monmouth, N.J.*
Following successful launching on July 26, 1963, and before and after successful injection into on-station synchronous inclined orbit at longitude 55 degrees West on 18 August 1963, an extensive and sucessful series of voice, teletype, facsimile, and data transmission tests were conducted through the Syncom II satellite from earth stations controlled by the U.S. Army Satellite Communications Agency, Fort Monmouth, N.J. and located at Fort Dix and Lakehurst Naval Air Station, N.J.; Camp Roberts, California; Agricultural Research Station, Beltsville, Maryland: and aboard the U.S. Navy ship, USNS Kingsport, first in the harbor at Lagos, Nigeria and later underway at sea. The results of these tests and the operational experiences and problems encountered during their scheduling and conduct are presented in this paper. The paper also established conclusively that the delay inherent in the 50 000 mile transmission path is completely acceptable and tolerable for voice communications. The data upon which this paper is based are derived from tests whose cumulative time to date through a communications satellite exceeds by orders of magnitude that of all other previous communications satellites combined. The paper also includes the results of the measurement of link characteristics such as received carrier and beacon power, noise, absolute delay, doppler shift, envelope delay, and transmission characteristics. The results are in good agreement with expected performance.

35.2 Control Centers for Military Satellite Communications Systems, S. M. Segner, F. A. Dieter, *U.S. Army Satellite Communications Agency, Ft. Monmouth, N.J.*
This paper discusses the satellite transmission subsystems characteristics from the viewpoint of integration into a common user system. The user requirements are translated into functions for the control center to perform. The physical and electronic problems involved with transmission via medium altitude random satellites and synchronous altitude satellites are delineated in terms of their effect on the overall control of communications system. The discussion then centers about the present status of control center development and in particular the ISACCC program. The scheduling is detailed in flow chart format and the problems of automation are covered from the viewpoint of man/machine balance, data transmission, and evaluation of system effectiveness during a research and development phase which has specific objectives peculiar to the military.

35.3 Light Weight Satellite Communications Link-Terminal, G. J. Goubeaud, *U.S. Army Satellite Communications Agency, Ft. Monmouth, N.J.*
This paper will in general describe the military need for a light weight satellite communications link-terminal. In addition, it will present a discussion of the technical feasibility of a link-terminal in terms of overall system performance with special emphasis on transportability and quick installation time. A discussion of the various parameters which influence communication capability is also presented. These parameters which are discussed are now within the current state of technology. In conclusion, desired technological advances in several areas are discussed together with their attendant effects on the link-terminal.

35.4 Some Preliminary Results of Multiple Access Experiments with Syncom and Telstar II, V. G. Robatino, *U.S. Army Satellite Communications Agency, Ft. Monmouth, N.J.*
A series of multiple access experiments was conducted using spectrum spreading mod/demod equipment which provided a 3 kc/s voice channel in a spread bandwidth of 5 Mc/s. Tests were performed with Telstar II and through the wide band transponder of the Syncom satellite. Simplex loop tests were performed at Camp Roberts, Calif. and a full duplex circuit was established between Camp Roberts and Fort Dix, N.J. "Interfering" subscribers were both simulated with locally added signals and by simultaneous transmissions from other ground stations in Lakehurst, N.J., Lagos Nigeria and Greenbelt, Md. Equipment configuration and test setup are described and test results reported.

35.5 Results of Syncom Communications Experiments, George Silverman, J. W. Lockett, J. C. Cittadino, *U.S. Army Satellite Communications Agency, Ft. Monmouth, N.J.*
This paper describes the procedures and techniques used in the reduction, analysis and evaluation of data obtained from Syncom II satellite system experiments. The use of electronic data processing, reduction, sorting, and plotting techniques will also be described. A statistical analysis to determine the relationship between statistical data and mathematical functions for such parameters as signal plus noise to noise versus intelligibility, teletype score, articulation index, etc., will also be explored.

Also included in this paper are results of early Syncom II system experiments which will be evaluated to show the relation between the calculated and design objectives and actual system performance for such parameters and system variables as signal plus noise to noise, tone distortion, teletype distortion, voice frequency circuit performance, facsimile performance, multi-channel performance, etc. Finally, this paper will show an overall comparison of evaluated data from the Syncom II system with the performance and standards of conventional communication systems.

35.6 Design of the Voice Portion of the Syncom Ground Station, G. P. Tripp, N. W. Feldman, *U.S. Army Electronic R & D Labs., Ft. Monmouth, N.J.*
The purpose of this paper is to describe a design layout for the voice channel portions of the Syncom Communications System and to define the necessary line-up parameters for the layout. Although the system design is for 4-wire operation, in order to permit integration with commercial systems 2 wire operation is anticipated. The elements of the system or "black boxes" will be described and their characteristics developed to fit into a satisfactory system line-up. A second lay-out including compandors in an effort to improve the signal-to-noise ratio of the transmission facility is also described.

SESSION 36

Wednesday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom S.

Semiconductor Devices

Chairman: E. J. Diebold, International Rectifier Corp., El Segundo, Calif.

36.1 Electroluminescent Response to Pulse Excitation, I. H. Stein, *U.S. Army Electronics R & D Labs., Ft. Monmouth, N.J.*
Zinc-sulphide electroluminescent cells, dissimilar in phosphor activation, cell thickness, and dielectric matrix material, have been subjected to high-amplitude, repeated, rectangular pulse excitation for the purpose of investigating the light emittance characteristics. The parameters of the excitation pulse have been varied in unequal steps for selected ranges of pulse width, voltage level, and repetition rate. Data on average light output under these conditions were measured using a photomultiplier calibrated with a secondary light source. This light source, filter-corrected to the blue and green electroluminescent spectral bands, was measured with a flicker photometer.

36.2 Electroluminescent Cross-Grid Devices: The Users' Viewpoint, W. Merel, *Weston Instruments Corp., Newark, N.J.*
Electroluminescent cross-grid devices have been fabricated and evaluated over the last five years. Yet, much difficulty is encountered in applying these components because critical parameters are not understood by device fabricators or design engineers. To clarify the situation, the paper, utilizing several panels as examples, defines visual and electrical parameters so as to "standardize" evaluation and application. An equivalent circuit is evolved to define critical electrical parameters. It is shown how these parameters have a bearing on electronic driving sources. A specification sheet similar to that used by semiconductor manufacturers is proposed to serve as a tool to enable circuit designers to utilize cross-grid electroluminescent devices effectively.

36.3 New Developments for the Improvement of High Voltage Rectification with Silicon Series Strings, C. L. Schuler, *General Instrument Corp., Newark, N.J.*
This paper contains information which makes it possible for design engineers to be apprised of the present state of the art in high voltage silicon rectifiers so that they may make intelligent design decisions for new high voltage equipment.

36.4 The Triac—Gate-Controlled Silicon AC Power Switch, E. K. Howell, *General Electric Co., Auburn, N.Y.*
The "Triac" is a new three-electrode semiconductor for ac power control. Although still in developmental stage, the triac's ability to perform bidirectional switching in response to a small gate signal makes it a contender for all present uses of SCR's in ac applications. By combining the function of a pair of SCR's in a single silicon wafer and package, the triac potentially offers lower cost, small size and more reliable control of ac power. The single gate reduces control circuit complexity, with further gain in reliability and economy. Natural immunity to transient voltages precludes use of any transient suppression devices and ensures long life. The Triac's construction, characteristics, control circuits and possible applications are described.

SESSION 37

Wednesday 10 A.M.–12:30 P.M.
New York Hilton, Regent Room

Instrumentation V

Chairman: W. H. Shirk, Jr., Leeds and Northrup Co., Philadelphia, Pa.

37.1 Electrochemical Devices for Timing Integration and Switching Applications, C. C. Beusman, *Curtis Instruments, Inc., Mount Kisco, N.Y.*
A novel electrochemical coulometer has been developed to measure current vs. time integrals and has wide application as an elapsed time meter, battery life indicator and general purpose integrator. The microcoulometer is fabricated from custom drawn precision bore glass capillary tubing. Filling the capillary bore are two columns of mercury separated by a small aqueous electrolyte gap. Etched nickel wire electrodes are inserted into the mercury columns and are epoxy sealed to the glass forming a completely liquid filled system.

With the application of pure or pulsed dc signals, current flows through the meter electropolating mercury from the anode to the cathode at a time rate proportional to the current flow. Mercury transfer effectively moves the gap along the tube length and total gap displacement (with uniform glass bore) is directly proportional to the current/time integral. In

DC to AC or

- Frequencies from 400 cps to 5 KC
- Output voltages from 5-500 VAC
- 50, 100, 200 VA Standard

Designed to change low voltage DC power to sine or square power, these small-size, transistorized inverters can be supplied in a wide range of output voltages and frequencies. Units feature regulation to ½% for input 24 to 30 VDC, short circuit protection, and meet the environmental requirements of MIL-E-5272C. Prices range from $185. to $595. Delivery of most units from stock.

Send for complete 20-page catalog or see E.E.M. pgs. 1255-1259.

abbott transistor

LABORATORIES, INCORPORATED

3055 Buckingham Rd. • Los Angeles 16

Direct Dial 213 • REpublic 1-9331

HEATH SERVO PEN RECORDER...TYPICAL VALUE IN A NEW RESEARCH AND TEACHING LAB INSTRUMENTATION SERIES!

FEATURES AND PERFORMANCE WORTH FIVE TIMES ITS LOW PRICE!

Unbeatable value! True potentiometric input. Five adjustable ranges: 10, 25, 50, 100 & 250 mv plus plug-in 5-pin connectors for special ranges. Rapid chart advance; pen lift; paper tear-off guide; optional motor speeds; 10" chart; 1 sec. response. Factory assembled & tested. Write for details on entire Malmstadt-Enke Lab series!

Assembled EUW-20A . . . 20 lbs. . . .
$19 mo. $195.00

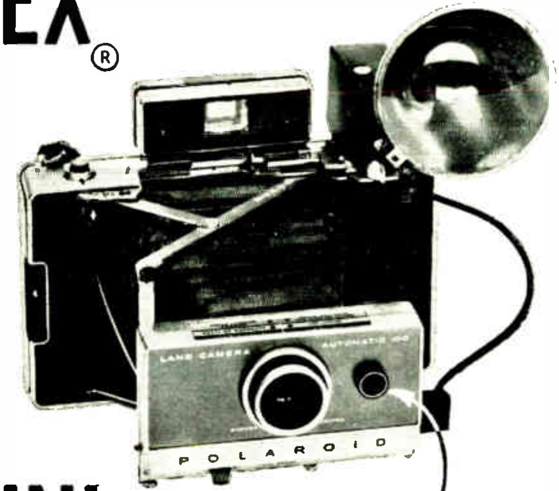
HEATHKIT by Daystrom

HEATH COMPANY 47-3-1
Benton Harbor 47, Michigan 49023

☐ Please send free folder on Lab Series Equipment.
☐ Please send Free Heathkit catalog.

Name__________
(please print)
Address__________
City______ Zone______ State______

POLAROID
CORPORATION
USES CLAIREX®



...AGAIN!

- **FIRST FLASH EXPOSURE CONTROL** USING PHOTOCONDUCTIVE CELL

  The world's most advanced camera, the **Polaroid Land Automatic 100,** contains a most advanced photoconductive cell by **Clairex** capable of high speed operation over a ratio of light levels greater than 10,000/1. This cell is a key component—a "light valve"—in the new camera's electronic shutter which permits perfect exposures in both color and black and white under **all** conditions, **including flash operation.** Precisely controlled characteristics, as well as speed and reliability, prompted **Polaroid** to rely on **Clairex** photoconductive cells for such an important task . . . a second time!

- **FIRST STILL CAMERA** WITH PHOTOCONDUCTIVE CELL CONTROL

  Over four years ago, **Polaroid Corporation** came to **Clairex** and asked it to supply the critical photoconductive cell component for its "Microeye" exposure control device, a "first" for still cameras!

  Have **you** considered the "light touch" . . . in **your** automation or control problem?

CLAIREX
CORPORATION

The Finest in Photoconductive Cells . . . in and out of This World

SEE US AT THE IEEE SHOW, MAIN FLOOR, BOOTH 1913 addition to direct visual readout by gap location, remote electrical readout can be obtained by a photoelectric means or by a capacitive potentiometric readout of gap location.

37.2 A Tachometer and Synchroscope for Reciprocating Engine Aircraft, M. J. Delaney, *The Bendix Corp., Sidney, N.Y.*
This paper describes a new electronic tachometer and synchroscope which has been developed for light aircraft employing reciprocating engines. The tachometer consists of a magnetic transducer, digital circuitry, and a conventional meter mechanism readout. The solution to a number of unique problems encountered in adapting electronic tachometry to aircraft is explained in detail. A companion synchroscope instrument has also been developed for dual engine application. These instruments are compact and economical while at the same time complying with aircraft standards for accuracy and performance.

37.3 Hydraulic Servomechanisms as Seismic Energy Sources, G. L. Brown, *Continental Oil Co., Ponca City, Okla.;* S. D. Moxley, Jr., *AVCO Corp., Cincinnati, Ohio*
This paper describes the application of a hydraulic servomechanism as an oscillatory seismic energy source in the frequency range of 15 to 100 c/s. The "Vibroseis" exploration system uses an FM input signal to the earth cross-correlated against the echo return to measure acoustic travel time. Hydraulic servo-vibrators have high output over wide bandwidth and can be electrically synchronized. The servosystem is analyzed in terms of system limits and servo loop stability. The reaction between the vibrator and the earth system is studied as dynamic mechanical system. The coupling of the vibrator to the earth system for several practical vibrator units is shown and possible applications suggested.

37.4 Fire Detection by Ultrasonic Doppler, S. Bagno, R. R. Gilbert, *Walter Kidde & Co., Inc., Clifton, N.J.*
An investigation of several techniques for the detection of fire by means of ultrasonic doppler is described. It is shown that the detection of fire in the absence of other motion is quite simple, and that the major problem is that of discriminating between fire and other motion such as moving personnel. Test results compare the difference between the effects of fire and other motion on the magnitude of a vertically propagated doppler, the degree of waveform assymmetry in the doppler, and the rate of growth of doppler magnitude. Test results are explained theoretically.

37.5 Studies of the Two-Vehicle Situation. R. Cosgriff, W. Rocca, A. Thomas, E. Todosiev, *The Ohio State University, Columbus*
Recently, renewed interest has developed in automating the automobile. One of the most difficult aspects of this problem is associated with the control of longitudinal placement of individual vehicles in a traffic stream. The requirements upon such control systems are that they be stable as individual units and that a platoon of vehicles be stable, a perturbation of the lead vehicle velocity will not grow as it propagates to the rear in the platoon. There are requirements upon comfort which involve the limiting of acceleration of individual vehicles. Likewise the vehicles must not be separated by excessive distances and the system must be safe. These considerations as well as others are combined and used to demonstrate that linear control systems are inadequate. Necessary nonlinear modifications are indicated. Results of tests of the characteristics of the human driver are also included which indicate that the human uses techniques in driving which fall within the nonlinear class of satisfactory control systems. A typical control system is suggested which meets most of the necessary requirements.

SESSION 38

Wednesday 10 A.M.–12:30 P.M.
New York Coliseum, Room A

Improving Written Communications

Chairman: Walter B. Dennen, Radio Corporation of America, Moorestown, N.J.

38.1 Your Key to Better Written Communication in Science and Industry: A Plan for Action, M. I. Bolsky, *Systems Development Corp., Paramus, N.J.*
This paper suggests that greater emphasis should be given to achieving more clear, concise, and effective writing by engineers and other technical personnel. It presents a four-part plan by which such writing can be brought about. The *first* step is DESIRE: management should make writing effectiveness one of the important factors by which a person is evaluated. The *second* step is KNOWLEDGE: engineers and other technical personnel must be given the knowledge of how to write better; assigning an editor to work with groups of people, on an on-going basis, is one way of doing this. The *third* step is ENOUGH TIME: technical personnel should schedule enough time for their writing. The *fourth* step is HABIT: the principles of good writing should be applied to everyday memorandums and documents, as well as to formal reports.

38.2 Specifications: Their Function, Generation, and Associated Problems, J. P. Streeter, *Burroughs Corp., Radnor, Pa.*
Admiral Rickover, in a recent address before the National Metals Congress, mentioned the seriousness of the specification problem that faces both Government and industry alike. He went on to demonstrate the gravity of the problem with specific examples. This paper deals exclusively with the problem outlined by Admiral Rickover. The specification problem is defined, its symptoms are examined, and its effects are explained. The generation of specifications and their relationship to the complete technical data package, are analyzed, and a brief history of specification philosophy is presented. Recent activities of trade associations (National Security Industrial Association) in the specification field are surveyed, and their recommendations to the Department of Defense are outlined. Plans on the part of Governmental agencies to combat the problem are stated to demonstrate recognition of the problem in the Government. The paper also examines the false dichotomy in the engineering writing field between technical writers and specifications writers. It suggests that it is up to groups such as the IEEE-PTGEWS to help in the solution of the specification problem.

38.3 A Communications Model for the Engineer, D. E. Montgomery, *Minneapolis-Honeywell Regulator Co., Minn.*
An unusual model describes communication. Questions discussed are as recent as right now and as old as language itself. How do you get ideas into the heads of others? Once they get there, how do you get people to react favorably to them?

The Communication Model looks at: (1) The source, (2) Message, and intended Receivers. Intervening variables are classified as (1) Psychological, (2) Physiological, and (3) Physical. Specific variables are described and a course of action recommended.

38.4 Report on the PTGEWS/PTGE Seminar on Writing Improvement Program for Engineers, C. A. Meyer, *Radio Corp. of America, Harrison, N.J.*
This paper will report the significant results of the Seminar on Writing-Improvement Programs for Engineers held at New York City, February 24–25, 1964. It will include an evaluation of the degree of need for better writing by engineers, as well as the specific areas that need attention. It will then summarize the major features of various writing-improvement programs described at the Seminar, covering both subject content and administration. It will conclude with a consensus of both the speakers and the attendees at the Seminar as to the effectiveness of the training programs described together with the recommendations developed for future action.

SESSION 39

Wednesday 10 A.M.–12:30 P.M.
New York Coliseum, Room B

Radas

Chairman: John E. Mutty, Jr., Aerospacecom (ESNEO), Waltham, Mass.

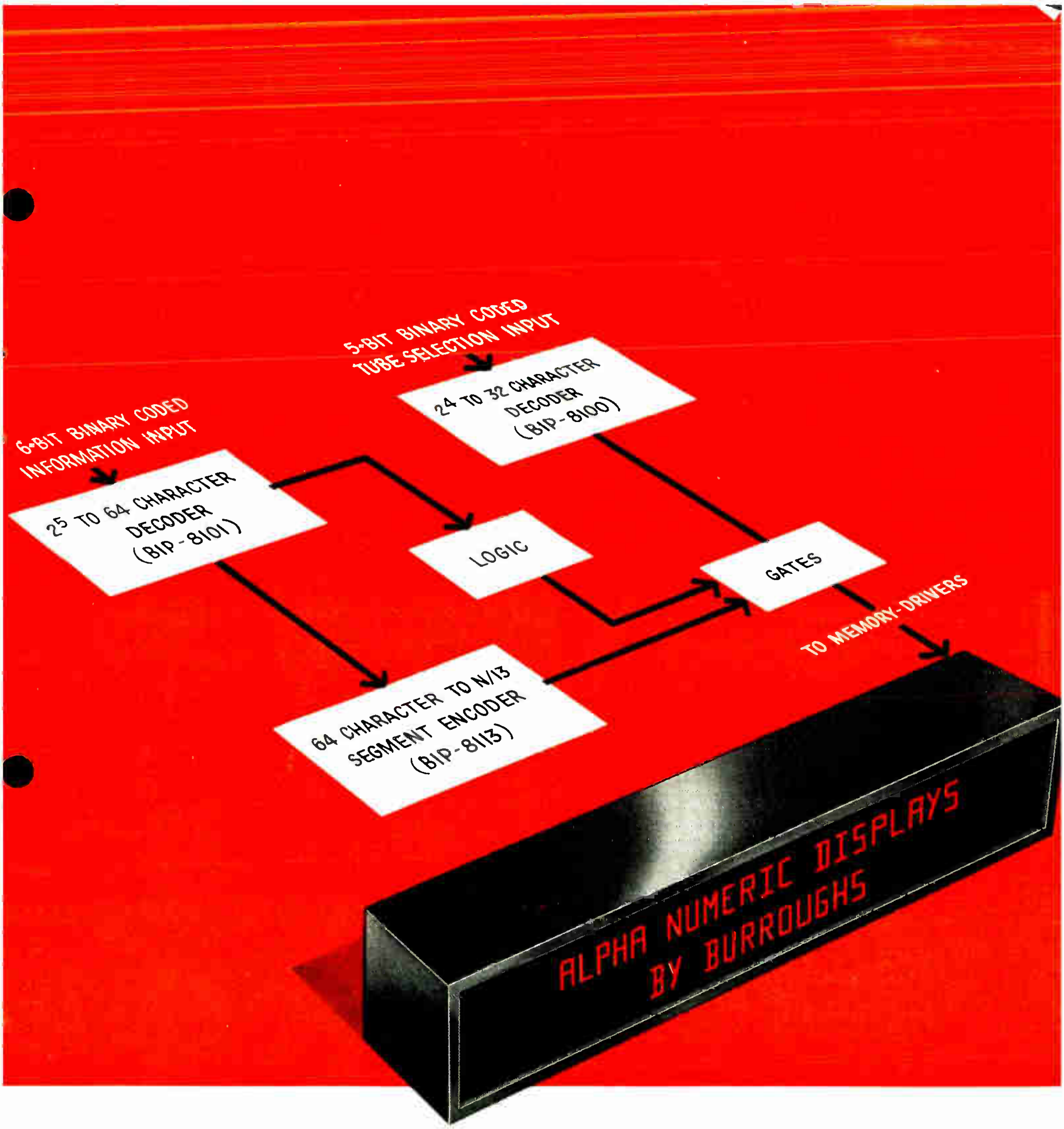
39.1 An Introduction to Random-Access, Discrete-Address Systems, C. H. Dawson, *Stanford Research Institute, Menlo Park, Calif.*
Random-access, discrete-address systems are defined and typical characteristics are given. The advantages and the conditions under which these advantages can be achieved are given together with possible applications. Possible types of address and information modulations are discussed. The effects of the mutual interference between the users of the common frequency band on address recognition and output signal-to-noise ratio and the way in which both continuous and low duty cycle systems can operate despite this interference are discussed. An annotated bibliography is included of some of the unclassified published papers on the subject of random-access, discrete-address systems.

39.2 (A) A Backscatter Multipath Model for Groundwave Pulse Communications Systems, R. W. Heffner, *The Martin Co., Orlando, Fla.*
A general model is developed to predict the clutter time stretch for groundwave pulse communications systems. Backscatter and displaced units multipath effects are normalized to the system propagation path loss slice levels. Determination of pulse time clutter is of value in modeling and evaluating co-channel pulse communications systems.

The parameters of frequency, σ_0 (area reflection coefficient), h_σ (reradiation height), system antenna heights, radiated pulse width and range displacement are used to model and predict the clutter time stretch versus system slice level.

Empirical results for pulse widths from 0.5 to 10 μsec at frequencies of 141 Mc/s and 430 Mc/s are included and compared to the propagation model. Displaced unit distances of 10 feet to 10 miles over a propagation dynamic range of 150 dB are compared.

39.2 (B) Propagation Measurements for a Frequency Time Coded Pulse Communications System, J. Lomax, W. Bedsole, *The Martin Co., Orlando, Fla.*
At frequencies of 140 and 430 Mc/s, propagation measurements were taken to investigate signal strength variations, multipath interference, and indigenous noise effects in a frequency-time coded pulse communications system. A rectangular pulse shape was transmitted in pulse widths between 0.5 and 10 μs. A variety of transmission paths were represented in three distinct terrain conditions. The propagation measurements presented in tabulated and graphical form show substantiation in a pulse system of Egli and Bullington's CW field strength measurements plus inclusion of field strength measurements for ranges as close as ten feet. Measurements of pulse stretch due to multipath are included, and empirical results regarding indigenous noise are presented.



everything from the input . . . out

Alpha Numeric Display Systems by Burroughs, designed around new Alpha Numeric Nixie® Tubes, give you everything from the input . . . out. These systems are adaptable to any kind of electronic information display requirements. System flexibility is enhanced by the use of standard highly reliable semi-conductor modules. Standard packages include memory-driver modules, decoding and encoding devices, and associated control circuitry. The modular concept facilitates custom design of display systems to meet individual functional and physical specifications. Visual display is made particularly effective by unique tube characteristics . . . unexcelled brightness and continuous line characters . . . which provide exceptional readability. In addition, any one of a number of available character sizes may be incorporated in a system to provide the best display for a given situation or application.

Burroughs' display systems group is available for consultation on your particular requirements. Write today for complete information on Burroughs Alpha Numeric Display Systems.

ANOTHER ELECTRONIC CONTRIBUTION BY
Burroughs Corporation
ELECTRONIC COMPONENTS DIVISION
PLAINFIELD, NEW JERSEY

"See us at the I.E.E.E. Show booths 1211-15"

39.3 Selection of a Pulse Modulation Communications System Based on Results of Intelligibility Measurements, C. Diaz, *The Martin Co., Orlando, Fla.*
Breadboard models of three pulse modulation systems, under similar modes of operation, were subjected to impulse noise (additive and subtractive), and system tapes were recorded using phonetically balanced word lists as the basic modulation. Recordings were played to trained listeners in a specially constructed sound-proof room. Grades were established for each system as well as for special recordings of 13 dB signal-to-noise ratio of Gaussian noise mixed with straight audio. The Gaussian noise tests produced a word intelligibility of 74.3 per cent. This grade established a reference for comparison of the intelligibility of the three systems tested and provided a translation of the military specifications that are applicable to pulse modulated communication systems. The intelligibility tests also established the degree of error pulse immunity of the pulse modulated systems when using different sampling techniques and pulse decision circuits.

39.4 Random Access Communications Using Frequency Shifted PN (Pseudo-Noise) Signals, H. Blasbalg, D. Freeman, R. Keeler, *International Business Machines Corp., Bethesda, Md.*
Random-access communications techniques using frequency shifted pseudo-random signals will be discussed. Mathematical expressions for the signal-to-noise ratio as a function of the number of active users will be presented along with other performance characteristics. An efficient simulator for these complex modulations will be discussed and measured results will be presented. Finally, digital matched filter configurations for extracting the intended signal from the clutter will be outlined.

39.5 False Addresses in a Random Access System Employing Discrete Time-Frequency Addressing, C. H. Dawson, Howard Sklar, *Stanford Research Institute, Menlo Park, Calif.*
A system is considered in which an address consists of a time pattern of pulses each of which may be at one of several frequencies. A false address occurs when pulses from interfering transmitters form a users address. Pulses are assumed to be square, of uniform amplitude and duration, and to combine without RF phase cancellation.

The following results, applicable to any number of interfering transmitters, any number of address frequencies and any number of receiver channels, are obtained: 1. The probability at any time of finding a false address pulse. 2. The probability of the length of a false address pulse exceeding a specified value. 3. The mean length of a false address pulse. 4. The mean false address pulse rate (that is, the number of false addresses per unit time). 5. The autocorrelation function and the power spectrum of the false address pulses.

SESSION 40

Wednesday 10 A.M.–12:30 P.M.
New York Coliseum, Room C

Rotating Machinery

Chairman: F. R. Terrant, Reliance Electric and Engineering Co., Cleveland. Ohio

40.1 Temperature Measurements of Rotors Having High Voltage Excitation, J. P. White, *Leeds and Northrup Co., Philadelphia, Pa.*
In the measurement of field temperature in rotating electrical generators and condensers by means of the double Kelvin bridge, a hazard exists due to the fact that the field potential is present in the measuring circuits. It is shown that this hazard may be successfully eliminated by the use of current and voltage transductors in conjunction with a ratio recorder. Field tests have shown that this is a practical method having an accuracy in the order of ±2 degrees C with ambient temperature variations of ±10 degrees C and ±10 per cent variations in the ac supply voltage.

40.2 Evaluation of Excitation Systems by Test, J. G. Sedwick, *General Electric Co., Waynesboro, Va.*
This paper follows AIEE publication 62–147 and IEEE paper CP 63-674 by actual testing of 3 types of excitation and regulating systems on the same generator: 1. Conventional SCPT exciter and transistor voltage regulator. 2. SCR exciter with transistor voltage regulator. 3. Rotating ac exciter and full wave inverting SCR regulator.

Other data included will be an evaluation of each system from the viewpoint of cost, reliability, and packaging and installation.

40.3 Voltage Transient Analysis of AC Generators with Trinistat Voltage Regulator, C. H. Lee, *Westinghouse Electric Corp., East Pittsburgh, Pa.*
A Trinistat voltage regulator is a new static regulator for ac generators. It has fast response and will improve the transient voltage regulation of power systems. The main purpose of this paper is to present a quick method of calculating maximum transient voltage regulation, and of estimating the voltage recovery time of a generator after a sudden load change. In modern power systems, the voltage transients due to sudden load changes are frequently of great concern to component and system engineers.

A quick technique for predicting voltage transient presented by this paper is rather important and useful. Calculated values of sample systems compared favorably with tested results.

40.4 A 1000 KW Gas Turbine Alternator for a Telephone Building, R. W. Sittner, *General Electric Co., Albany, N.Y.;* H. J. Donnelly, *New York Telephone Co., Albany*
In the installation to be covered in the paper, an electrical control system automatically matches output power to varying loads, and protects against overspeed and overheating by varying the fuel flow. The control furnishes constant output shaft speed, which in turn governs the alternator frequency within precise limits. The fuel and control systems permit complete automatic engine operation. The electrical system employed also provides manual control of startup and shutdown by means of push buttons, which may be located remotely if desired. The system insures proper operation and load sharing with diesel alternators or other gas turbine alternators in parallel. A coordinated electrical protection factor has been furnished for the 4160-V alternator, 5 kV cable, transformer and downstream. Collapse of field excitation has been provided in place of a 5 kV air circuit breaker. The circuitry provides automatic start and automatic load transfer.

40.5 Calculation of Internal Fault Currents in Synchronous Machines, V. A. Kinitsky, *Drexel Institute of Technology, Philadelphia, Pa.*
The synchronous machine with an internal fault in its armature winding is represented by an equivalent circuit in three symmetrical components which can be connected to the corresponding network. Thus the fault currents can be calculated from the obtained equivalent network.

The calculation of internal fault currents has been programmed for the IBM-7090 digital computer and the calculated values have been compared with the result that were obtained experimentally.

SESSION 41

Wednesday 2:30–5 P.M.
New York Hilton, Trianon Ballroom

The West Ford Experiment

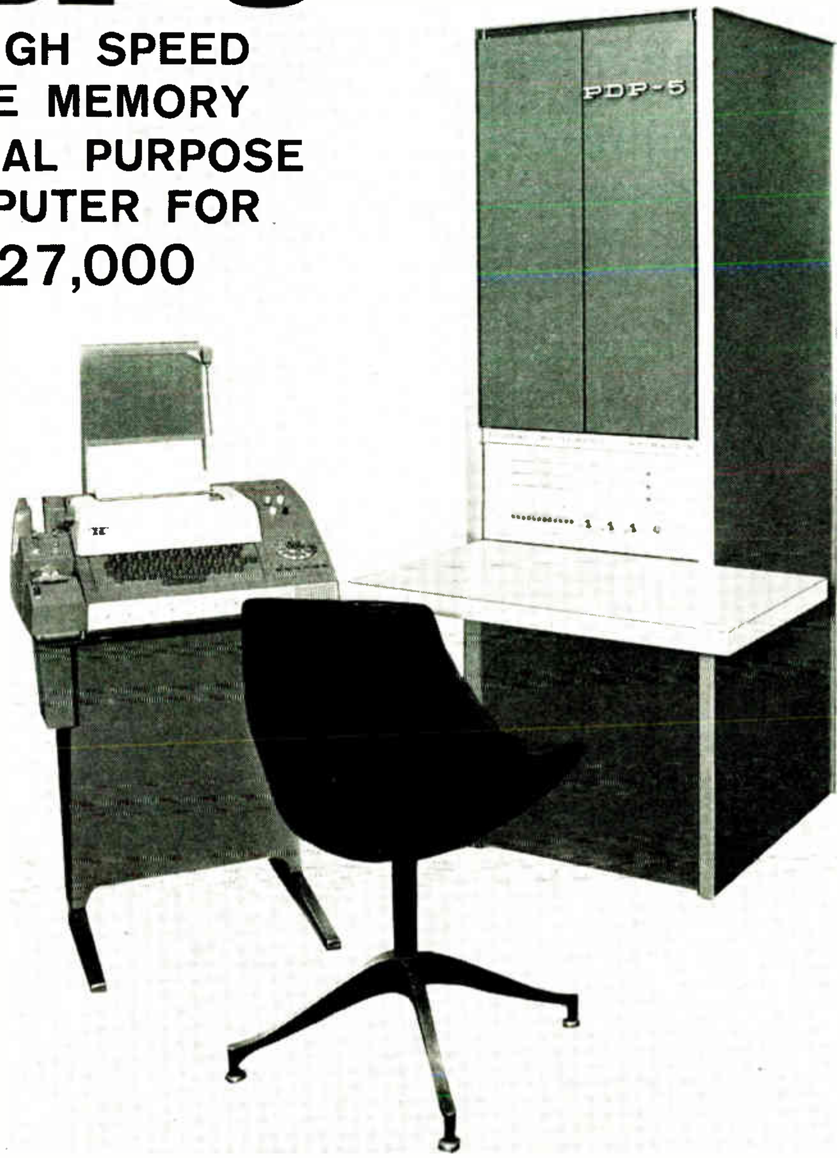
Chairman: J. R. Pierce, Bell Telephone Labs., Murray Hill, N.J.

41.1 West Ford System Concept, W. E. Morrow, Jr., *Lincoln Lab., Massachusetts Institute of Technology, Lexington*
The use of orbiting dipoles as a microwave scattering medium for reliable long range radio communication will be discussed. Continuous global communication can be achieved with only two rings of dipoles, one polar and one equatorial, orbiting the earth at altitudes of about five or six thousand kilometers. A continuous ring of orbiting dipoles can be formed about the earth from a single satellite dipole dispenser within one or two months if the dipoles are dispensed from a satellite with a distribution of velocities up to a few meters per second. Scattering cross sections at 8000 Mc/s of 3000 square meters per kilogram of payload can be achieved with dipoles having diameters of the order of 3×10^{-3} centimeters. Efficient digital modulation-demodulation techniques for this medium have been developed which do not require a detailed knowledge of the received signal phase. These techniques are required because of the rapid fluctuations in the propagation characteristics of signals scattered from a dipole belt.

41.2 The West Ford Dipole Dispenser, D. C. MacLellan, M. C. Crocker, *Lincoln Lab., Massachusetts Institute of Technology, Lexington*
The problem of establishing an orbiting dipole belt of particular dimensions imposes constraints on the method used to dispense the dipoles. The solution chosen is that of binding the dipoles together in an evaporating matrix material and allowing incident solar energy to release them from the surface of a rotating cylinder. This technique of dispensing dipoles, the method of processing fine wire to produce properly packaged dipoles, and the procedure for impregnating the dipole packages with the evaporating binder material are described. The problem of protecting the dipole packages from breakup due to launch vibration is discussed, together with the design of the mechanical ejection mechanism which released the packages from the parent vehicle in orbit. The actual performance of the dispenser device in orbit and the results of ground tests of the dispensing technique before and after launch are discussed.

41.3 The Formation, Dispersion, and Lifetime of the West Ford Dipole Belt, I. I. Shapiro, H. M. Jones, C. W. Perkins, *Lincoln Lab., Massachusetts Institute of Technology, Lexington*
A detailed theoretical model that included all known perturbing forces was constructed to predict the orbital behavior of the individual West Ford dipoles, from launch to final reentry through the atmosphere. Radar and optical measurements confirm that the belt formed as predicted, and later radar measurements indicate that its cross section is increasing in accord with calculations. The changes in the mean orbit of the belt, determined from radar data, are also in agreement with theory to within the experimental error. These results, therefore, lend credence to the prediction that most individual dipoles will have an orbital lifetime of less than three years, and none will have a lifetime exceeding five years.

41.4 West Ford Terminal Equipment, B. E. Nichols, David Karp, R. V. Locke, Jr., H. H. Hoover, *Lincoln Lab., Massachusetts Institute of Technology, Lexington*


PDP-5

The ground stations used in the West Ford experiment, one in California and one in Massachusetts, can transmit and receive CW X-band communications signals simultaneously. In addition, each station can be changed momentarily to a powerful radar capable of tracking and measuring the belt and other satellites. The unique high performance of these stations also permits many other scientific experiments. The latest available radio and radar techniques and components are used at these stations and include high power X-band klystrons, masers, parametric amplifiers, and new design waveguide components. The operation of the stations and the microwave components and techniques will be described in this paper.

41.5 Measured Physical Characteristics of the West Ford Belt, F. E. Heart, David Karp, Ferenc Nagy, Jr., W. R. Crowther, W. B. Smith, *Lincoln Lab., Massachusetts Institute of Technology, Lexington*

Over the life of the West Ford belt, an experimental measurements program has been in operation. The goals of this measurements program include orbital characteristics, geometric characteristics, and electrical characteristics. Several distinct experimental approaches to such measurements have been employed, including the use of monostatic radar experiments are bistatic propagation experiments. Experiment design has managed to cope with the necessity for obtaining precision measurements on a very diffuse, small cross section target. Results have been obtained which permit characterization of the present belt and comparison with predictions about belt behavior in general.

41.6 Experimental Belt as a Communications Medium, I. L. Lebow, P. R. Drouilhet, Jr., W. B. Smith, Ferenc Nagy, Jr., *Lincoln Lab., Massachusetts Institute of Technology, Lexington*

Communication using the dipole belt has been studied in two types of experiments. Both involved transmissions from Camp Parks, California to Westford, Mass. First, the scattering function of the belt was measured from the time of the initial dispensing until closure. No anomalous behavior has been observed. The multipath spread is about 100μs and is due to beam limitations; the doppler spread ıa increased from about 500 c/s to 2 kc/s four months after launch. Second, digital information has been transmitted at rates varying from 20000 bits/sec initially to approximately 50 bits/sec four months after launch. The basic communications technique is binary frequency-shift-keying with frequency hopping to counteract intersymbol interference. Diversity of various kinds has been employed, and results are in general agreement with theory.

SESSION 42

Wednesday 2:30–5 P.M.
New York Hilton, Mercury Ballroom

Instrumentation VI

Chairman: F. L. Hermach, National Bureau of Standards, Washington, D.C.

42.1 The Compensated Current Comparator: A New Reference Standard for Current Transformer Calibrations in Industry, N. L. Kusters, W. J. M. Moore, *National Research Council of Canada, Ottawa*

The compensated current comparator combines in one device the high ratio accuracy of the three-winding ratio transformer or current comparator with the energy transfer properties of a normal current transformer. Its ratio error is very small and so independent of the energy transfer function that it can be operated at very high burden. Even negative burdens may be imposed and, when operated in this mode, the device fulfills the functions of a high current primary supply transformer. As such, it is highly suited to *in situ* calibrations in industry. Construction details of a multiratio compensated current comparator, covering all normally encountered ratios from 5/5 to 1200/5, is given. Its ratio accuracy, for burdens up to 250 volt-amperes, is better than 1 part in 10^5. A test set, for use in calibrating current transformers up to errors of 1 per cent and 100 minutes, is also described. The set employs three conductance and three capacitance decades, with a three-position range switch, and is direct reading.

42.2 Calibration of a Kelvin-Varley Voltage Divider, A. F. Dunn, *National Research Council of Canada, Ottawa*

Earlier descriptions of methods for providing a set of corrections to be applied to a Kelvin-Varley voltage divider unfortunately do not correct a multiple dial setting to agree with the errors observed in practice. In addition, the method of applying the corrections is laborious and time-consuming. The proposed method leads to corrections that are easy to apply and agree, to a high degree of consistency, with the results observed in use. The theoretical reason for this approach is presented, as well as methods of calibrating a divider to provide the appropriate set of tabular corrections.

42.3 Ratiometry—A New, Simplified Method of Measurement, Calibration, and Certification, Loeb Julie, *Julie Research Labs., Inc., New York, N.Y.*

Ratiometry is an extremely accurate, generalized system of measurement suitable for use at all levels of certification and calibration. It parallels classical methods, but offers higher accuracies and the advantages of greater speed and simplicity. A two-point reference to NBS fundamental units, at 1 ohm and 1 volt allows ratiometric extrapolation and interpolation of five- to seven-digit measurements to more than 100 megohms and higher than 1000 volts. Each ratiometric method is complemented by one or more independent backup methods that permit user validation of accuracy and reliability. Minimal use of NBS reference points eliminates many "transporation" errors and greatly reduces down-time for NBS certifications.

42.4 The Application of Electronics in Instruments for Standards and Calibration, Peter Richman, *Rotek Instrument Corp., Watertown, Mass.*

As the level of measurement precision and accuracy required in the field reaches and surpasses that which was recently unavailable even in the standards laboratory, the unique properties of electronic instrument standards, when properly conceived, can provide rugged, reliable, secondary standards and even primary standard performance.

Consistent component selection methods are detailed, and design and performance described for typical subsystems including feedback amplifiers, power amplifiers, power ratio transformers, and precision zener diodes. Several instrument design examples, including alternative block diagram approaches, are given, primarily from the field of ac standards and measurements. Applications to related problem areas are indicated.

42.5 Frequency Response Plotter, W. I. L. Wu, C. D. Lindsay, *Singer Metrics Div., Bridgeport, Conn.*

This paper describes a novel method for the inspection of the fine-grain characteristics of crystal and similar sharply resonant devices. The instrument gives a continuous display of response vesus frequency. The receiver amplifier uses synchronous selective tuning with variable bandwidth, giving increased dynamic range and freedom from spurious frequencies and noise. Synthesis of the test frequency and ability to sweep this frequency with a high degree of stability, as well as capabilities, limitations and general applications for design and production, are discussed.

SESSION 43

Wednesday 2:30–5 P.M.
New York Hilton, Sutton Ballroom N.

Power Generation

Chairman: G. H. McDaniel, AEP Service Corp., New York, N.Y.

43.1 Adaptive Digital River Flow Predictor for Power Dispatch, E. B. Dahlin, *Pottstown, Pa.*; E. Kindingstad, *Minneapolis-Honeywell Regulator Co., Pottstown, Pa.*

Solution to the problem of transient river flow is of particular interest in conjunction with optimum load dispatching of hydraulic power plants whose storage ponds are relatively small compared to the plant and river discharge. The capacity is then small enough so that the water already in the river system, rather than expected future rainfall or melting snow, is of prime concern. The variation in plant efficiency with pond level is another factor of significance for exact selection of most economic operating strategy. Hydroelectric power companies usually employ hydrographers who make predictions on future river flow based on measured river stage at selected points upstream and, for long-term forecast purposes, utilize actual rainfall in the river basin and local weather forecasts. The accuracy of the river prediction is an important factor in the overall plant efficiency, since the generating strategy is based on its outcome.

Accurate prediction of transient flow in rivers is an immensely complicated task because of the large number of parameters that enters into the problem. In order to become practically manageable, a mathematical model describing the river flow will have to be based on certain simplifying assumptions. The errors resulting from these assumptions must be evaluated with regard to their influence upon the optimizing economics of the power system operation. If a digital computer is used to solve the river prediction problem, it is possible to perform a large amount of detailed calculations in a short time, thus providing the solution at regular intervals over the day.

43.2 A Method for Planning Annual Economic Operation of a Thermal Power System, K. Hara, M. Kimura, N. Honda, *Tohoku University, Sendai, Japan*

Economic load dispatching should be made on the basis of a reasonable schedule for periodic overhaul outages and reserve capacities in the long-range operation of a system. Consequently, the reasonable schedules for generating equipment and economic load dispatching should not be considered separately, but should be treated as parts of an integrated scheduling operation. In this paper a thermal power system is studied, and both the operation cost of generating units and the quality of system service are considered. By this method usual economic load dispatching is extended and an integrated long-range operation scheduling that contains the reasonable schedule for generating equipment is developed.

43.3 Yankee Reactor Instrumentation, Operation and Maintenance History, D. A. Hansen, Jr., *Yankee Atomic Electric Co., Rowe, Mass.*

The instrumentation and controls required for the operation of the Yankee reactor and primary plant are described, and the operation and maintenance history of this instrumentation is followed from initial installation and testing of the equipment through the operation

of the first and second reactor cores. Descriptions and histories are given for the primary plant pressure, temperature, level, and flow channels; the nuclear instrumentation source, intermediate, and power range channels; and the in-core flux wire and thermocouple channels. The educational backgrounds and training experience of the personnel required to perform routine and preventive maintenance on Yankee instrumentation are outlined.

43.4 First Year of Operation of the Electrical Service in the BR3 Nuclear Power Plant, L. Maesen, *Centre d'etude de l'Energie Nucleaire, Mol, Belgium*

The reactor BR3, used in the first Belgian nuclear power station, is also the first reactor of the pressurized-water type to be started in western Europe. Since December 15, 1962, the plant has been operating normally. The utilization factor during 1963 averaged more than 70 per cent. The preparatory period for the start-up and the first operating year of the power plant have allowed the operating staff to assemble much information concerning the principal aspects of the different cycles and, among other things, about the electrical equipment.

After enumerating the essential differences between the conception and the realization of the electric circuits in a nuclear power station and in a conventional thermal power plant, the paper describes the remarks and observations of the operating staff about the equipment as supplied and also the remedies applied by them for solving various problems.

43.5 Operating and Maintenance Experience of Electrical and Instrument Components at the Saxton Nuclear Power Plant, D. E. Hetrick, *Saxton Nuclear Experimental Corp., Saxton, Pa.*

During the start-up, checkout, and initial phases of operation it was necessary to debug, suppress noise, and establish optimum operating conditions in electric and instrumentation systems used in the Saxton Nuclear Plant. Since that time the problems have been of a minor nature. The performance of the electrical and instrument components has been satisfactory from both operation and maintenance standpoints.

SESSION 44

Wednesday 2:30–5 P.M.
New York Hilton, Sutton Ballroom S.

Circuit Theory I

Chairman: R. J. Schwarz, Columbia University, New York, N.Y.

44.1 Cut-Set Matrices and the Cederbaum Algorithm, F. T. Boesch, *Bell Telephone Labs., Whippany, N.J.*

This paper presents a review of the relation between a fundamental cut-set matrix and the node-pair admittance matrix. The main contribution lies in a simplified derivation and utilization of the Cederbaum algorithm, which relates the realization of cut-set matrices to the synthesis of resistor networks. The Cederbaum algorithm is based on two theorems which are entirely algebraic in nature, and they were originally derived from the algebraic properties of totally unimodular matrices. A considerable simplification is provided by a network derivation of these two theorems. The algorithm itself is also simplified by network concepts.

44.2 A Topological Test for the Realizability of a Class of Resistive n-ports, K. K. Nambiar, L. N. Kanal, *Philco Corp., Blue Bell, Pa.*

A simple topological procedure, requiring no computation is presented for testing the realizability of an open-circuit resistance matrix satisfying the relation

$$|r_{ij}| = r_{ii} \qquad i = 1, 2, \ldots n$$

for some value of the index j. The method described in this paper is applicable to matrices of arbitrary order and an example is presented using a 20 × 20 matrix. It is also shown that three matrices considered by Cederbaum (viz., Foster's matrix, Weinberg's matrix, and Cederbaum's matrix in *IRE Trans. on Circuit Theory*, Sept. 1961, pp. 324–329), which required a considerable amount of computation before their realizability or nonrealizability could be decided by Cederbaum's method, become very simple exercises for the topological method described here.

44.3 An Iterative Approximation Procedure for Automatic Filter Synthesis, B.R. Smith, G. C. Temes, *Northern Electric R & D Labs., Ottawa, Ont., Canada*

The synthesis of m-derived image parameter filters or of Chebyshev passband insertion loss parameter filters, which prescribed frequency-dependent minimum stop-band attenuation, normally involves the use of graphical methods to find the necessary number and location of the attenuation poles. These methods are tedious and inaccurate. This paper describes an iterative approximation process, somewhat similar to Remez' second method, for the synthesis of low-pass and bandpass filters. The process is very fast and its programmed version fits into a 40 000-position computer memory. A brief analysis of the optimality and convergence of the procedure is included. Finally the actual computer programs are described and some examples are given.

44.4 A Solution to the Approximation and Realization Problems for Crystal Ladder Filters, J. D. Schoeffler, *Case Institute of Technology, Cleveland, Ohio*

The standard elliptic or equal-ripple filter functions are not realizable in the form of a ladder network whose elements are piezoelectric resonators. In this paper, a solution to the approximation problem is derived which gives a transmission function with equal ripple in the passband, together with attenuation poles at real finite frequencies and which is realizable by a ladder network of resonators. The accuracy problem associated with realization of bandpass filters on a digital computer are circumvented by carrying out the realization with a transformed frequency variable, resulting in a design time of a few seconds. Experimental and numerical results presented indicate that reasonable resonator parameters result and that the tolerance requirements are not excessive.

44.5 The Linear Phase Approximation Problem, J. O. Scanlan, *University of Leeds, England*

An indication is given of the effect of a nonlinear phase characteristic in causing distortion in a transmission system. A comparison is made between the various known systems that produce an approximation to a linear phase response. The system functions concerned are normalized, for purposes of comparison, in such a way that the bandwidth of the amplitude response, as well as the degree of approximation of constant group delay, for each system can be compared. It is found that a system described by Mullick (*IRE Trans. on Circuit Theory*, Sept. 1961, pp. 302–305) is superior in regard to both amplitude-response bandwidth and degree of approximation of constant group delay.

SESSION 45

Wednesday 2:30–5 P.M.
New York Hilton, Regent Room

Radio Communication Systems

Chairman: I. T. Corbell, Lynchburg, Va.

45.1 Automatic Group Delay Time Equalization in Microwave Links, T. Sarkany, *Telecommunication Research Institute, Budapest, Hungary*

A new system is described according to which an electronically variable equalizer is set automatically during operation, resulting in minimum intermodulation noise. Variation of group delay affects the phase modulation of a subcarrier located above the baseband, and the new system is based on providing an error signal for the equalizer from demodulation of this subcarrier.

In case of television signal transmission, the audio subcarrier normally used may be utilized for this purpose, and control voltage is provided by the audio output signal resulting from the video line-synchronizing signal. Thus automatic group-delay time equalization provides also minimum picture-to-sound crosstalk.

In the case of multichannel transmission, the pilot carrier also can be employed as the subcarrier.

45.2 A Dual-Channel Communication System by Employing a Degenerate Parametric Amplifier, Syuiti Hayasi, Torao Nagai, Junzo Murakami, *Tokyo Shibaura Electric Co., Ltd., Kawasaki, Japan*

Use of a parametric amplifier operated in a closely degenerate condition is expressed for receiving two waves which are modulated in opposite spectrums by a signal. These two frequencies correspond to a so-called signal and idler channel in a parametric amplifier, and thus can be combined there when a coherent pump source is applied in the proper phase. A 3-dB improvement of noise figure is feasible compared to an ordinary degenerate parametric amplifier and an even better noise figure is calculated compared to a parametric amplifier with the best designed pump frequency. This improvement becomes more evident when a low-noise antenna is employed.

45.3 The Design of the Conical Log-Spiral Antennas, J. D. Dyson, *University of Illinois, Urbana*

Although the balanced two-arm conical logarithmic spiral antenna has found wide application as a broad-beam, extremely wide-band, circularly polarized antenna, only very broad guide lines on the design of these structures have been published. A recent systematic investigation has been undertaken to study the near fields, the radiated far fields, and the input impedance of these antennas. This information has been analyzed to provide some general design data in the form of curves and nomographs.

45.4 High-Power CW Microwave Amplifier Design, L. L. Fisher, *Energy Systems, Inc., Palo Alto, Calif.*

This paper will discuss design considerations for such systems. These will include the prime power source, military and commercial component specifications, controls, safety considerations for both personnel and equipment, high-voltage supplies, auxiliary power supplies, klystron power amplifier tubes, RF components, cooling systems and test equipment. Examples are shown of 5- to 75-kW RF output power amplifier designs ranging from 400 to 5200 Mc/s.

SESSION 46

Wednesday 2:30–5 P.M.
New York Coliseum, Room A

Packaging and Interconnections

Chairman: Maurice Apstein, U.S. Army Material Command, Washington, D.C.

IEEE BOOTH 3701-5

COMMUNICATIONS RECEIVER FOR SSB

300 kc to 30 mc
with xtal
stability

$995

Eddystone Model 830/2

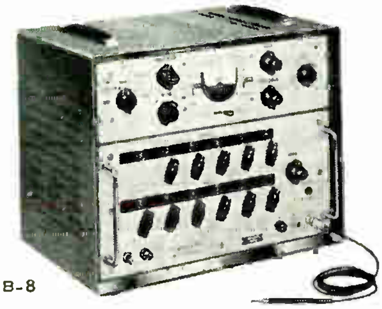
- **xtal circuit achieves 1 kc/ hr stability.**
- **Variable 1st I.F. accepts frequencies ±100 kc about xtal frequency.**
- **±100 kc bandspread with 1 kc resolution.**
- **2nd I.F. can be xtal controlled for ultimate stability.**
- **Sensitivity better than 3uv for 15db S/N**
- **Separate AM/SSB detectors with upper/lower sideband switch selected.**
- **xtal calibrator gives 100 kc check points.**

Write
for detailed
catalog sheet.

MARCONI
INSTRUMENTS

DIVISION OF ENGLISH ELECTRIC CORPORATION
111 CEDAR LANE • ENGLEWOOD, NEW JERSEY
Main Plant: St. Albans, England

Gertsch CRB bridges measure both in-phase and quadrature voltage ratios —with high accuracy



MODEL CRB-8

Complex Ratio Bridges are ideal for precision voltage and phase comparisons between signal and reference vectors. Instruments are designed for testing transformers, tach-generators, rate gyros, all types of transducers, AC amplifiers, AC networks, and AC systems. All CRB instruments feature self-contained, phase-sensitive null indicators.

Model CRB-8 — a new broad-band bridge providing continuous frequency coverage from 350-5100 cps—with no plug-ins. Instrument measures angles as small as .001°, and is accurate to .001% (10ppm). 6-digit readouts are provided for both in-phase and quadrature ratios. Loading on the device under test is virtually eliminated by extremely high signal input impedance — better than 20,000 megohms at null.

A wide variety of CRB instruments is available in both cabinet and rack mounted designs. Compact all-transistorized units feature accuracies to .005%. A militarized model is certified per MIL-T-21200 . . . meets stringent environmental requirements. Gertsch also manufactures an automatic complex ratio bridge which displays both in-phase and quadrature ratios on 5-place Nixie readouts.

Write for complete literature on the CRB line.

Gertsch

GERTSCH PRODUCTS, INC.

3211 S. La Cienega Blvd., Los Angeles 16, Calif. • UPton 0-2761 • VErmont 9-2201

46.1 Parametric Considerations and Fluid Physics Evaluation for Mechanized Joining of High-Density Electronic Packages, J. D. Keller, *The Martin Co., Orlando, Fla.*

A long-term study of the effects of fluid physics on mechanized soldering techniques resulted in the development of a new set of processing parameters, and a novel soldering system that handles highly sensitive components to rigid missile and space systems specifications. The study has determined that fluid physics is critical in mechanized soldering techniques involving heat-sensitive components, thin-film-covered substrates, integrated circuits on printed conductors and micromodules. To reach the new parameters design researchers investigated the effects of (1) mechanically moving hot fluids on solid surfaces, (2) the dihedral angles of wetting, (3) surface energies, (4) bonding mechanisms, and (5) solidification technology of binary and ternary metallic systems. Slow motion pictures were used during the investigation for dynamic analysis and comparison of hand- vs. machine-made interconnections.

46.2 A New System Providing Reproducibility and High Reliability in Soldered and Insulated Wire Junctions, H. P. Sherlock, *Raychem Corp., Redwood City, Calif.*

A concept of creating insulated soldered joints in a single, controlled operation has recently been developed. This involves a device consisting of a fluxed solder preform inside a heat-shrinkable, sealing-type insulating sleeve. In a single, controlled heating operation, the sleeve shrinks, the sealing rings and solder flow, forming the encapsulated junctions. The result is a soldered, insulated, and encapsulated joint which can be reproduced with a consistancy and reliability previously impossible with conventional soldering techniques. The concept, the manufacturing technique involved, and a comparison of the electrical and mechanical characteristics with other types of joints are described.

46.3 A New Interconnection Technique for Integrated Circuits, Dimitry Grabbe, *Photocircuits Corp., Glen Cove, N.Y.*

A new technique for interconnecting integrated circuits with printed wiring allows the use of conventional resistance welding equipment and does not require bending the leads of modules in flat or wafer packages. The technique consists of inserting carbon steel pins into plated-through holes and forming a continuous metal alloy between the pin and the plated-through hole by a diffusion process. Integrated circuits can be welded directly to the pins, which can be set at any desired height above the surface of the board. The technique allows the removal and replacement of defective modules without damage to the printed circuit board.

46.4 Techniques in the Fabrication of Welded and Encapsulated High Density Electronic Packaging (Part II), K. L. Uglione, Jr., S. Maszy, A. R. Bell, Jr., R. Spanholtz, *The Martin Co., Orlando, Fla.*

This paper, the second part of a discussion begun at the 1963 IEEE Convention by the first two authors, covers advances made in the last year in the technique of fabrication of welded and encapsulated high-density electronic packaging. Advances in the state of the art in resistance welding are discussed as well as design modifications in welded module fabrication. Reliability factors in resistance welding are also covered.

New techniques for high production rate manufacture of molded modules are outlined. Special emphasis is given to the unique uses of epoxy transfer molding powders for this purpose.

46.5 Design and Application Considerations of Multilayer Printed Wiring, W. Rigling, E. C. Williams, *The Martin Co., Orlando, Fla.*

The advent of modularized, miniaturized packaging has emphasized the need for simplified interconnection of the multitude of terminations involved. The most recent development of merit is multilayer printed wiring. There are presently available several systems which adequately meet varied electrical, structural, and environmental requirements. These systems vary widely in attributes and shortcomings. A detailed analysis of each system is made based on the base materials available, bonding techniques, conductor materials, and interlayer and external connection techniques. The relative merits of each system under typical military environments are presented in table form, providing designers with a guide for the selection of the optimum system based on end item requirements. The text also includes a discussion of multilayer printed wiring reliability, design flexibility, producibility, serviceability, and special construction variations.

SESSION 47

Wednesday 2:30–5 P.M.
New York Coliseum, Room B

Audio and Acoustics

Chairman: Frank A. Comerci, CBS Labs., Stamford, Conn.

47.1 Application of the Acoustic Waveguide in the Design and Testing of Compression Drivers, D. G. Arnold, *Jensen Mfg. Co., Chicago Ill.;* J. V. White, *Northwestern University, Evanston, Ill.*

The acoustic waveguide, although nearly unknown in the audio industry, provides a nearly ideal environment for testing compression drivers. This paper describes the advantages of a waveguide over the conventional anechoic chamber and reverberant room for most tests, and demonstrates its usefulness as a tool for the design engineer. Analogies between the acoustic waveguide and the conventional electromagnetic waveguide are demonstrated, and measurements bear out the validity of the analogs. Constructional considerations are discussed, and it is shown that inexpensive vinyl tubing will provide a waveguide suitable for measurements of several characteristics with better accuracy then conventional methods now permit.

47.2 The Squad Radio Exponential Horn and Driver, D. S. Morris, *U.S. Army Electronic R & D Labs., Ft. Monmouth, N.J.;* D. E. Brinkerhoff, *General Motors Corp., Kokomo, Ind.*

The effectiveness of the helmet-mounted squad radio in a battlefield environment is largely determined by the capability of the receiver to deliver adequate sound power to the ear of the user without impairing his ability to hear sounds around him. During the development of the squad radio receiver, emphasis was placed on finding a solution to this problem. High audio power could not be used to provide necessary sound power levels due to the size, weight, and battery drain limitations of the receiver. Therefore, effort was placed in optimizing the efficiency of conversion of electrical audio power to acoustical power. The result of this effort is a low-cost, compact, lightweight exponential horn–driver unit that will provide enough sound power to the user's ear to overcome anticipated battlefield noise. This paper is a discussion of the detailed requirements of the horn–driver unit, the methods used in its development, and the performance of the final units.

47.3 The Electret Microphone, G. M. Sessler, J. E. West, *Bell Telephone Labs., Murray Hill, N.J.*

A new kind of condenser microphone with a solid dielectric foil electret between the electrodes is described. The use of the electret eliminates the need for an external dc bias. The high capacitance of the microphone (62 pF/cm²) reduces the requirements of the amplifying system. Sensitivities of experimental units are between −50 and −60 dBV for a sound pressure level of 1 dyn/cm². The free-field frequency response is within ±3 dB from 50 to 15 000 c/s. During the past 15 months, the stability of electret microphones has been measured. Over this period, the sensitivity has changed less than ±1.5 dB.

47.4 Proposed Articulation Rating for Loudspeakers, H. E. Allen, *Jensen Mfg. Co., Chicago, Ill.*

The loudness rating for loudspeakers proposed by Hopkins and Stryker and adapted for commercial use by the Electronic Industry Association is based on a compromise between speech and music spectrum data and hearing under quiet conditions. Loudspeakers for speech only are usually used in noisy locations and the loudest loudspeaker does not necessarily give the best system performance. The proposed rating, based on published articulation data will allow a more significant figure to be assigned to a loudspeaker for comparison to other loudspeakers when other system conditions are the same. Demonstrations show the effectiveness of the proposal.

47.5 On the Information Rate of Pitch Signals, H. L. Shaffer, Ladislav Dolansky, *Northeastern University, Boston, Mass.*

Recent interest in the problems of talker recognition and speech naturalness enhance the need for a more satisfactory transmission of the pitch component of processed-speech signals. In this paper the problem of the information rate necessary for the transmission of the pitch signal is studied. Considering the successive pitch-period intervals of connected voiced portions of speech as a random variable with an associated probability distribution, the conditional entropies of random variable sequences of various lengths are obtained, using Fano's expressions for the conditional entropies. For the experimental evaluation of these entropies, 26 speakers pronouncing 576 voiced portions of speech, corresponding to 12 500 individual pitch periods, are used. The experimental results will be presented and discussed.

SESSION 48

Wednesday 2:30–5 P.M.
New York Coliseum, Room C

Systems Science

Chairman: A. R. Teasdale, The Martin Co., Baltimore, Md.

48.1 The Use of Adaptive Constrained Descent in System Design, Tadao Murata, *University of Illinois, Urbana*

This paper describes the application of an iterative method, the adaptive constrained descent, to system design where system parameters are constrained by both upper and lower limits. The method used here is essentially a direct search method, which, unlike many classical methods, does not depend on the use of derivatives nor on power series approximations. The technique always insures convergence and initial guesses can be arbitrarily chosen in some cases. This fact makes it possible to design networks directly from given characteristics using a high-speed digital computer. The method is straightforward and needs only performance index computation and comparison of each trial solution. Details on programming methods are presented, along with flow charts.

48.2 Evaluation of System Performance, Frank Huddleston, *The Martin Co., Baltimore, Md.*

The performance of a communications network was calculated by means of a computer simulation model. Trade-off studies, performed to show the effect of various parameter variations, were combined with the basic system performance evaluation in an over-all flow chart. From this chart, the effect of any parameter can be observed in terms of an artificial systems parameter, and the effect of system performance as a function of the systems parameter can be predicted. The chart shows the interrelationship between parameters, and the relative cost, in dollars, of obtaining system improvement by various methods.

48.3 The Tracking of a Nonstationary Maximum with Analog Devices, A. Lavi, *Carnegie Institute of Technology, Pittsburgh, Pa.;* E. J. Mastascusa, *Magnetics Inc., Butler, Pa.*
This paper gives a new method for the analysis and synthesis of a controller to track a time-varying optimum operating point. In particular, the maximization of the average of a quadratic performance index of a general system is considered, where the location of the maximum and the shape of the performance index function are time varying. It is shown that optimization can be reduced to a mean-weighted square error minimization problem. The controller consists of linear integrators in conjunction with linear time invariant filters and instantaneous multipliers. Thus an analog computer can be easily adapted to control the system.

48.4 State Models of Systems of Multiterminal Linear Components, H. E. Koenig, Yilmaz Tokad, *Michigan State College, East Lansing*
This paper endeavors to delineate a systems concept as related specifically to physical systems, with inferences to transportation, economic, social, and other systems. It is shown that a well-defined and properly executed discipline of analysis based on this general systems concept can have significant implications to both education and industry.

SESSION 49

Thursday 10 A.M.–12:30 P.M.
New York Hilton, Trianon Ballroom

Transmission

Chairman: H. R. Stewart, New England Electric System, Boston, Mass.

49.1 Dynamic Programming—Transmission Line Design, G. W. Stagg, M. Watson, *AEP Service Corp., New York, N.Y.*
The theory of dynamic programming is applied to electric transmission-line design, a multistage decision problem in which tower types, heights and locations must be selected to obtain an optimum design along a given right of way. The application of this technique has effected a substantial saving in material costs, in some cases as much as 10 per cent. The constraints of ground clearance, fixed positions for angle towers, and tower loading capabilites are adhered to in the resulting design. The computer program, which performs the analysis and design calculations, also provides an economical means of evaluating several alternative routes for a proposed transmission line.

49.2 Corona Phenomena from Water Drops on Smooth Conductors Under High Direct Voltage, M. Akazaki, *Kyushu University, Fukuoka-Shi, Japan*
Because of the very high voltage levels now being used on power systems in North America and elsewhere it has become necessary to determine more exactly the corona characteristics of conductors under high voltage stress. Both radio influence (RI) and power loss created by corona discharges on conductors are very important factors in the planning and design of new transmission lines. Although a general assessment of the characteristics of these two corona phenomena for particular conductors is obtained by using test lines, detailed laboratory studies are also necessary for an understanding of the mechanisms involved. This is particularly true when attempting to analyze corona characteristics during rainfall. Here, complex effects are caused by raindrops falling in close proximity to the conductor, by splashing of droplets when they hit the surface, and by drops hanging from the conductor. In addition to fundamental laboratory investigations, there is some experimental evidence that RI from a dc test line of positive polarity is less during a rainfall than it is in dry weather, and also that it gradually increases to the normal value after the rainfall ends. The power loss, however, is greater during rainfall than in dry weather. By way of contrast, it appears to be widely accepted that for ac lines both power loss and RI are larger during rainfall than the normal fair-weather values. In this paper the author presents laboratory studies that further clarify our understanding of corona phenomena from conductors during rain.

49.3 A Design Method of Damping Circuits for DC Line Overvoltage, Takahide Machida, *Central Research Institute of Electric Power Industry, Tokyo, Japan*
Overvoltages occurring in dc transmission systems are generally caused by backfire and commutating failure in the converter. In addition, there is an inherent internal overvoltage in the dc line. However, these overvoltages can be prevented by the use of damping devices installed in the dc line. The design for the circuits and elements of the damping devices needs to take into account (a) the selection of values in such a way that the multiple and attenuating time constants of the line overvoltage will be as small as possible, (b) the effects of the ripple components in the direct current, and (c) the economic effects of the damping condensers.

49.4 Parallel Operation of AC and DC Power Transmission, H. A. Peterson, D. K. Reitan, *University of Wisconsin, Milwaukee;* A. G. Phadke, *Allis-Chalmers Mfg. Co., Milwaukee, Wis.*
Operation of a high-voltage large-capacity (500-kV, 1000-MVA) ac transmission line in parallel with a high-voltage large-capacity (±375 kV, 1000-MW) dc line is studied from the point of view of power system operation. The ac and dc lines are assumed to connect two power systems simulated by equivalent synchronous machines. The phenomena considered include steady-state load flow, steady-state effects of three-phase faults, and transient stability of the composite system.

The study was begun by building models of high voltage ac/dc converters that could be used with a conventional ac network calculator. Load-flow studies using the model were quite straightforward. A digital computer program was written to solve the load-flow problem of the composite system. The results obtained using this program were found to be in good agreement with the model load-flow studies.

49.5 A Short-Circuit Testing Laboratory in an Educational Institution, P. O. Langguth, *UNESCO Technical Assistance Mission, Indian Institute of Technology, Bombay*
The establishment of a short-circuit testing laboratory in an educational institution is quite an innovation, particularly in an area of the world where the conventional high-power switchgear testing laboratory is nonexistent. Affording postgraduate training and research in arc phenomena and the scientific development of arc extinction devices. this excellent facility will provide the country with switchgear engineers and contribute to the design and local manufacture of modern switchgear. Although minimal in rating, the design of the laboratory—particularly the generator, controls, and instrumentation—presented a number of unique problems, since it was most desirable to minimize loss of short-circuit power in the test circuit.

49.6 Sakuma Frequency-Converter Project, I. Takei, *Electric Power Development Co., Tokyo, Japan*
Power-system frequency in Japan has developed on a 50-c/s basis in the northern half, and on a 60-c/s basis in the southern half of the country. Past efforts to standardize the frequency have been unsuccessful, and now both systems have developed so extensively that this has become virtually impossible. To obtain the advantages of interconnection despite this handicap, modern high-voltage dc techniques are used. In a single station, 50-c/s power is converted to dc, and the dc to 60 c/s (or vice versa). This is thus, in effect, a dc transmission system without a line. However, location of both rectifiers and inverters in the same station permits some simplification, as compared to a conventional dc tie.

SESSION 50

Thursday 10 A.M.–12:30 P.M.
New York Hilton, Mercury Ballroom

Radio Propagation

Chairman: Richard C. Kirby, National Bureau of Standards, Boulder, Colo.

50.1 The Effect of Multipath Interference on the Intelligibility of Speech Transmitted Over an FM System Employing Time Division Multiplexing, C. W. Stuckey, E. W. Wood, *Georgia Institute of Technology, Atlanta*
Multipath interference occurs in wide-band FM systems when two or more signals of approximately equal strength arrive from the same transmitter over paths which differ greatly in length. In contrast, the specifications of FM systems which employ time-division multiplexing suggest that such systems may be subject to multipath interference when the path lengths differ by less than one mile. Since equal power levels are more probable at reduced path length differences, the incidence of multipath interference might be expected to be greater for FM systems which use TDM.

This paper reports the results of two path interference tests on a typical FM system which uses TDM. Interference was found to be caused primarily by (1) limiter noise due to absence of the carrier, (2) noise produced by amplitude modulation due to lack of effective limiting action at low signal levels, (3) multiplexer random gating, and (4) phase modulation of the direct signal by the delayed signal. The predicted intelligibility of speech transmitted over this system is expressed as a function of the delay time (path length difference), relative power, absolute power, relative phase angle, and their interactions. Predicted intelligibility is based on system audio output S/N ratio measurements.

50.2 Air to Undersea Communication with Magnetic Dipoles, S. H. Durrani, *General Electric Co., Lynchburg, Va.*
Simplified expressions are derived for electromagnetic fields caused in the two media by vertical and horizontal magnetic dipoles located in air above the sea. Subject to mild restrictions on distance from the interface, the results hold in the "quasi-near range" extending from a few meters to several kilometers, depending on frequency.

Electric and magnetic dipoles are compared for maximum induced field strength in the sea; the loop antenna is found to be superior,

provided it has enough turns. An expression is derived for the range over which satisfactory communication is possible under specified conditions.

50.3 Expected Radio Noise Levels in the Upper Atmosphere from 100 c/s to 100 Gc/s, E. J. Oelbermann, Jr., *HRB-Singer, Inc., State College, Pa.*
It is concluded that radio noise in and above the ionosphere is due almost entirely to terrestrial noise, which penetrates the lower ionosphere at frequencies below 1 Mc/s. Cosmic noise below this frequency is absorbed in the plasma above the most highly ionized region at heights of 2000 km or more. Hence the frequency dependence and intensity of noise in the upper atmosphere is closely related to that observed on the ground. A number of experimental sources are compared to show the probable frequency variation of noise intensity. These include satellite and rocket measurements obtained by ALOUETTE, LOFTI-I, Penn State, and the University of Michigan.

50.4 Some Effects of Atmospheric Turbulence on Optical Heterodyne Communications, S. Gardner, *TRG, Inc., Melville, N.Y.*
The loss in received signal power produced by atmospheric turbulence is obtained for an optical heterodyne communication system. Phase fluctuations in the plane of the receiving aperture are assumed to be isotropic, with a joint Gaussian probability density. Effects due to amplitude fluctuations and motion of the turbulence are assumed to be of the second order.

Numerical results are presented for the loss in received signal power as a function of the statistical properties of refractive index, the wavelength, range, and the size of the receiving aperture. Finally, for a fixed optical frequency, curves of aperture size versus range are presented for different values of signal power loss.

50.5 An Approach to Optimum Troposcatter System Design Based Upon New Prediction Techniques for Intermodulation Distortion Due to the Propagation Medium, Howard Prescott, *Radio Engineering Labs., Inc., Bethesda, Md.*
State-of-the-art advances in the prediction of the statistical distribution of intermodulation distortion due to the propagation medium in troposcatter systems have had a major impact on system design.

It is now possible to develop a composite noise distribution that includes all the major noise sources in a troposcatter system. Prior to the development of a prediction technique for the distribution of intermodulation distortion due to the propagation medium, a realistic distribution of composite system noise could not be attempted. It is shown, through illustrative examples and measured data, that the new distribution is more meaningful than previous methods for estimating system performance. Finally, a method is presented whereby several tandem links can be analyzed in terms of the distributions of major noise sources in order to optimize tandem-link performance for specific types of service.

SESSION 51

Thursday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom N.

Recording and Audio Measurement

Chairman: D. E. Brinkerhoff, General Motors Corp., Kokomo, Ind.

51.1 The RCA Victor "Dynagroove" System, H. F. Olson, *Radio Corp. of America Labs., Princeton, N.J.*
The RCA Victor "Dynagroove" system is a planned evolution of improvements in all aspects and elements of sound recording by means of disk records. To achieve this objective the Dynagroove project has employed artistic and scientific skills in the areas of music, electronics, acoustics, psychology, engineering, chemistry, and rheology. This paper describes the system from the artist's conception of the music to the reproduction of the sound as perceived by the listener in the home.

51.2 An X-Field Micro-Gap Head for High-Density Magnetic Recording, Marvin Camras, *IIT Research Institute, Chicago, Ill.*
As the gap in a magnetic recording head is made smaller, a point is reached at which the gap cannot supply adequate bias field for undistorted low-frequency response without erasing the high frequencies. In the X-field head a vertical component of magnetization is superposed on the conventional semicircular pattern at the head gap, to give a field which has more rapid decay at the trailing edge and at the same time has a more uniform intensity through the thickness of the tape coating. A new X-field design overcomes objections to previous models, and can be produced economically.

51.3 A Direct Meter-Readout ϕ-H Tester for Magnetic Tape, A. Baaba, D. F. Eldridge, E. Leman, *Memorex Corp., Santa Clara, Calif.*
A high-sensitivity high-accuracy laboratory ϕ-H tester especially for use with magnetic tape was designed for direct meter readout of the quantities ϕ_r, ϕ_m, and H_c, with a minimum of operator controls and adjustments. The ϕ-H loop may also be observed on an oscilloscope if desired. Sensitivity is sufficient for a single 1/4-inch-wide strip of magnetic tape to give direct readings on the meter. An attenuator provides for reducing sensitivity over a 500-to-1 range. The tester will operate continuously at fields up to 1000 oersteds, with less than 2 percent drift. It can operate for short periods at higher fields up to 1300 oersteds.

51.4 The R-C Amplifier-Type Active Filter: A Design Method for Optimum Stability, W. R. Kundert, *General Radio Co., West Concord, Mass.*
It is recognized that the *R-C* amplifier filter has many advantages over its passive *R-L-C* counterpart for low-audio-frequency narrow-band applications. The major disadvantage to an active filter lies in its sensitivity to component tolerance and drift. The design method presented optimizes transmission stability when the probable "drift" (tolerances, temperature and aging effects, tracking errors) in each circuit parameter is known. Design equations are derived for a group of two-pole networks with external zeros. Some experimental high-Q filters are discussed. Emphasis is placed on a continuously tunable four-pole filter which has attenuation of 80 dB at 2½ times center frequency.

SESSION 52

Thursday 10 A.M.–12:30 P.M.
New York Hilton, Sutton Ballroom S.

Circuit Theory II

Chairman: E. S. Kuh, University of California, Berkeley

52.1 Computer Generation of Equivalent Networks, D. A. Calahan, *University of California, Berkeley*
A complete solution is outlined for the problem of generating networks equivalent to a given network while forcing certain elements to preselected values. The method, based on the work of Schoeffler and Waren, allows equivalent networks to be successively generated, each different from the preceding one by an incremental amount. Thus, it is possible to continually monitor the element values and, if any become negative or diverge from the desired values, to alter the transformation. The results of applying the program to doubly terminated filters and active filters are given. It is shown that it is possible to transform lossy filters from lossless ones by successive incremental transformations and to incorporate certain parasitics of transistors in the synthesis of transistor bandpass filters.

52.2 A Method of Time-Domain Approximation for Arbitrary Inputs, B. Liu, *Princeton University, N.J.;* H. E. Meadows, *Columbia University, New York, N.Y.*
This paper presents a method for solving the time-domain approximation problem for arbitrary inputs directly, without recourse to the frequency domain. Such a direct approach avoids the cumbersome process of actually taking the transforms of real signals, a process difficult to instrument simply. Using the concept and techniques of signal decomposition into orthonormal exponentials, the proposed method provides the desired impulse response of the network by determining the coefficients of its orthonormal expansion. These coefficients can be determined simply and straightforwardly. Furthermore, this method has the added merit that it may be easily implemented.

52.3 Duality Concepts in Time-Varying Linear Systems, A. Gersho, *Bell Telephone Labs., Murray Hill, N.J.;* N. DeClaris, *Cornell University, Ithaca, N.Y.*
The duality between the roles of time and frequency leads to a natural extension of Zadeh's results on time-varying linear systems. A fundamental and versatile description is achieved through the use of a family of eight system functions. The approach is applied to deterministic as well as randomly varying systems for both the stationary and nonstationary case. It is shown that second-order statistics of the output and input signals can be related with a Fourier transformation. Basic properties of time-varying linear systems, including stability and magnitude-phase relations, are discussed, and new synthesis procedures are presented. Finally, the characterization procedure is shown to be effective in the study of random channels, optical filters, and Doppler phenomena.

52.4 On the Properties of Combinations of Parametric Elements, J. Klapper, M. S. Ghausi, *New York University, Bronx, N.Y.*
This paper discusses the properties of combinations of nonlinear elements under small-signal conditions. Energy relations are derived for a circuit containing nonlinear resistance, nonlinear capacitance, and nonlinear inductance, each pumped with an arbitrary phase angle. A number of useful properties not found in circuits having only a single nonlinear element are exhibited. They include the possibility of perfect isolation between input and output, parametric amplification with low-frequency pumping and without the use of higher-order nonlinearities, converters with considerably more up-converter gain, converters capable of suppressing certain frequencies, and converters with a flatter frequency response.

SESSION 53

Thursday 10 A.M.–12:30 P.M.
New York Hilton, Regent Room

Electronic Components and Materials I

console and an input/output buffer, in conjunction with a high-speed digital computer. The simulation allows a wide range of variations in the control system parameters for evaluation in either continuous or discontinuous modes of vehicle operation.

55.2 Quickened Manual Flight Control with External Visual Guidance, T. Gold, *Sperry Gyroscope Co., Great Neck, N.Y.*
Schemes for enhancing visual flight control based on quickening concepts are described. The pilot receives guidance information from the relative positions of projected virtual images appearing through the windshield and landmarks in the real world. The vehicle may then be controlled to couple to a preselected flight path in space terminating on that landmark. Quickening concepts are then applied to provide flight director control. The pilot tracks the landmark with a projected director image, and thereby constrains the vehicle to stabilize on the desired flight path.

These techniques permit the pilot to control and monitor the course of his vehicle while in complete visual contact with the real world. The precision and confidence with which the pilot can implement the control task are thereby enhanced.

55.3 Analytical Methods in the Study of Man-Machine Systems, B. L. Perry, H. P. Birmingham, *U.S. Naval Research Lab., Washington, D.C.*
The "human factors" approach is an interdisciplinary effort oriented toward the achievement of maximally effective man-machine systems. This emerging science has particularly close ties to mathematics, electronics, physics, and experimental psychology. This presentation delineates the application of analytical techniques in the study of man-machine systems. The utility of the Laplacian concept in characterizing human behavior within systems is also discussed. The benefits of these approaches are evident in examples of the optimal design of vehicular control systems and in sophisticated approaches to the selection and training of operators.

55.4 Peripheral Augmentation of Range Perception in Pictorial Displays, H. G. Sperling, R. C. McLane, D. A. Anderson, *Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*
This paper is primarily concerned with manual controllability of a six-degree-of-freedom vehicle in which separate control of each degree of freedom is provided. One of the specific goals in the research was to quantify the information presented by a pictorial display and to seek out methods of providing equal accuracy of control in all axes. A peripheral display was found to be necessary to augment fore-aft range perception. A control station mock-up, including a six-degree-of-freedom input control and a vertical pictorial or contact-analog type display with an integrated quickened tracking symbol, was combined with a real-time simulation of vehicle characteristics for controllability performance tests.

SESSION 56

Thursday 10 A.M.–12:30 P.M.
New York Coliseum, Room C

Basic Sciences I—Circuits and Systems

Chairman: James Mulligan, New York University, N.Y.

56.1 Frequency-Converting AC Theory Applied to the Analysis of Nonlinear Oscillation and Amplification, Morio Akiyama, *Kohgaku-in University, Tokyo, Japan*
In this paper the author defines new notations of complex vectors, including not only currents and voltages, but variable inductances, etc., which vary periodically with time. By means of representative nonlinear oscillation and amplification circuits, common analytical expressions are given for nonlinear reactances and resistances and frequency converting networks. Their dynamic characteristics are compared.

56.2 Algorithms for Circuit Enumeration, B. R. Myers, *University of Notre Dame, Ind.;* J. W. LaPatra, *University of California, Davis*
The problem considered in this paper is determining the number, location, and length of all the circuits in a linear graph. This is done by utilizing a graph classification system which permits logical subdivisions of all linear graphs. Criteria and formulas are developed to provide algorithms for circuit enumeration within the graph classes. This is done by examining the permutation families developed for the case of the complete graph. Various incomplete graphs are generated within the frame of the classification system by omitting elements. The circuits for the incomplete graph are enumerated by assessing the changes in the permutation array due to the omissions of the elements for the particular incomplete graph. This leads to circuit enumeration in a form suitable for machine computation.

56.3 Electric Field Suspension of Inertial Masses, R. C. Staats, *Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*
The electrically suspended gyroscope (ESG) is a nearly ideal attitude reference element for extended duration space missions. It offers high accuracy and long-life potential due to nonmechanical coupling of moving parts. To actually realize long life, however, requires a rotor suspension servo capable of maintaining rotor levitation for months, and perhaps even years, without failure. This paper describes basic suspension servo approaches which can provide this capability. Starting from the principle of virtual work, simplified equations are derived for the electric force on an ESG rotor. These equations are then used to develop simple, highly reliable suspension mechanizations.

56.4 General Theory of Finite Laplace Transforms and Application to Analysis of Distributed-Parameter Circuits, T. J. Higgins, *University of Wisconsin, Madison;* R. E. Oesterlei, *Century Electric Co., St. Louis, Mo.*
The purpose of this paper is to advance the general theory of finite Laplace transforms; to outline a new procedure using them, for solution of boundary-value problems characterized by partial differential equations with constant coefficients, which is both simpler and more direct in use than is the presently used procedure, utilizing infinite Laplace transforms; to develop a table of finite Laplace transforms; and to illustrate all details of use of theory, procedure, and transform-table in practice by solution of several numerical examples that were derived from the domains of both transmission-line theory and electrostatic-field theory.

56.5 Generation of Millimeter Waves by Means of the Doppler Effect, C. C. T. Wang, M. D. Sirkis, *University of Illinois, Urbana*
Mathematical analysis describing transverse deflection of a relativistic electron beam by an electromagnetic wave has shown that the frequency of the consequent radiation from the beam is shifted from that of the deflecting wave by a double Doppler effect. This radiation can deliver nonzero average power to a load if the Doppler condition, which relates the frequencies and phase velocities of the two waves and the beam velocity, is satisfied. An experiment in which approximately 2 mW at 39.7 Gc/s was generated in substantial agreement with the theory is discussed.

SESSION 57

Thursday 2:30–5 P.M.
New York Hilton, Trianon Ballroom

The Electric Power System of Tomorrow

Chairman: C. A. Woodrow, General Electric Co., Schenectady, N.Y.

57.1 Balanced Design of Generation Systems. I. H. Landes, W. D. Marsh, C. D. Galloway, *General Electric Co., Schenectady, N.Y.*
The design and planning of generating systems permit wide latitude in the selection of plant vocation unit size and unit type. Recent developments in prime mover technology and in methods of system analysis make it possible to identify design patterns of substantial economic benefit. These factors are discussed in this paper in terms of their overall value to the electric utility industry.

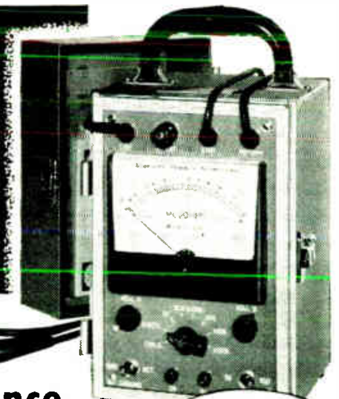
57.2 What's Ahead in Transmission Systems?, J. K. Dillard, *Westinghouse Electric Corp., East Pittsburgh, Pa.*
Engineering designs are virtually completed for the nation's first 500-kV systems and a 700-kV line is being designed for eastern Canada. Research at 700 kV has been under way for better than three years both at Pittsfield Project EHV and Apple Grove, W. Va. The paper, which deals principally with voltages above 700 kV, contains a forecast of the need for higher voltage, points out the engineering problems that will be encountered, and makes an assessment of the research required to establish design practices.

57.3 The New Look in Distribution Systems, E. H. Clark, *Southern California Edison Co., Los Angeles*
Technical design of distribution systems has been changing rapidly in recent years and further improvements will continue in the future. This paper, however, deals principally with the changes resulting from public demand for improved appearance of distribution systems. The trend toward lower cost of underground distribution and the development of improved pole-top arrangements are discussed. Developments in distribution substation design are included to indicate the trend towards lower cost and better public acceptance in substations in residential areas.

57.4 An Opportunity for the Power Industry in Research and Development, L. J. Linde, *Allis-Chalmers Mfg. Co., West Allis, Wis.*
Traditionally research on electric power apparatus and systems has been done largely by equipment manufacturers. The cost, which has been considerable, is of course paid for by the electric utility industry in the price of the equipment purchased. There is a growing feeling among electric utility executives that more research and development should be undertaken directly by the utilities, with greater participation by educational organizations. One example of this approach is described in this paper along with the philosophies and reasoning that prompted this divergence from the more usual procedure.

57.5 Value Analysis in System Development A. P. Fugill, *Detroit Edison Co., Mich.*
This paper deals with the necessary function of management appraisal of the capital expenditures proposed for the continuous development of an electric power system. It stresses the recognition that after basic philosophies and policies on system development

NEW
VIBROTEST®
Megohmmeter Model 2850



Measures resistance to 10,000,000 megohms

ONLY **$250** fob Chicago

versatile·accurate·reliable

dual test voltage . . . 500 vdc and 50 vdc

24" total scale length . . . 1 to 10,000,000 megohms in 6 decades

measures resistance on printed circuits, transistor and miniaturized circuit components, cables, motors, etc.

measures leakage resistance of capacitors

measures grounded and ungrounded sections of three-terminal resistors

2-35.7

advanced features

- constant test voltage over full range
- no overload damage
- positive line voltage control
- maximum guarding flexibility
- latest tube-miniaturization techniques

Get all facts . . . write for Bulletin 2-1.4

Associated Research, Inc.
Manufacturers of Electrical Testing Instruments since 1936
3792 Belmont Ave., Chicago, Ill. 60618

NEW DESIGNATION 6280/416B

L. M. ERICSSON 6280/416B

built with L. M. Ericsson's ruggedized long-life construction

For superior microwave
- Amplification
- Oscillation
- Mixing

The 6280/416B features . . .
- High transconductance
- Low noise factor
- Frame grid construction

Contact State Labs for technical information and specification sheets.

PURCHASING AGENTS—for price information on the complete line of L. M. Ericsson 10,000 hour tubes, contact:

Electronic Tube Supply Specialist.

STATE LABS, INC.
215 Park Ave. South, New York, N.Y. 10003
(212) ORegon 7-8400 Cable: STATELABS

For Constant Resistance With No Contact Bounce

SPECIFY TELEX SWITCHES

Telex switches provide constant contact resistance over the life of the switch. Unique wire bridge design provides unusually high contact pressure with no measurable contact bounce. Excellent cleansing action of wiping crossbar assure reliability of dry circuit application. Extremely long life of 500,000 operations on each of following Telex switch types. Write for detailed information for your application requirements.

ARRAY SWITCH

Design simplicity and special modular construction of these Telex switches allow more poles than conventional units of equivalent size and weight. Each button operates 8-poles single throw—normally opened or closed—or 4-poles double throw, or any combination. All or any buttons may be interlocked with or without lockout. Also available in momentary and alternate actions. Switch resistance is .050 ohms nominal and is constant over the life of the switch. Insulation resistance at 500 VDC between adjacent switch contacts or ground is 40,000 megohms. Choice of colored buttons and numerals and optional light indicators. Sockets accept a miniature flange-based T 1¾ lamp which can be replaced from the panel front without tools. Variations designed to meet individual specifications.

ILLUMINATED PUSHBUTTON SWITCH

The Series TM Pushbutton Indicator Display Switch provides continuous 4-bulb operation. Colored bulb caps with transparent screen or clear bulbs and colored screens provide a wide variety of color codes. Bulbs replaceable from the front without special tools. Barriers and mounting springs are permanently attached for ease of assembly and improved reliability. Extremely long life—500,000 operations at 1 amp 30 VDC.

MICROMINIATURE TOGGLE SWITCH

The Microminiature Toggle Switch weighs only 0.17 grams (.006 oz.) and is available in both S.P.S.T. and S.P.D.T. configurations. Capable of over one-half million positive, trouble-free switching operations, it measures only 5/32" x ⅛" x ½". Leads for printed circuit mounting available. Contact rating is 1 amp. 30 VDC resistive with consistent contact resistance.

WRITE FOR COMPLETE INFORMATION

TELEX/*Acoustic Products*

3054 Excelsior Blvd. • Minneapolis 16, Minn.

TELEX

are established there is need for a continual analysis of the interpretation of those philosophies and policies in terms of the projects proposed for the construction budget. Specifically it describes one electric utility company's method of insuring that a balanced program of system development is being followed and that the maximum value is received from each dollar spent on the capital budget.

SESSION 58

Thursday 2:30–5 P.M.
New York Hilton, Mercury Ballroom

Communication and Modulation Techniques

Chairman: L. A. De Rosa, ITT Communication Systems, Paramus, N.J.

58.1 An Experimental Single-Sideband Frequency Modulation System, J. L. Dubois, *Shure Brothers, Inc., Evanston, Ill.;* J. A. Aagaard, *Northwestern University, Evanston, Ill.*

By the use of the proper combination of angle modulation and amplitude modulation it is possible to generate a wave that may be detected without distortion on a conventional FM detector, but which has all its energy concentrated on one side of the carrier. A single-sideband FM transmitter has been constructed by implementing each part of the mathematical equation for this wave. The signal generated by this transmitter was found to have approximately two thirds of the bandwidth of a conventional FM signal with the same deviation index. The amplitude modulator is required to have response to direct current, and a considerable increase in transmitted power is necessary during modulation.

58.2 Theoretical Comparison of Exponent Demodulation by Phase-Lock and Frequency-Compressive Feedback Techniques, E. J. Baghdady, *ADCOM, Inc., Cambridge, Mass.*

Demodulation of FM and PM signals by phase-locked loop (PLL) and frequency-compressive feedback (FCF) techniques is of great interest in the development of satellite and space communications systems. Controversy surrounds the comparative merits and the ultimate performance capabilities of these techniques in the detection of weak FM and PM signals in random-fluctuation noise. A parallel formulation of the theory of operation and the basis or design optimization of these techniques is presented in this paper. The analysis helps bring out serious shortcomings in almost all of the analytical models used to date in the study and comparison of PLL and FCF demodulators, and provides the basis for optimizing and comparing the threshold reduction performance of these techniques. The phase-locked loop is shown to be the more desirable choice for most practical situations.

58.3 Time Synchronization Techniques, G. L. Johnson, V. R. Latorre, *The Boeing Co., Seattle, Wash.*

In modern communication systems, accurate timing information is often an important operational constraint. This is particularly true in high-speed digital data systems, which frequently require rather close synchronization. This paper discusses current time-synchronization methods and then presents a technique for obtaining synchronization accuracies on the order of a microsecond by means of a forward-scattered signal from meteor trails. An experimental instantaneous time synchronization system between the Seattle facility of the Boeing Company and the station at Montana State College is described, and the advantages of this mode of operation are discussed.

58.4 Results of Investigations of Analog and Digital Communication Techniques, H. D. Becker, *Cornell Aeronautical Lab., Inc., Buffalo, N.Y.;* A. S. Kobos, *Rome Air Development Center, Griffiss AFB, N.Y.;* J. G. Lawton, *Cornell Aeronautical Lab., Inc., Buffalo, N.Y.*

This paper summarizes the results of theoretical investigations of several areas of data transmission. It includes the effects of a channel with frequency offset upon the probabilities of error of *m*-state differentially coherent phase shift keyed systems, binary noncoherent frequency shift keyed systems, and noncoherent carrier keyed systems. An analysis of differentially coherent phase shift keyed digital data systems operating over a fading FM tropospheric scatter circuit is next presented. Then the effects of amplitude and phase fluctuations on the performance of digital data systems in fading frequency division multiplex FM and single-sideband transmission systems are analyzed.

Finally, the results of an investigation of optimum demodulation of FM signals are given. Integral equations describing the operation of a maximum likelihood receiver are developed. A comparison, valid above threshold, is made with a receiver consisting of a discriminator followed by a post-detection Wiener filter for the case where the modulating signal is a random process.

58.5 DATEC—Digital Adaptive Technique for Efficient Communications, S. G. Varsos, B. Norvell, *The Martin Co., Orlando, Fla.*

By taking full advantage of voice statistics, a considerable reduction (5/1) of the average pulse-rate of a delta-modulation waveform is obtained. This renders the family of delta-modulation techniques attractive for a larger number of applications. A complete system description of DATEC is presented. Overall circuit implementation is discussed, together with a summary of the extensive laboratory performance evaluation work. Curves of intelligibility performance under noise and interference for the conventional delta vs. DATEC are presented.

DATEC is applicable to many pulse-type voice communications requiring low pulse duty-cycle for multiple-channel use (minimizing crosstalk and aiding addressing) and conservation of power (battery-operated units). Its design offers an instantaneous, natural, and efficient voice-actuated switch implementation. It retains all the advantages of delta modulation without any additional detectable disadvantages.

SESSION 59

Thursday 2:30–5 P.M.
New York Hilton, Sutton Ballroom N.

Engineering Management

Chairman: James E. McLinden, Roslyn Heights, N.Y.

59.1 The Concept Library: Containing the Information Explosion, R. B. Miller, *International Business Machines Corp., Poughkeepsie, N.Y.*

Innovation and evaluation by systems engineers and managers could often profit from one hour "education capsules" in unfamiliar fields. Concise statements outlining a domain about operational concepts, principles and mechanisms, if immediately available, often provide adequate briefing. Also, using information retrieval systems requires structured knowledge of key concepts and terms in unfamiliar domains. Format samples are shown of one page summary concepts in several fields. Each page includes topical maps of parameters and synonyms for deeper inquiry. A proposal is outlined for an information retrieval and educational system based on such summaries. Results would minimize time, search, files, and irrelevant detail.

59.2 Patents and the United States Government, G. D. Coplein, *Darby & Darby, New York, N.Y.*

This paper surveys various aspects of Government patent policy. The major Government contracting agencies' policies on acquiring patent rights in sponsored R and D contracts are discussed with emphasis on the standard NASA and DOD type patent rights clauses. The steps for obtaining an exclusion of patent rights under applicable R & D contracts are explained. A discussion of the standard ASPR authorization and consent and patent indemnity clauses and the ways a patent owner can recover from the Government for patent infringement is also given.

59.3 Rationalizing the Management of Technological Innovation, F. V. Fortmiller, *Cambridge Research Institute, Mass.*

A productive research and development process is complex, integrated, and coherent. It begins with a definition of research goals based upon company objectives; it continues through the exploration, development, production and the profitable marketing of different, modified, cheaper, or higher quality products or techniques. The paper outlines a conceptual scheme, contemporary methodology, and techniques that individual companies can employ to set long-term company objectives and to define research goals, and to select and administer research and development projects. The presentation employs examples drawn from the experiences of individual companies and the Department of Defense. Emphasis is placed on contemporary techniques.

59.4 Engineers as Managers: Good or No Good?, F. J. Gaudet, *Stevens Institute of Technology, Hoboken, N.J.*

According to some top industrialists, engineers do not make good management men because they are "thing-minded" rather than "people-minded", too rigid in their thinking, and too dependent on details for high-level decision making. All of this implies that there is a stereotype of an engineer. This is not true. Recent studies show that engineers, in terms of their interest, are—like graduates of liberal arts colleges, law schools, and schools of business administration—many different kinds of persons whose talents can be used in many different areas. On the basis of personality, certain engineers will not make good managers. However, this is also true of some business administrators, or law or liberal arts graduates.

SESSION 60

Thursday 2:30–5 P.M.
New York Hilton, Sutton Ballroom S.

Symposium on Data Transmission

Chairman: W. R. Bennett, Bell Telephone Labs., Holmdel, N.J.

60.1 Error Problems in Sampling Representations, J. B. Thomas, B. Liu, *Princeton University, N.J.*

This paper is concerned with the various error problems arising in the implementation of sampling representations for signals. The principal errors discussed are those caused by equipment inadequacies. In particular, the cause of error, its evaluation, and if applicable, its optimum reduction are presented for the following types of errors: (1) time jitter error, or that caused by imperfect timing of the sampling instants; (2) amplitude sam-

Three Excellent NEW Wide-Sweep Oscillators

50 KC - 1300 MC

NEW! MODEL 121-B *0.5 mc-1050 mc*

Sweeps more than 300 mc wide. Provides a more pure, more flat 0.5 volts after built-in switched attenuator. Harmonic markers.

$1295.

To 1300 mc with P-122-A head

NEW! MODEL 159-B *1 mc-300 mc*

Sweeps 300 mc wide, well within tight ±0.25 db flatness specification. Plug-in marker heads: pulse, single birdie, harmonic. All transistorized.

$795.

NEW! MODEL 154-A* *50 kc-100 mc*

High-level 1.0 volt output in extremely flat sweeps up to 100 mc wide. Featuring Kay's fine pulse-type markers which stay sharp on narrow sweeps too, highlighting the 154's superior, bonus performance on narrow sweep. All transistorized.

$795.

All Of The Above Instruments Are Swept Electronically

*SPECIFICATIONS — MODEL 154-A

FREQUENCY RANGE: 50 kc to 100 mc
SWEEP WIDTH: 200 kc to 100 mc
OPERATING MODES: 5 to 60 cps, manual, CW
RF OUTPUT: 1.0 volt RMS into 50 or 70 ohms, metered
FLATNESS: ±0.25 db over widest sweep
ATTENUATOR: Individually switched 20,20,20,10,6 and 3 db steps, plus approx. 3 db variable.
SWEEP OUTPUT: Sawtooth synchronized with sweeping oscillator; approx. 12 v. P-P.
MARKERS: Up to 8 crystal-controlled pulse-type markers located between 1 and 100 mc. Pos. pulses approx. 7 volts peak. Var. birdie marker developed from external oscillator.
POWER SUPPLY: Approx. 20 watts input, 117 v. (±10%) 50-60 cps., regulated.
WEIGHT: 28 Lbs.

For Complete Catalog Information, Write

KAY ELECTRIC COMPANY
PINE BROOK, MORRIS COUNTY, N.J.

Visit Kay at the IEEE Show Booths 3512–3518 pling error, or that caused by uncertainty in the amplitude of the sample values; (3) aliasing error, or that caused by violation of the assumption of bandlimitedness; and (4) truncation error, or that caused by the use of only a finite number of samples.

60.2 The Timing Problem in Digital Communication—A Survey, B. K. Kinariwala, *Bell Telephone Labs., Inc., Murray Hill, N.J.*
The main advantage of transmitting information in binary-pulse form results from the fact that such pulses can be regenerated repeatedly. An important function of each regenerative repeater is to restore the signal pulses to their assigned positions at the centers of equally spaced time slots. Random timing deviations, or position modulation, of the output signal pulses result from input noise and other sources at each repeater. The statistical properties of these timing deviations have been rather extensively studied by several people in the past decade or so. The present paper is an attempt to survey and consolidate the accumulated body of knowledge on this fundamental problem in digital communication.

60.3 A Method for Optimizing Performance of Pulse Transmission Systems, L. E. Franks, *Bell Telephone Labs., Inc., N. Andover, Mass.*
The selection of a variable system function, such as filter response or pulse shaping characteristic, to achieve optimum system performance is examined as a particular type of variational problem. A linear combination of relevant performance measures—e.g., noise interference, pulse dispersion, interchannel crosstalk, etc.—is formulated as an arbitrarily weighted energy distribution in either the time domain or the frequency domain and is to be extremized with respect to the variable system function. Necessary conditions for the extremum to exist are given in terms of linear integral equations and an approximation technique for their solution is presented. This approach is particularly applicable to the design of pulse transmission system, and several illustrative examples of this type are discussed.

60.4 Reliability of Two-Way Communication, L. S. Schwartz, *New York University, Bronx, N.Y.*
This paper examines the reliability of two-way communication with certain classes of codes and cumulative decision policies. Two classes of codes are examined: (1) matrix codes for single, double, triple, and partial four-error correction and (2) a class of burst-error-correcting codes of somewhat random structure, having the property of reasonably simple decoding with the capability of correcting all bursts of length up to somewhat less than half the number of check digits. The cumulative decision policies operate by filling in nulls (erasures) before testing for acceptability and by using "similarity" and "difference" checks to overcome receiver uncertainty regarding the point of transition from the previous to the new message.

60.5 Bandwidth and Spectra of Phase- and Frequency-Modulated Waves, Norman Abramson, *Stanford University, Calif.*
The spectrum of a cosine angle-modulated by a Gaussian random process (GRP) of (almost) arbitrary spectrum is investigated. Such a GRP provides a convenient model for voice signals, television signals, and other types of complex communication signals. A simple closed-form expression for the bandwidth of the modulated signal in terms of the bandwidth of the modulating signal is found. A general expansion for the shape of the spectrum of the modulated cosine is derived. In addition to reducing, in certain limiting situations, to known results, this expansion provides a practical means of obtaining the spectrum in intermediate cases. Examples are presented showing the spectrum of a cosine modulated by (1) a lowpass GRP with rectangular spectrum, and (2) a bandpass GRP of Gaussian spectrum.

SESSION 61

Thursday 2:30–5 P.M.
New York Hilton, Regent Room

Electronic Components and Materials II

Chairman: David A. McLean, Bell Telephone Labs., Murray Hill, N.J.

61.1 New Composite Materials for Packaging Semiconductor Devices, A. M. Huntress, *Texas Instruments Inc., Attleboro, Mass.*
A new, clad metal for transistor eyelets and other semiconductor parts is discussed. The material is a three-layer composite consisting of a central layer of copper clad on both sides with a thin layer of Kovar. This material is expected to be useful in the manufacture of special transistors for operation at higher than normal power levels because of its increased heat dissipation properties. A complete analysis of the thermal expansion characteristics of various composite ratios is presented and its bearing on glass-to-metal sealing is discussed. A brief review of other new composite materials such as parts for integrated circuits manufacture and weldable printed circuit boards is given.

61.2 Electronic Transient Suppressors, V. W. Vodicka, *Joslyn Electronic Systems Div., Goleta, Calif.*
Electrical and electronic equipment is often damaged by transients. These natural or man-made phenomena can be suppressed or eliminated by the use of modern electronic transient arresters. The basic component is a gas-filled spark gap using isotope prompting capable of operating in less than a microsecond at various preset "clamping" levels (150 volts to 30 kV). These are combined with other specially developed components such as silicon carbide resistors, multilayer diodes, silicon controlled rectifiers, etc., to reduce the transient levels further and to produce redundancy, where needed. The following systems can be protected: voice, data, carrier communication equipment on wire and cable, VLF to UHF receivers, transmitters, antennas, computers, power supplies, generators, motors, etc.

61.3 Heat-Shrinkable Tooling for Producing Molded Ground Support Harnesses, D. D. Rodger, *Raychem Corp., Redwood City, Calif.*
This paper describes the materials, components and production processes required to produce waterproof, molded harnesses without using permanent metal tooling. By using heat-shrinkable boots and breakouts, which are designed to be filled with polyurethane, polysulfide, or RTV silicone molding compounds, harnesses can be designed and built in a matter of days. The heat-shrinkable molds are left in place to provide added protection, which reduces the requirements on the molding compounds, thus making it possible to use room-temperature curing materials, which normally could not be used alone. Expensive and time-consuming operations of designing and producing aluminum or steel tooling are eliminated. A large variety of sizes and shapes of molded parts are available from stock, making it possible to produce numerous harness configurations.

61.4 A New Hollow-Beam Microwave Triode for Communication and Navigation Applications, R. C. Morwood, K. E. Love, *Eitel-McCullough, Inc., San Carlos, Calif.*
A new planar triode capable of 75 watts useful power output at 2100 Mc/s is described. The center part of the conventional planar triode structure has been removed. This "hollow beam" geometry permits the grid dissipation rating to be increased in direct proportion to the cathode area. Gains of 10 dB (full power) and 14 dB (small signal) were obtained. Internal tube elements, brought outside the vacuum envelope in short, direct paths, introduce minimum discontinuity in cavities. Grid-cathode spacing is precisely fixed by machining the cathode after coating with the grid mounting plane as reference.
This tube is ideally suited for applications such as voice communication, telemetry and navigational aids. In these applications it can be used either as a CW or pulsed amplifier or oscillator. The greater power available from this new planar triode will provide greater range and more reliable communication systems in the microwave frequency region.

SESSION 62

Thursday 2:30–5 P.M.
New York Coliseum, Room A

Arrays and Ionosphere

Chairman: David K. Cheng, Syracuse University, N.Y.

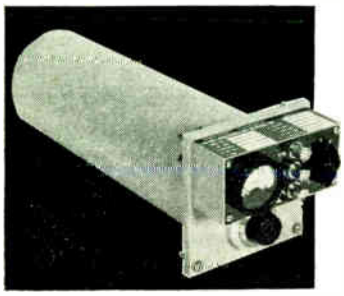
62.1 Short Pulse Radiation Effect of a Long Array Utilizing Series and Corporate-Series Feed, Harlan Rosenblatt, *The Martin Co., Baltimore, Md.*
In radar system design in particular, and in some communication system applications, it is important that almost all radiated energy be included within a very small angle, and thus a long transmitting antenna is required. In both applications, it is also sometimes necessary that the transmitted signal comprise a short pulse, the length of which is less than the array length. If all of the elements are corporately fed, this leads to no operational difficulty, but the construction of such an array could be extremely cumbersome. On the other hand, if the array is series fed, the various parts of the array will not radiate simultaneously. This paper analyzes the effects of series feeding a long array with a short pulse with respect to the time varying far field pattern that results and the resulting spectrum narrowing at various angles. The paper also suggests and analyzes several compromises between series and corporate feed and discusses the improvement brought about by each.

62.2 Linear Array Synthesis, M. T. Ma, *General Electric Co., Syracuse, N.Y.*
This paper describes some new methods of synthesizing linear antenna arays. The methods are developed from a re-examination of the classical theories on approximation and interpolation. Both the ordinary and the trigonometric interpolations are considered. With these methods, one is able to synthesize an array such that (1) the upper bound of the errors between the specified and synthesized patterns can be estimated, (2) either the maximum deviation or the mean-square error can be minimized if the total number of elements in the array is prechosen, or (3) the least required number of elements can be determined if the error specifications are given.

62.3 An Equivalence Theory Between Elliptical and Circular Arrays, Y. T. Lo, H. C. Hsuan *University of Illinois, Urbana*
An equivalence relation of a family of arrays defined under a linear transformation is established. By means of this theorem the far field of an elliptical array can be obtained from that of an equivalent circular array, similarly for two- and three-dimensional arrays. As an example a uniformly excited cophasal elliptical

ALL-SILICON SOLID STATE

FREQUENCY STANDARDS



COMPACT • RUGGED

Model 2.5	Model 5A
$2,600.00	$1,850.00

Other products by SULZER include:

- Frequency dividers
- Frequency multipliers
- Frequency comparators
- Time comparators
- Also portable precision clocks

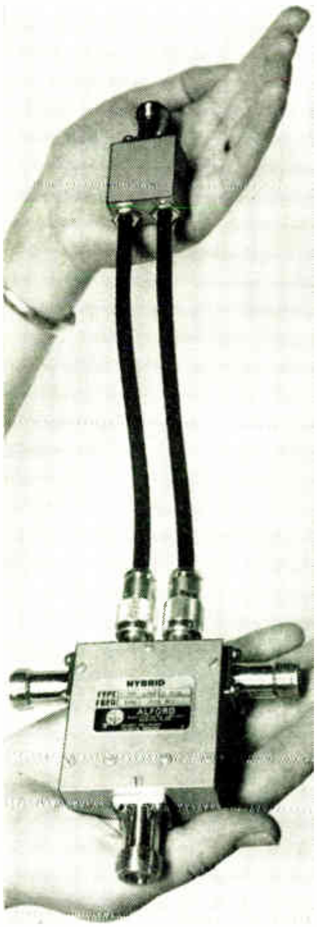
SPECIFICATIONS

	MODEL 2.5	MODEL 5A
Output	1 volt to 50 ohm load at 2.5 Mc, 1 Mc and 100 Kc	1 volt to 50 ohm load at 5 Mc, 1 Mc and 100 Kc
Stability	1×10^{-10} or better over 24 hours over ambient temperature range +5 to +35 degrees C with power supply variation from 22 to 32 volts (at ¼ amp) for load variation ±20%	5×10^{-10} or better over 24 hours over ambient temperature range —10 to +60 degrees C with power supply variation from 22 to 32 volts (at ¼ amp) for load variation ±20%
Front Panel Frequency Control	linear, with range of 100×10^{-9} sensitivity of 5×10^{-11} per division	linear, with range of 100×10^{-9} sensitivity of 1×10^{-10} per division
Size	4½" x 4½" x 11¾" for shelf, bulkhead or rack mounting	4½" x 4½" x 11¾" for shelf, bulkhead or rack mounting

Standby power supply Model 5P (10 hours battery) for use with either unit. 4½"x4½"x11¾"

SULZER LABORATORIES, INC.

621 LOFSTRAND LANE • ROCKVILLE, MARYLAND



Compact RF Hybrids Type 2210

These broad-band transmission-line hybrids have high isolation and low VSWR over very wide frequency ranges and yet are very small even at UHF and VHF frequencies through the use of a symmetrical two-coil balun and two flexible cables instead of rigid transmission line elements. The basic unit is approximately 4 x 4 x1½" with Type N connectors. The cables are approximately 1/6 wavelength long. This design permits considerable variation in overall dimensions and positions of terminals. Typical characteristics are given below.

Catalog No.	Frequency Range (mc)	Minimum Isolation (db)	Rated Maximum SWR Parallel	Rated Maximum SWR Series
2210-20	20-40	45	1.35	1.45
2210-40	40-80	45	1.40	1.45
2210-50	50-90	45	1.35	1.45
2210-90	90-160	45	1.30	1.45
2210-120	120-240	45	1.35	1.45
2210-200	200-380	45	1.35	1.45
2210-360	360-580	45	1.30	1.45
2210-550*	550-1000	45	1.35	1.55
2210-750*	750-1050	45	1.35	1.35
2210-1000*	1000-1400	45	1.35	1.45
2210-1300*	1300-1800	45	1.40	1.40

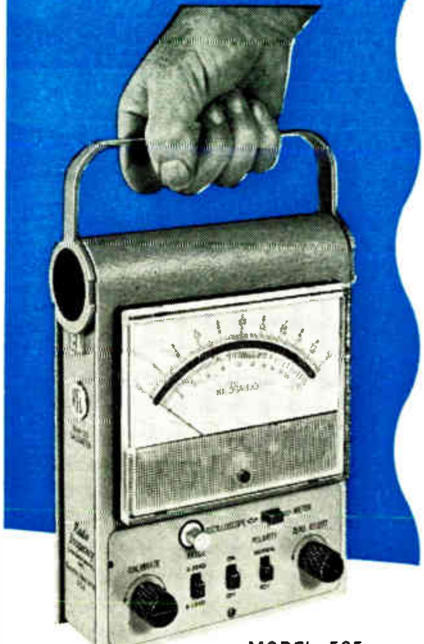
*These Hybrids have rigid, instead of flexible, transmission lines. Other models available for frequency ranges up to 10,500 mc.

AMCI **ALFORD** *Manufacturing Company*

® 299 ATLANTIC AVE., BOSTON, MASS.

Phone: 617-426-2150 TWX: 617-451-3883

Handiest SELF-CONTAINED Gaussmeter



MODEL 525

Compact, lightweight and fully self-powered, the new Model 525 Hall-effect Gaussmeter fits easily in your briefcase . . . designed for the traveling engineer.

FEATURES

RANGE: 50 to 25,000 gausses; direct reading accuracy (room temp.): ±3.25% to 10kg, ±3.75% to 25kg, including tolerance of recommended reference magnet.

REFERENCE MAGNET: Usable with any reference magnet of appropriate value; new, small size 2000-gauss (0.75%) flat-probe reference magnet particularly recommended.

PROBE: Choice of axial or flat probe; sensing areas down to 0.05 sq. in. (0.05" x 0.1"); fit into .02" air gaps; probes accurate to ±3% from −20° to +60°C.

INDICATING METER: 6-inch TBS meter; mirror scale.

ZERO RANGE: Indicating pointer adjustable for zero-left or, for measurement of unknown polarities, zero-center.

ADDITIONAL FEATURES: Sensing polarity of probe reversible by front-panel switch; built-in storage compartment for one probe and 2000-gauss reference magnet; AC output for scope display.

DIMENSIONS: 9½" x 6½" x 3"; 4½ lbs.

PRICE: $235. including batteries; prices of probes and reference magnets vary with types selected.

Write for Technical and Application Data

Radio Frequency LABORATORIES, INC.
Boonton, New Jersey, U. S. A.

array is considered. For nonuniform excitation, the method of symmetrical components may be applied despite the fact that there is no rotational symmetry for elliptical arrays. This theory can also be applied to the case of continuous source distribution on an ellipse or in elliptical aperture. By so doing solutions can be obtained without using the complicated wave functions pertaining to the original geometry. As an example an optimum array in the sense of Dolph-Chebyshev is considered. Similarly, a Taylor distribution for an elliptical aperture can also be achieved.

62.4 A Radiation Pattern Synthesis Technique for End-Fire Arrays, R. A. Michelson, J. W. Schomer, *The Boeing Co., New Orleans, La.*

A nonlinear programming technique derived from the "method of steepest descent" is applied to the problem of synthesizing far-field patterns for end-fire arrays. The amplitudes and phases of excitation, as well as the element positions may be used as variables. Radiation patterns are synthesized for both linear and nonlinear end-fire arrays. A reduction of the levels of the side lobes in the patterns for these arrays is possible by altering either the progressive phasing or the uniform element spacing. Examples of side-lobe suppression of end-fire arrays are given.

62.5 Determination of the Ionospheric Electron Content Utilizing Satellite Signals, P. R. Arendt, A. Papayoanou, H. Soicher, *U.S. Army Electronics R & D Lab., Ft. Monmouth, N.J.*

Various methods for the determination of the ionospheric electron content are possible when satellite-borne signals can be used. The paper compares the results from Doppler shift, Faraday rotation, Doppler data combined with Faraday rotation data, top-side and bottom-side soundings, and from penetration signals. The often-neglected prerequisite for the application of Doppler and Faraday methods is radio propagation along the same ionospheric path for the different frequencies involved. Criteria for correct application are discussed. The comparison of inflection time moments is chosen for data selection. The usage of the Doppler slopes at the time of simultaneous inflection provides reliable data of the electron content. The diurnal variation is given. The Faraday rotation rate measurement has been made a continuous one by special equipment of G. Vogt. The simultaneous use of two Doppler slopes at different frequencies and of the Faraday rotation rate at one of these frequencies results in the measurement of the effective component of the geomagnetic field. Thus, a method free from any assumptions is on hand for the electron content. From the radio-frequency sounding of the top-side sounder satellites and from simultaneous bottom-side soundings a complete ionospheric profile is obtained, the integration of which results in data for the total content. The higher frequencies of the top-side sounders are reflected from the ground when they penetrate the ionosphere. The corresponding time delay is also converted to data of the electron content. A comparison of all methods yields in an accurate determination of the electron content.

62.6 Processing the Signal Return from an Ionized Trail, Will Gersch, *Purdue University, Lafayette, Ind.*

The ionized trial associated with an atmospheric re-entry vehicle or particle or a rocket engine exhaust is considered as a channel or filter between a signal transmitter and receiver. This channel is identified as the equivalent of a spatially distributed time varying filter or equivalently as a range and velocity distributed channel. Return signal processing techniques that are to measure or identify the channel model are considered. These techniques include the matched filter, a generalized correlation computer, and a periodogram processor. Long time duration and large signal bandwidth transmitted signals are required in relation to the reciprocal channel velocity and range spread for accurate channel measurement. A limit to range resolution with which the range-velocity distributed channel can be unambiguously observed is demonstrated to exist. This result implies that there is a limit to the useful signaling bandwidth.

SESSION 63

Thursday 2:30–5 P.M.
New York Coliseum, Room B

Defense Systems

Chairman: Delmar C. Ports, Arlington, Va.

63.1 New Klystrons for Modern Multimegawatt Radars, A. Jorge, L. Singer, *Sperry Gyroscope Co., Great Neck, N.Y.*

This paper discusses recent advances in pulsed multimegawatt klystrons and their relation to improved system capabilities sought by the radar system designer. Significant achievements in high power, energy per pulse, electronic bandwidth, and other basic parameters are illustrated in detail by three recent multimegawatt klystron projects for X-, C-, and L-band systems. Emphasis is placed on transmitter distortion and overall system performance as related to the amplitude, phase, and spurious output characteristics of the klystrons. The variation in power output and phase linearity with beam voltage, drive power, frequency, and magnet current is discussed. The measurement techniques are also reviewed. The reliable performance of the klystrons has made possible the most sophisticated shipborne radars in existence today. These radars are an integral part of the ARIS I and ARIS II programs.

63.2 One-Step Converter for Ease of Voltage Conversion, J. A. McLeod, *General Electric Co., Utica, N.Y.*

A lightweight and low-loss regulated dc-to-dc power supply in power ranges of 5 to 500 watts has been developed to simplify voltage conversion and regulation in just one step. In contrast to a conventional, regulated dc-to-dc supply in which the series element must absorb a relatively large amount of the input power because of simultaneous regulating voltage and load current, the new one-step converter absorbs very little power. The series element acts as a switch, so that when it is on, load current flows through its low saturated resistance; when it is off, only a small leakage current flows.

63.3 A High Resolution, Microwave Modulated Optical Doppler Radar, R. B. Hankin, *The Hallicrafters Co., Chicago, Ill.;* A. C. Todd, *Illinois Institute of Technology, Chicago*

A new high-resolution optical Doppler radar system circumvents limitations of conventional RF Doppler radars and optical Doppler systems using photomixing. The theory of operation of this optical Doppler radar, as presented in this paper, is based on the measurement of the relative target velocity by utilizing the information contained in the Doppler shift of the *envelope of a microwave modulated optical carrier.* Implementation of the microwave modulated optical Doppler radar is discussed with particular emphasis given to the dynamic crossed-field electron multiplier as an ideal homodyne converter–amplifier. The operation of the system does not depend on the coherence of the carrier, because of the unique characteristics of the dynamic crossed field electron multiplier.

63.4 Active Swept Frequency Interferometer Radar, E. H. Filer, *Rome Air Development Center, Griffiss AFB N.Y.*

A new concept in interferometer radars called the active swept frequency interferometer radar is being developed by the Rome Air Development Center. This radar is a precision tracker with high accuracy and good resolution in six dimensions. The technique utilizes a linear frequency modulation to obtain range and angle data. A feasibility system is under development that will track targets of 1 square meter over 1000 nautical miles.

SESSION 64

Thursday 2:30–5 P.M.
New York Coliseum, Room C

Basic Sciences II—Fields and Systems

Chairman: Sidney S. Shamis, New York University, N.Y.

64.1 The Solution of Boundary Value Problems with Asymmetric Boundary Conditions by Means of Finite Fourier Transforms, G. Cinelli, *Argonne National Lab., Ill.*

New finite Fourier transforms and the corresponding infinite series bring the solution of boundary value problems with asymmetric endpoint conditions within the domain of integral transform theory. Multiple finite transforms based upon the new kernels together with the appropriate infinite series are given. In particular, the solution of the two-dimensional Laplacian for all possible combinations (16) of Dirichlet and Neumann boundary conditions is shown. Faltung theorems for the new transforms are also established. As an illustration of the theory the solution of the eddy-current equation under various boundary conditions is given.

64.2 Field Mapping Through More Than One Boundary, Parts I and II, A. A. Halacsy, *Mountain View, Calif.*

In part I a graphical procedure is presented for plotting the lines of force and the equipotential lines of a potential field for cases in which the field penetrates several boundaries. These boundaries separate different materials. For these cases, the paper shows that the field can be composed of fields of single point charges placed in a uniform medium. This procedure is applicable to any field for which the mathematics are the same, such as magnetic electrostatic, electrodynamic, thermal, fluid-dynamic and mechanical stress fields.

In part II the mathematics of tagging numerical values to the flux lines and equipotential lines of fields plotted across boundaries is developed for the process of field mapping presented in Part I. The process is combined with the technique of conformal mapping. As an example, the electrostatic field of an electric point-charge in a plane is calculated graphically across two boundary lines separating three materials of different dielectric constants—for instance, air, a phenolic, and glass. The lines of force and the equipotential lines are drawn in each material and practical hints are given for the procedure.

64.3 Generalized Methods of the First-Order Approximation and of the Refined First-Order Approximation for the Analysis of Nonlinear Two-Degree-of Freedom Systems, H. S. Tsou, *Sperry Rand Corp., St. Paul, Minn.;* T. J. Higgins, *University of Wisconsin, Madison*

A general procedure for the analysis of quasi-linear systems with two (or more) degrees of freedom is developed in exhaustive detail. Then the method of the first-order approximation is refined by taking into account terms which

Coors produces the largest isostatically formed ceramic parts now available to industry. Complete homogeneity of ceramic is assured because of this unique Coors process used in forming large parts. Homogeneity is essential in high-frequency, high-power applications—radomes, envelopes and windows—because hot spots and punctures created by voids and air pockets are virtualy eliminated by Coors. Complete uniformity also means reliable, uniform strength properties. In addition to fabricating large precision ceramics, Coors can metallize such king-size ceramic parts as shown here. Write for Data Sheet 3001, "Coors Forming Methods Give New Latitude in Designing with Ceramics," or call your nearest Regional Sales Manager: SOUTHERN CALIFORNIA, *Kenneth Lloyd, 847-6812, Huntington Beach, Calif.*; BAY AREA AND NORTHWEST, *John E. Marozeck, EM 6-8129, Redwood City, Calif.*; MIDWEST, *Tom Daly, 529-2510, Chicago, Ill.*; CENTRAL, *Donald Dobbins, GL 4-9638, Canton, Ohio*; EAST COAST, *John J. McManus, MA 7-3996, Manhasset, N.Y.*; *Herbert W. Larisch, 563-4487, Philadelphia, Pa.*; NEW ENGLAND, *Warren G. McDonald, 222-9520, Attleboro, Mass.*; SOUTHWEST, *William H. Ramsey, UN 4-6369, Houston, Texas.*

Coors
CERAMICS
ALUMINAS • BERYLLIAS • MAGNESIAS • SPECIAL OXIDES
Coors Porcelain Co., Golden, Colo.

were originally dropped. The method of first-order approximation and its refinement enable determination of the corresponding solutions for the transient and steady-state responses of quasilinear systems with two (or more) degrees of freedom · including not only the nonresonant case, but also the various intricate resonant cases. The method of first-order approximation also enables quick determination of the locations of the singular points, and of the radii and frequencies of limit cycles, and of the nature of their stability. All points of theory developed in this paper are well-illustrated by solution of two circuit examples, typical of those that occur in practice.

64.4 Ultrasonic Convective Cooling, J. E. McCormick, T. W. Walsh, *Rome Air Development Center, Griffiss AFB, N. Y.*

This paper discusses an in-the-house research investigation of ultrasonic cooling techniques. Natural and forced convective cooling parameters were measured, with and without the application of ultrasonic agitation. It was experimentally determined that application of the technique resulted in as much as a threefold improvement in heat transfer. Comparisons of the effectiveness of the various modes of agitation were drawn. The heat transferred increases with increases in vibrational frequency. Conclusions concerning the potential worth of the technique, as applied to electronic equipment, are included. One possible application is in the area of high-power tubes, where a possible increase in lifetime, or increased power output, may be obtained.

64.5 Plasma Diagnostics Using The Raman Effect, R. P. Urtz, Jr., *Rome Air Development Center, Griffiss AFB, N. Y.*

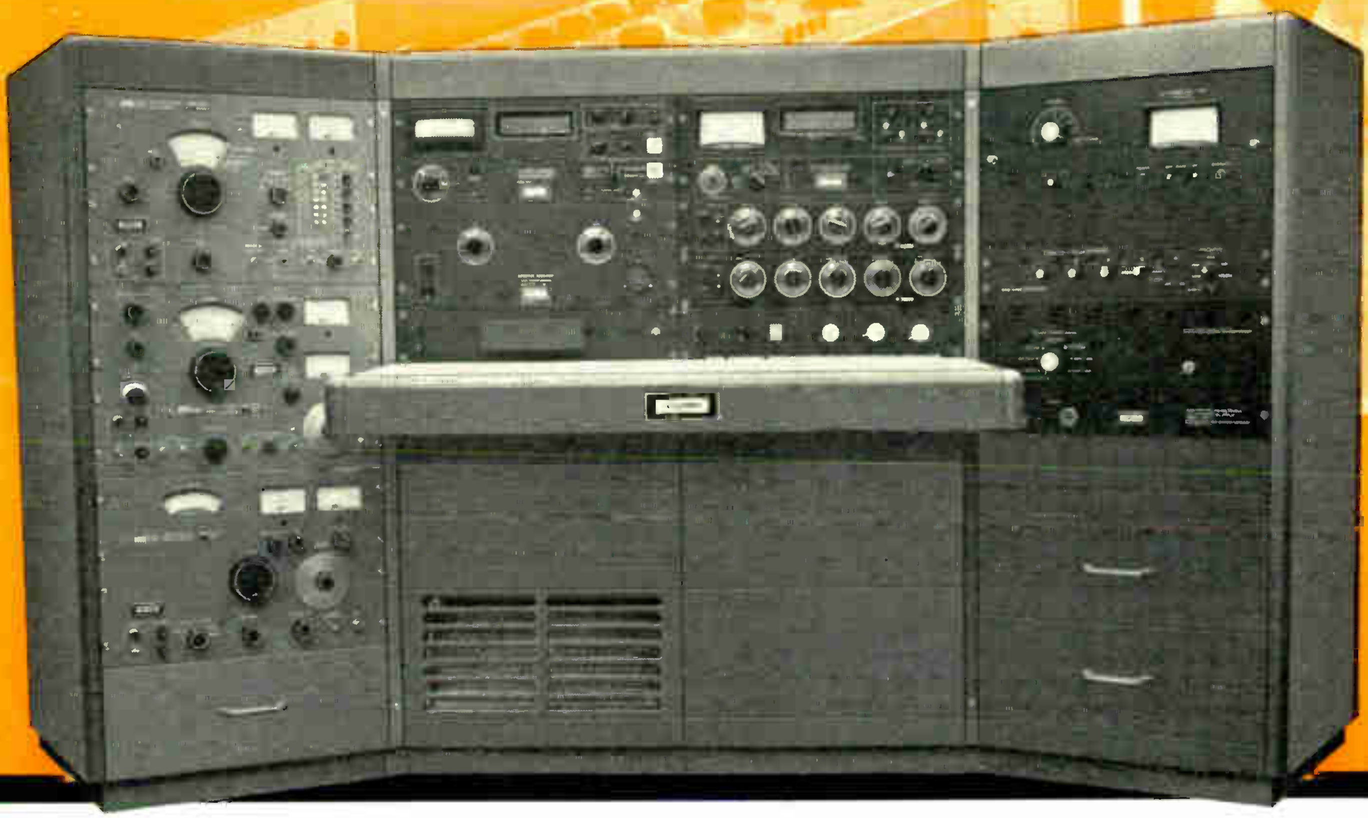
A novel plasma diagnostic technique utilizes the Raman scattering of a laser beam from a plasma. Detection of the Raman scattering will provide qualitative information on the molecular and ionic species present in a plasma. By measuring the relative intensities of the Stokes and anti-Stokes Raman lines a determination can be made of the density and temperature of the individual species present in a plasma. The theory correlating the Raman intensity with the density and temperature of the species is presented along with preliminary experimental results. The applicability of this technique in connection with various types of plasmas is shown.

64.6 Current-Pressure Characteristics of Glow-Type Discharges, P. M. Mostov, Bertram Siegel, *Republic Aviation Corp., Farmingdale, N. Y.*

Current(j)-pressure(p) characteristics of glow-type discharges are a basic element in a wide variety of advanced device and instrument configurations. Fundamental properties and modes, and how they are affected by various parameters, are deduced. Townsend-mechanisms are employed, within the uniform electric field approximation. When possible, published coefficients are utilized to spot key features, critical points, types of nonlinearities and useful bounds, affording physical insights and often obviating the necessity of extensive calculations. Using empirical expressions for Townsend's first coefficient, coupled with nondimensionalization procedures, additional deep-seated characteristics, are exhibited. Several j-p modes are delineated; j-levels, sensitivities, bandwidths, etc., including methods of controlling them, are treated. An operating-parameter diagram, on which a variety of domains are traced, correlates qualitative/quantitative features and provides design selection basis. Variation of j with gap-spacing(g) is similar to that with p; the interpretation, however, is distinctly different. Where electrical relaxation consists $\ll$ time in which p, g change significantly, the solutions may be taken as dynamic; and distinct j-waveform responses to time-varying parameters are shown possible.

SEE US AT THE IEEE SHOW!

Measure and calibrate current & voltage—DC to 1000 mc



Model LTU is illustrative of a unique Metrics Division capability in the fabrication of integrated calibration and measuring systems. The console consists mostly of Sensitive Research catalog items neatly packaged together to meet the specifications of a major computer manufacturer. Therefore, in spite of its special requirements, it is so standard that its cost is comparable to the total price of all items if purchased separately.

This efficient, reliable calibration system is ultra modern in appearance and function. It was designed and assembled by Sensitive Research instrument engineers who have been in the business of making respected standards since 1927. The only difference is that now they also call upon the considerable capabilities of the other product lines within the Metrics family. Therefore, since some Panoramic and Empire instrumentation was required in the console, it was easy to include. This is what makes the Metrics Division capability so unique!

The console consists essentially of the following self-sufficient modules and additional features:

Model LTC-2, a new ±0.035% accurate, high speed *calibration standard* covering ranges of 200 μv – 1110 v and 0.001 μa – 11 1 amps over a frequency span of DC and 7 cps – 25 kc/s. **Model LTPS-11,** a new variable frequency (10 cps – 100 kc/s), low distortion (0.05%), stable (0.005%), *ac power source* that features a noteworthy 200 va output. **Model RFS,** a new high resolution *RF readout system,* for measuring AC/DC differences and frequency influence. When employed with *micropotentiometers, coaxial thermal converters,* and an *A-T voltmeter,* calibrations can be made from 1 μv – 500 v at frequencies up to 1000 mc/s. A special panel containing *12 precision thermoelements* enables RF current measurements from 1 ma – 10 amps. **Model FLH-1,** *ac/dc transfer standard* with ranges of 1.5 – 1125 v. This unit has never been reported outside the NBS stated uncertainty of ±0.01% up to 30 kc/s and ±0.02% up to 50 kc/s.

Additional capabilities are incorporated, including a *Lindeck microvolt source,* a *micropotentiometer calibrator, 3 signal generators, dc power supplies* (remotely controlled, and programmed, and designed with interlocking circuits for overload protection), a *high sensitivity galvanometer* and a multirange ±0.5% accurate millivoltmeter.

A Commander Type MR, ±0.005% accurate *dc potentiometer system* complete with *portable saturated standard cells* as a reference, could readily have been included in the console. It would have occupied only 19" x 27" of additional panel space.

More information — Do you require a calibration and/or measuring console tailored to meet a big engineering need and a small budget? Contact Sensitive Research instruments... a product line of The Singer Company, Metrics Division.

Sensitive Research* INSTRUMENTS

THE SINGER COMPANY
METRICS DIVISION

915 PEMBROKE STREET
BRIDGEPORT, CONNECTICUT

ELECTRICAL AND ELECTRONIC INSTRUMENTS FOR TEST, CALIBRATION, AND MEASUREMENT

*A Trademark of THE SINGER COMPANY

S-64-2

teachers, and industrialists from the United States and abroad.

The 1964 INTERMAG Conference will start with an invited session on superconducting devices where eminent authorities will describe the latest trends and developments in this field. Special emphasis will be given to the role of superconductivity in nonlinear magnetics.

The program will be concerned with five major subject categories, which include Superconductivity; Recording; Memory and Logic; Power Control and Amplification, and Properties of Magnetic Materials. The 16 sessions include 85 contributed papers and eight invited papers. Proceedings of the conference will be available to all registrants at the beginning of the conference.

A special guest luncheon speaker will be Dr. P. H. Abelson, director of the Geophysical Lab., Carnegie Institution of Washington, and editor of *Science*, the official magazine of the American Association for the Advancement of Science. His talk topic will be entitled "Recent Research Highlights."

Dr. W. L. Shevel of the Thomas J. Watson Research Center of International Business Machines is general chairman of the conference, Dr. J. J. Suozzi of Bell Telephone Labs. is vice chairman, and Dr. R. C. Barker, Program Committee chairman.

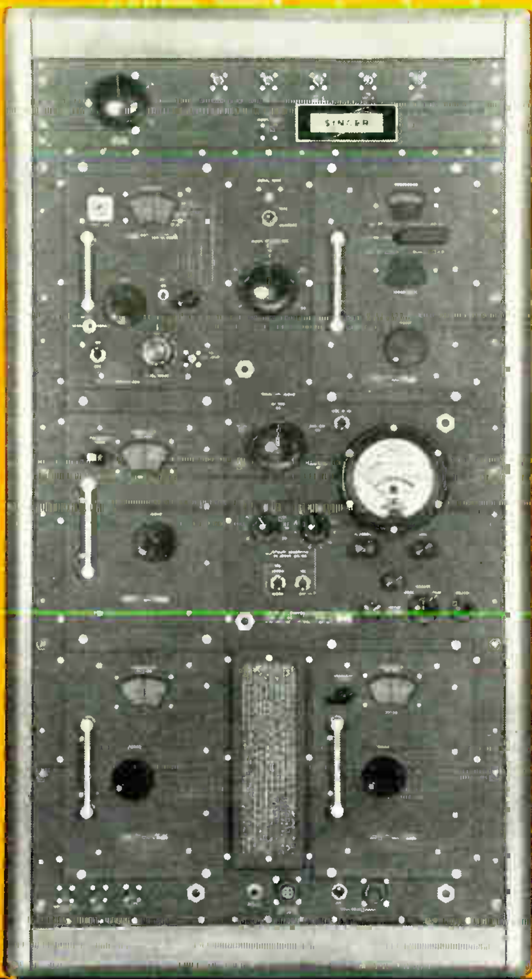
IFIP Congress 65 seeks papers for technical symposium

The Program Committee of the International Federation for Information Processing has issued a call for submitted papers for the symposium of the technical program of IFIP Congress 65, to be held May 24–29, 1965, in New York.

Submitted papers will be considered only for the symposium portion of the IFIP Congress 65 program. They may be tendered for the following list of symposium topics and proposed for any additional topics:

1. Algebraic automata theory and artificial languages
2. General theory of logical nets
3. Self-organizing systems and growing automata
4. Pattern recognition
5. Automatization of theorem proving
6. Automatization of the translation of informal languages
7. Parallel and concurrent systems
8. Mass memories
9. High-speed random access memories
10. Pattern recognition devices

For lab or field, there is an NF-105 for every RFI measurement*



* Electromagnetic compatibility
* Field intensity
* Antenna analysis
* Noise studies
* Shielding effectiveness
* Spurious radiation
* Harmonic measurements

SEE IT AT THE IEEE SHOW!

PERMANENT INSTALLATIONS – Newest in the NF-105 family of Noise and Field Intensity Meters, the Model NF-105F, serves permanent installations or those that cannot tolerate even the short delay of unit replacement in the regular NF-105. Rack mounted in fixed locations, in vans or in airplanes, it supplements rather than supersedes the regular NF-105 for quick scanning of the entire frequency range from 14 kc to 1 gc.

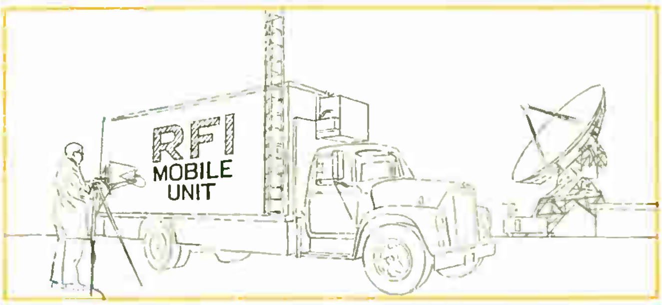
ULTRA-SENSITIVITY – Model NF-105/M-126 is the ultra-sensitive instrument. Available in both portable and fixed-location designs, it has sensitivities of minus 126 to minus 130 dbm for narrow band measurements.

PORTABLE VERSATILITY – Most popular instrument of them all, the NF-105 covers the range from 14 kc to 1 gc by means of five quick-change tuning units and one basic measuring unit (no expensive redundancies). It has X-Y output for recording and IF output for panoramic viewing.

SELF-CALIBRATION – For special applications, Model NF-205 may be preferred. Similar to Model NF-105, it utilizes a single repetition rate mercury type impulse generator.

The entire range 20 cps to 21 gc is now covered with just three instruments – the NF-315 (20 cps-15 kc), NF-105 (14 kc-1 gc), and NF-112 (1-21 gc) – instead of the six or more required with other, less versatile makes.

For complete information, contact the address below or your nearest Empire representative, requesting Catalog No. 634 and a demonstration.



EMPIRE† INSTRUMENTS

THE SINGER COMPANY
METRICS DIVISION

915 PEMBROKE STREET
BRIDGEPORT, CONNECTICUT

ELECTRICAL AND ELECTRONIC INSTRUMENTS FOR TEST, CALIBRATION, AND MEASUREMENT

† A Trademark of THE SINGER COMPANY

E-64-2

11. New components
12. Content addressable memories
13. Multiple computer systems
14. Microelectronics and integrated circuitry
15. Use of computers in computer design
16. Remote consoles and displays
17. Digital automatic control
18. Applications of laser technology to information processing
19. Approximation theory, integrals, integral transforms, differential equations
20. Linear systems
21. Alternative direction methods and partial differential equations
22. Constructive analysis (analytic continuation), non-well-set problems
23. Mathematical programming
24. Problems in differential and partial differential equations
25. Combinatorial problems
26. Nonnumerical methods
27. Flow-network methods
28. Mathematical scheduling problems
29. Recent developments in general-purpose programming languages
30. Design of processors for programming languages
31. Formal aspects of programming languages
32. Requirements and prospects for commercial programming
33. Special-purpose programming languages
34. List processing and applications
35. Supervisory programs
36. Information system implementation
37. Information system testing
38. Information system reliability
39. Theory of sorting and chaining
40. Methods for describing information systems
41. Data-communication-message forwarding

A summary of each paper, including the explicit explanation of what is new and significant, should be received by the program chairman or vice chairman by September 1. The summary shall not total more than 1000 words, or roughly four typewritten double-spaced pages. Four copies should be sent to the following: B. Langefors, program chairman, Svenska Aeroplan Aktiebolaget, Linköping, Sweden, or A. S. Householder, program vice chairman, Oak Ridge National Lab., Oak Ridge, Tenn.

IEEE and MEMMA plan Mining Industry Conference

A Mining Industry Technical Conference, sponsored by IEEE and the Min-

Spectral lines

To have the cake, or eat it? (continued) Most U.S. engineering colleges were founded in the 40 years following the passage of the Morrill Land-Grant Act in 1862. In the same general period, the world witnessed a phenomenal conjunction of inventions—the internal combustion engine, the vulcanization of rubber, the pneumatic tire, the automobile, the steam turbine, the use of steel in construction, the electric lamp, the Pearl Street central station, the electric motor, electric traction, the ac power system, the telephone, the Edison effect, the Hertz confirmation of Maxwell's prediction of electromagnetic radiation, the Fleming valve, Marconi's span of the Atlantic by radio waves, De Forest's triode, the Wright airplane.

This fantastic technological explosion was produced by a small number of itinerant inventors, aided by the discoveries of a mere handful of serious scientists. In this forward thrust the inventors were largely men from the shops, with more drive, curiosity, and intuition than their fellows, and they derived much of their success through tinkering and inspired guesswork. Our burgeoning colleges of engineering participated in these developments only in peripheral fashion, or not at all: our colleges were following industry, not leading.

Their educational methods were derived from Europe where the apprentice system was usual; the doctrinaire engineering knowledge of the day was rooted in the early arts and crafts. Teaching was based on the devices and applications of the day: the technical world was bounded. Our problems had been solved; the demand on engineers was to design more and larger dams, more and longer bridges, more powerful motors, more miles of highways. Not yet could we foresee new needs; only rarely did an engineering student have a teacher who would explore the unknown. The engineering colleges educated for immediate use and application.

Today the world is in another technological explosion—of scientific advance, new materials, new energy sources, new engineering systems, research; and an educational system built on past experience, on use, and on application, shows its faults. Who knows of the use or the application to be made of our knowledge in the future? The technical world is no longer bounded. It and our needs can change. As knowledge expands we continually move into new fields and we face problems for which there is no past experience. Indeed, the future will provide challenging problems for which the basic knowledge is now unknown.

The simple engineering problems have been solved, and we do not progress by repeated solution of once-solved problems. But the new problems are more complex, and at today's level of sophistication no one man may be expert enough in the many disciplines required to solve a new problem. The engineer will work with a team and must be able to hold his own and often take the lead in association with other engineering disciplines and with the chemist, the physicist, the biologist, or the mathematician.

The colleges of engineering must recognize that they prepare their graduates for a lifetime of challenges—the changing world, the massing of new knowledge, the necessity for depth and breadth, the requirements of teamwork and citizenship. Some of our colleges see this need for a new approach and a new philosophy—they do not teach of art which may be obsolete tomorrow; they have broadened their treatment of the sciences underlying engineering application; they stress mathematics as a language, a tool, and as training in logical reasoning; they emphasize the humanities. They teach to educate the man, not merely to train an engineer, and teach him how to learn and to continue learning throughout the remainder of his life.

Most segments of the electrical and electronics industry support and encourage such thinking; other engineering groups oppose. One source says the trend to more basic science is improper and inconsistent with the needs of industry and mankind, and supports the assertion by pointing to the success of engineers trained in our professional field curricula and given nuts-and-bolts courses. Against this we would like to cite the lack of success of similarly trained engineers in the wartime laboratories, or in situations where they faced new and changing ground rules.

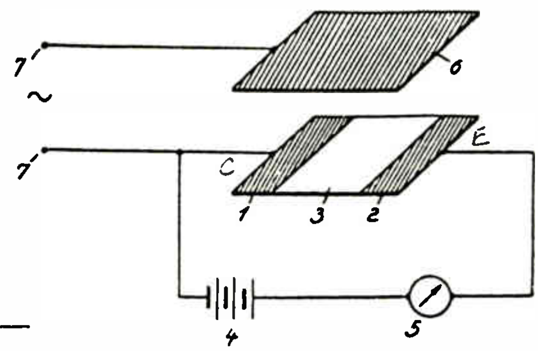
In further support of our point are the calls from industry for retreading and re-educating those engineers who were taught to use, and to apply 15 or more years ago; these men often lack the scientific fundamentals and the mathematical training on which to progress into new fields. Several of our colleges are meeting this need.

Without further advance of the colleges toward a fundamental and mathematical education for the application of science, we seem to face technological obsolescence of our graduates. We should normally expect to continue their education as the field advances—what dismays is that there was so little of fundamental import in their original training. The segment of industry that is unhappy with recent graduates must make up its mind; nuts and bolts and engineering art in college can lead to dated engineers; fundamental science and mathematics in college may permit engineering progress into the new world.

Once again we say—industry cannot have its confections on the shelf, and simultaneously enjoy a diet of cake.

J. D. Ryder

Fig. 1

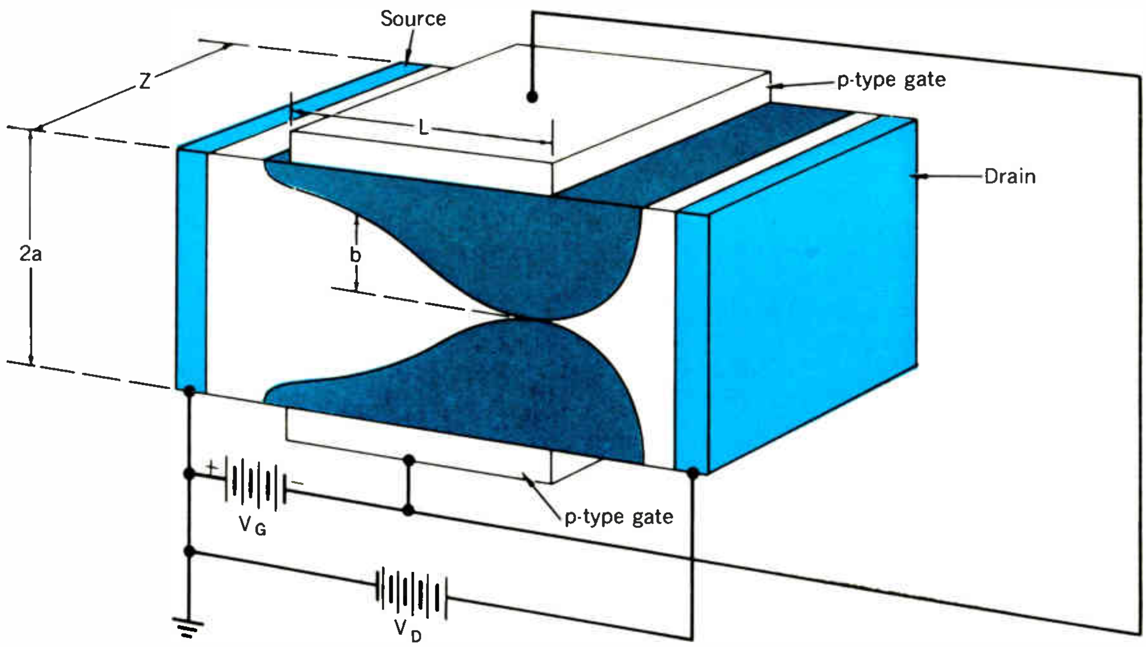


The field-effect transistor—

an old device with new promise

Fabrication by evaporation, insulated-gate construction, and predictable performance are contributing to the emergence from obscurity of the unipolar field-effect transistor

J. T. Wallmark *Radio Corporation of America*



"One of the important characteristics which distinguishes the field-effect transistors described here from the more conventional types is that the working current is substantially 'unipolar.' In the point-contact, filamentary, and junction types an important process is the injection of minority carriers into regions having relatively high concentrations of majority carriers. In the region of injection, space-charge neutrality is maintained to a high degree by currents of majority carriers which neutralize the space charge of the minority carriers. Since carriers of both signs are involved, these processes may be referred to as 'bipolar.' In a 'field-effect' transistor, the current flow is carried by one type of carrier only. The changed conductance between input and output terminals results from changing numbers of carriers of this one type. For this reason the name 'unipolar transistors' is proposed . . .

"In Fig. 1 we represent an example of a unipolar field-effect transistor. It is a three-terminal device, and consists principally of a layer of p-type material sandwiched between two layers of n-type material, the doping being much stronger in the n-type material, which is designated as n^+. The 'working current' is carried by holes flowing in the x-direction in the p-layer. The terminals are inserts of heavily doped p-type material, designated p^+. Under operating conditions, reverse bias is applied across the p-n junctions, and space-charge regions form in which the carrier concentration is negligible. As a consequence, the current flows in a *channel* of p-type material bounded by the space-charge regions.

"If the reverse bias at one p^+ terminal is larger than at the other, the channel will be narrower at the one terminal . . .

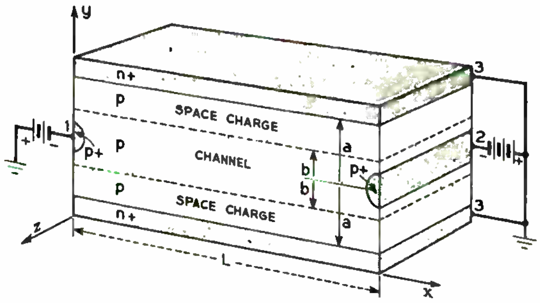


Fig. 1. Unipolar field-effect transistor. Space-charge region and channel in a $(n^+)p(n^+)$ structure.

"In passing, we shall point out that the unipolar transistor of Fig. 1 is in some ways a closer analog to a vacuum tube than are the bipolar transistors. If we imagine that a signal is applied between terminals 3 and ground, then the effect will be to widen and narrow the channel which carries current between 1 and 2. This is closely analogous to the action of a grid which controls the current flow in a 'channel' of thermionic electrons flowing between the grid wires. As in the bipolar case, the control is exerted by flow of electrons by one mechanism on flow by another mechanism; in this case, flow by excess electrons in the n^+ regions controls flow of holes in the channel. A difference from the bipolar case is that the controlling and controlled currents differ not only in conduction mechanism but also in spatial location."

(W. Shockley, "A Unipolar 'Field-Effect' Transistor," *Proc. IRE*, Nov. 1952, pp. 1365–1366.)

In 1935 Oskar Heil of Berlin obtained a British patent[1] on "Improvements in or Relating to Electrical Amplifiers and Other Control Arrangements and Devices." Figure 1 is the inventor's original illustration describing his device. The light area marked *3* is described as a thin layer of a semiconductor such as tellurium, iodine, cuprous oxide, or vanadium pentoxide; *1* and *2* designate ohmic contacts to the semiconductor. A thin metallic layer marked *6* immediately adjacent to but insulated from the semiconductor layer serves as control electrode. Heil describes how a signal on the control electrode modulates the resistance of the semiconductor layer so that an amplified signal may be observed by means of the current meter *5*. Using today's experience and language, one might describe this device as a unipolar field-effect transistor with insulated gate.

Fig. 1. Drawing from British patent no. 439,457 showing early field-effect structure; inventor: O. Heil.

Fig. 2. Schematic diagram of unipolar field-effect transistor according to description by W. Shockley in 1952.

In 1952, W. Shockley[3] described a unipolar field-effect transistor (see editorial box) with a control electrode consisting of a reverse-biased junction, shown in Fig. 2. Such transistors were subsequently built and tested according to C. Dacey and I. M. Ross,[5] who also added an analytical treatment of the performance limits of such devices in 1955. Until recently, however, the field-effect transistor remained in the laboratory stage of development.

Three factors have contributed to make the unipolar field-effect transistor emerge from previous obscurity. First, the understanding of semiconductor physics and the related advance of semiconductor technology now make it possible to fabricate devices with predictable performance. Second, there are new technological features such as fabrication by evaporation as described by

Weimer,[24] and particularly the insulated-gate construction described by Hofstein and Heiman,[54] and others,[15,20] which promise much improved performance over the reverse-biased-junction gate construction. The insulated-gate construction is shown in cross section in Fig. 3. The third factor is the very considerable extent to which transistorization of electronic equipment has now progressed. In this situation it becomes increasingly annoying to find a number of functions where the bipolar transistor falls far short of devices such as electron tubes, making complete transistorization impractical or uneconomical. Therefore a need has arisen for a transistor with the characteristics of the field-effect transistor to complement the bipolar transistor in particular applications.

This article summarizes the characteristics and the performance limits of field-effect transistors to the extent that they are different from those of bipolar transistors. The technical possibilities of unipolar field-effect transistors as active devices and as building blocks for integrated circuits are reassessed.

Fig. 3. Schematic diagram is shown of insulated gate field-effect transistor (cross-sectional view).

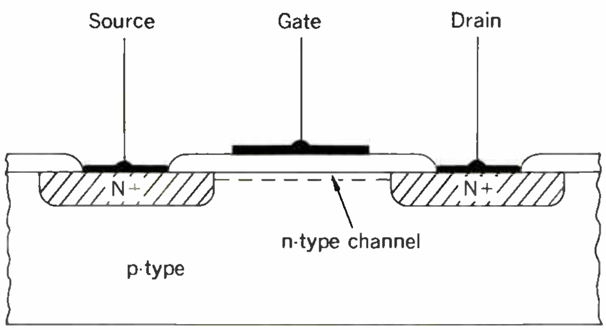
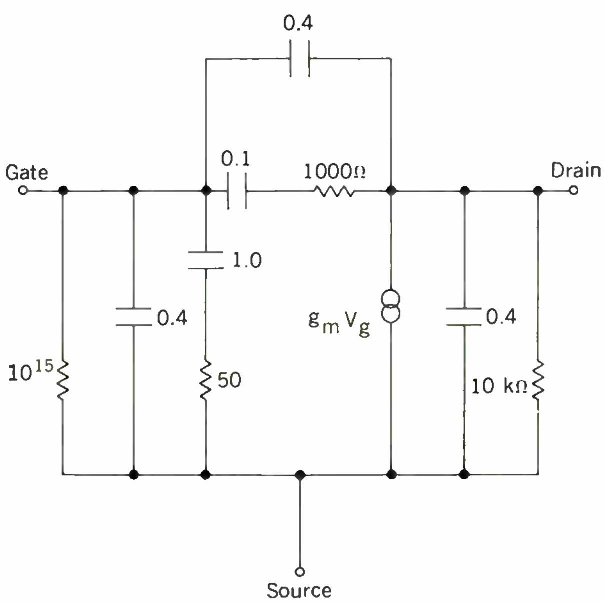


Fig. 4. Equivalent circuit of insulated gate field-effect transistor and factors making for low input capacitance.



Active device characteristics

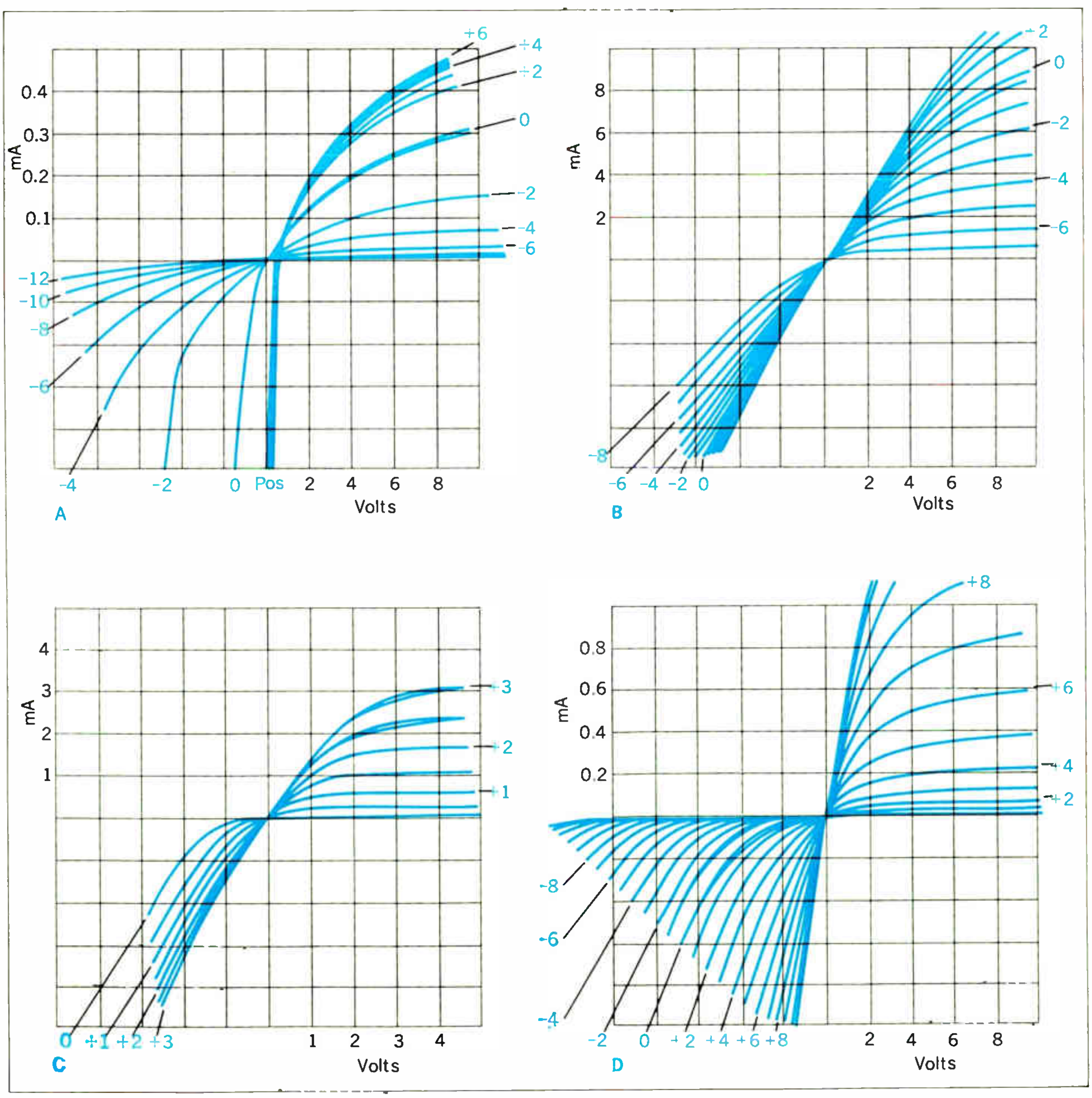
Input impedance. The most obvious feature of the field-effect transistor is its high input impedance. The saturation current drawn by the reverse-biased gate of a germanium field-effect transistor with typical resistivity and dimensions amounts to about 1 μA, corresponding to an input resistance of the order of 1 megohm at the operating point at room temperature. For a silicon transistor, the current is about 10^3 times smaller, and the input resistance is consequently about 10^9 ohms at room temperature. The saturation current increases by about one order of magnitude for a rise in temperature of 30 to 50°C. Therefore, when appreciable power is dissipated or the cooling is insufficient, the input resistance may decrease. In contrast, the insulated gate field-effect transistor has a gate input resistance of 10^9 to 10^{15} ohms. The latter value is of such magnitude that when an electric charge is deposited on the gate it takes at least several days time for the leakage of charge to be detected by observing the change in current on the output side.

Associated with the junction gate is an input capacitance which has a value of 20 to 100 pF at a transconductance of 1000 to 3000 μmhos for most field-effect transistors now commercially available. This capacitance can be made considerably smaller for the insulated gate than for a reverse-biased junction and is typically 1 to 2 pF for the same transconductance. A breakdown of the factors that contribute to this capacitance is obtained from the equivalent circuit for such a transistor shown in Fig. 4. The capacitances in the stem between leads and the contact areas amount to about 0.4 pF. In the device itself, the capacitance between drain and gate (feedback capacitance) is less than 0.1 pF while the gate-to-source capacitance is about 1 pF for a device with a transconductance of 1500 μmhos.

Current-voltage characteristics. Current-voltage characteristics obtained on a curve tracer for four different field-effect transistors are shown in Fig. 5. Transistors tested were: (*A*) a silicon junction device, (*B*) a silicon insulated-gate depletion type, (*C*) an evaporated cadmium-sulfide device, and (*D*) a silicon insulated-gate enhancement type. For comparison, all devices were operated with positive and negative drain voltage and with positive and negative gate voltage, although the junction input device is not designed for the dual mode of operation. When the gate has no bias ($V_g = 0$), transistors (*A*) and (*B*) draw a large drain current, while transistors (*C*) and (*D*) draw negligible current, typically less than 1 μA. When the gate is biased positively, transistor (*A*) quickly saturates at the same time that the gate resistance becomes very low. In Fig. 5, this results in an apparent voltage offset at $I_d = 0$ because of the construction of the curve tracer. When V_d is negative, the point at which the gate becomes forward biased shows up as a kink in the curves where they cross the dashed line. The decrements in drain current for negative increments in gate voltage decrease rapidly in case (*A*) which may also be expressed as a transconductance that varies strongly with gate bias. In cases (*B*), (*C*), and (*D*), the decrements in drain current for the same increments in gate voltage are uniform over a large range; in other words, the transconductance is nearly constant over a large range of current.

Frequency response. The frequency response of field-effect transistors has been analyzed by Dacey and Ross[7] who concluded that the response would be limited in germanium by the fact that the carrier mobility saturates, beginning at a critical field of about 10^3 volts/cm. Higher fields would require such excessive power dissipation that it would be difficult to remove the generated heat. A comparison based on this finding between field-effect transistors and bipolar transistors was made by Early (*Proc. IRE*, vol. 46, 1958, p. 1924) and indicated a superiority in frequency response of the bipolar transistor over the field-effect transistor by a factor of ten. However, a later analysis by Rose (*RCA Review*, vol. 24, Dec. 1963, p. 627) has indicated that the same physical phenomenon, the dielectric relaxation time of the material between the emitter and the control, limits the frequency response of all solid-state triodes—bipolar, field-effect transistors, field-emission triodes, and space-charge-limited triodes. If, instead of the critical velocity, the thermal velocity is accepted as an upper limit to the velocity of the carriers in field-effect transistors, the frequency response is indeed the same for bipolar transistors and field-effect transistors. The limiting frequency is then given by

Fig. 5. Curve traces of drain current vs. drain voltage with gate voltage as parameter for: A—Silicon, junction gate. B—Silicon, insulated gate, depletion mode. C—Cadmium sulfide, insulated gate, enhancement mode. D—Silicon, insulated gate, enhancement mode.



$$f = \frac{6 \times 10^6}{L}$$

where L is the length of the gate in centimeters in the direction of current flow. In bipolar transistors L is the emitter stripe width (or the emitter-to-base spacing). In practical devices, stray reactances, which are difficult to avoid, lower this figure considerably.

Figure 6 plots the gain-bandwidth figure F for a number of commercial field-effect transistors, where

$$F = \frac{g_m}{2\pi C_{gate}}$$

and C_{gate} is the total gate capacitance with drain and source grounded. Each horizontal line denotes a different manufacturer. The data have been obtained from commercial data sheets which usually give a maximum and a minimum transconductance with a typical value in between. This explains the ranges shown in Fig. 6. The bottom line gives values for insulated-gate field-effect transistors. A denotes silicon units, which have a higher frequency response than commercial field-effect transistors, which all have junction input. B denotes laboratory results for evaporated cadmium-sulfide units. The difference in frequency response reflects the fact that carrier mobility in cadmium sulfide is lower than in silicon.

The insulated gate field-effect transistor exhibits a higher gain-bandwidth product than junction input types because it is easier to fabricate a short gate with the insulated-gate technology than with a junction-gate technology.

Because the field-effect transistor is a majority carrier device, it does not exhibit carrier storage in switching applications. The switching speed is determined entirely by the R-C time constant of the gate capacitance charging through the channel resistance. With a low-impedance driver, switching times as low as a fraction of a nanosecond have been observed, but for one field-effect unit driving another, switching times of 10 to 20 ns are more realistic at present.

Bilateral symmetry, offset voltage. Many field-effect transistors are made symmetrical, with source and drain interchangeable. Bipolar transistors also can be made symmetrical but not without a sacrifice in performance. In the long run a sacrifice in performance may result for the field-effect transistor as well. For example, the source series resistance gives a strong negative feedback and also contributes to the noise of the unit far more than the drain series resistance. It is, therefore, advantageous to offset the gate toward the source electrode, thereby gaining performance but sacrificing symmetry.

In contrast to bipolar transistors, the field-effect transistor has no voltage offset. This is illustrated in Fig. 7, which shows the central portion of the current-voltage characteristics greatly magnified. Note that the curves are monotonic through the origin. For voltages sufficiently small compared to the pinch-off voltage, the curves are approximately linear. The resistance values obtained range from a minimum of $1/g_m$, i.e. about a few hundred ohms, to the resistance of a reverse-biased junction (the drain junction) of about a few hundred megohms.

Radiation tolerance. Radiation doses for field-effect

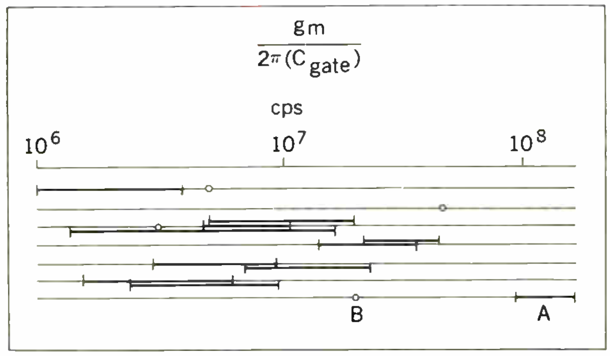


Fig. 6. Gain-bandwidth figure of merit for field-effect transistors. A—Experimental silicon insulated gate units. B—Experimental cadmium sulfide insulated gate unit.

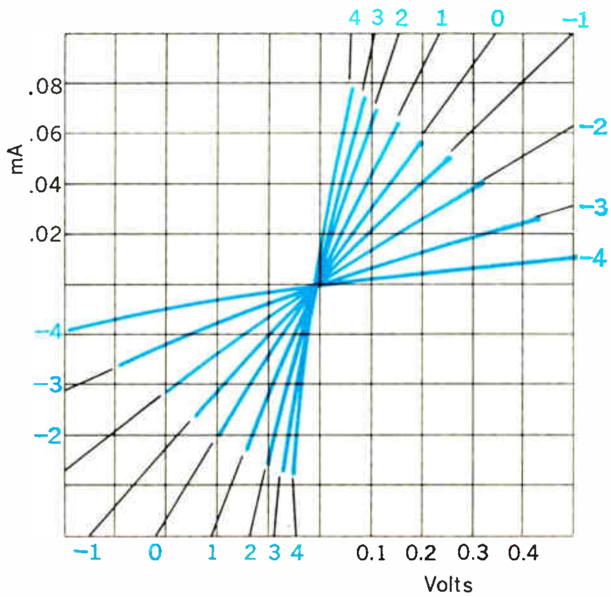
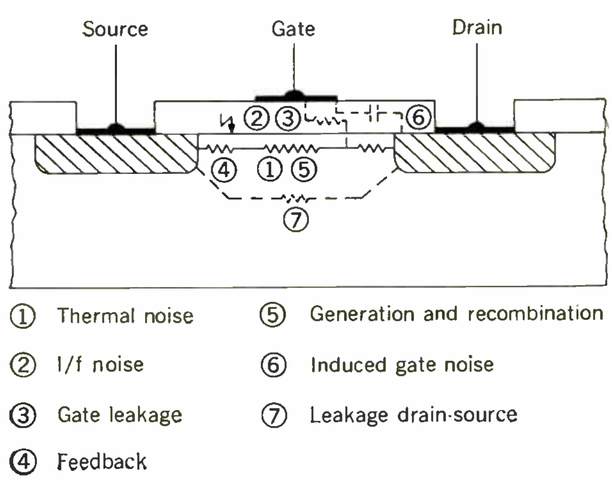


Fig. 7. Curve trace of drain current vs. drain voltage with gate voltage as parameter for low drain voltages.

Fig. 8. Schematic of noise sources in field-effect transistors.



transistors are tolerable up to a value where either the mobility or the doping level change—generally about ten times the dose at which lifetime degradation begins. Field-effect transistors may be expected to tolerate a radiation dose approximately ten times greater than bipolar transistors of comparable dimensions. At present little data are available on radiation tolerance of field-effect transistors. Existing data are summarized in Table I. The bipolar transistor is made radiation immune by using a semiconductor material in which the minority carrier lifetime is initially very short and by making the base region very narrow. The field-effect transistor, however, is made radiation immune by using semiconductor material with initially low mobility and high doping level. It seems highly probable that the ten-times greater radiation tolerance of the field-effect transistor will remain.

Noise behavior. While the main noise source in bipolar transistors is the shot noise connected with the flow of minority carriers, the main source of noise in field-effect transistors is the thermal noise in the output resistance.

A summary of the different noise mechanisms that are important in field-effect transistors is shown in Fig. 8. At low frequencies, $1/f$ noise occurs. In field-effect transistors with junction input the $1/f$ noise is greater than the thermal noise below about 100 c/s. In insulated-gate transistors, the $1/f$ noise is as yet quite large and exceeds thermal noise at frequencies as high as several megacycles. Whether or not this may be improved is not yet known. At high frequencies the drain-to-gate feedback capacitance causes thermal noise to be fed back to the gate and to be amplified. However, since the signal is also fed back, the signal-to-noise (S/N) ratio is, to a first approximation, unchanged. In the source end of the channel, a source resistance constitutes an unbypassed resistance, the thermal noise of which appears in the input and becomes amplified. As a resistance in the drain lead does not have this disadvantage, it may be desirable to offset the gate toward the source. If the gate insulation is defective, the corresponding leakage current through the oxide gives rise to very strong noise. Also leakage current from drain to source through, on the surface of, or outside the semiconductor gives noise.

The noise figure of a field-effect transistor is only a few tenths of one dB at moderate frequencies and with sufficiently high input resistance; e.g., 3 megohms. Since the noise figure varies with the input resistance, it is more convenient to use an equivalent noise resistance as is done for electron tubes. The equivalent noise resistance for a field-effect transistor is

$$R_{eq} \approx 0.5/g_m$$

One of the main degradation phenomena in bipolar transistors during use is lifetime deterioration. As this phenomenon is of no consequence in field-effect transistors, the prospect for life and reliability is correspondingly better.

Choice of material. Another consequence of majority-carrier conduction is the large number of semiconductor materials which are potentially useful for field-effect transistors but not for bipolar transistors. This is borne out by Table II, which lists the semiconductors that have been used for bipolar transistors (marked ‡),

I. Neutron dose n/cm² to reduce transconductance of unipolar field-effect transistor to 70 per cent of initial value*

Type	Semiconductor	Number of Units Tested	Dose, n/cm²
Junction gate . . .	Si†	3	1×10^{14}
	GaAs†	1	4×10^{15}
	Si‡		3×10^{13}
	Si§	3	1×10^{13} to 6×10^{13}
Insulated gate, depletion type	Si§	3	1×10^{13} to 3×10^{14}
Insulated gate, enhancement type	Si§	3	3×10^{14}

* It is assumed that damage is linear with dose; 1 MeV electron = 10^{-2}n/cm².
†See reference 21.
‡ Quarterly Progress Report no. 6, AF (616)-6278, Westinghouse Electric Corp.
§ Measurements made at RCA.

II. Potentially useful semiconductors for field-effect transistors

Designation (Periodic Table)	Type of Semiconductor
I-V	Cs_3Sb*
I-VI	Cu_2O†
II-IV	Mg_2Sn* Mg_2Si*
II-VI	CdS† CdTe* ZnO† ZnS† CdSe†
III-V	GaAs*†‡ GaSb* GaP*† AlSb* InSb* InP*‡ InAs*
IV	Ge*†‡ Si*†‡ SiC*†
IV-VII	PbS*‡ PbSe* PbTe* TiO_2†
V-VI	Bi_2Te_3*
VI	Te*
VI-VIII	NiO†

* Junction formation.
† Resistivity sufficient for unipolar transistors.
‡ Semiconductors with lifetime sufficient for bipolar transistors.

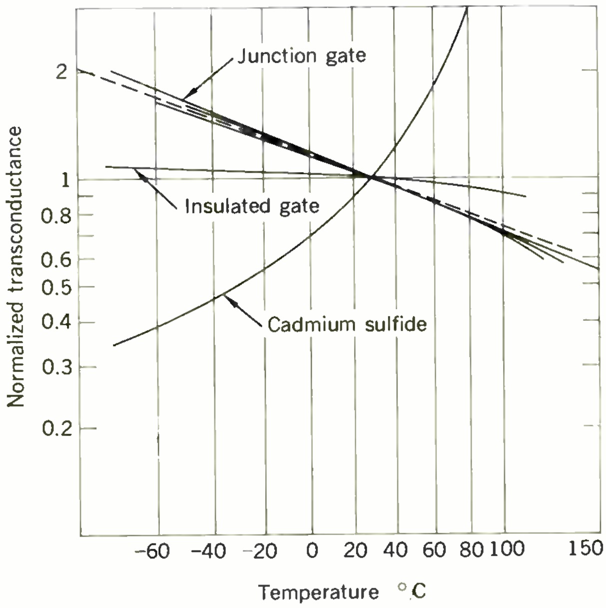
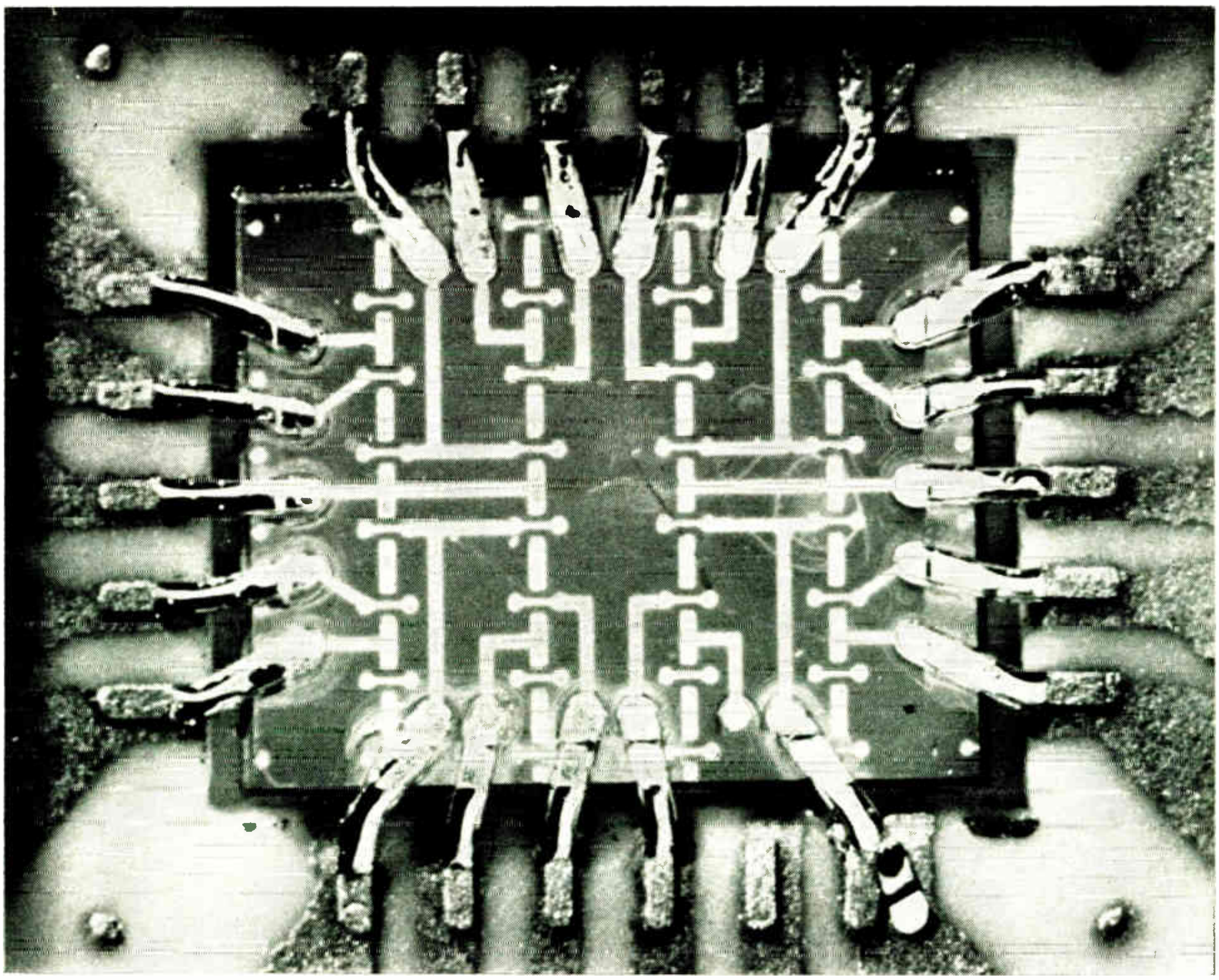


Fig. 9. Transconductance vs. temperature for silicon, junction and insulated gate; cadmium sulfide, insulated gate.

as well as some of the common semiconductors that are potentially useful for field-effect transistors. The criteria for usefulness are either that both p- and n-type material can be made so that a channel can be properly isolated from the bulk or from the gate, or that the resistivity can be made sufficiently high to prevent an induced channel on the surface from being shunted through the bulk by conduction. The Shockley type of field-effect transistor is an example that satisfies the first criterion, and the insulated gate field-effect transistor is one that satisfies the second. While very few semiconductor materials at present are useful for bipolar transistors, the opposite is true for field-effect transistors.

When it comes to making transistors for special purposes requiring a particular semiconductor, it will frequently be necessary to resort to field-effect structures. Consider, for example, the necessity of using wide band-gap materials such as silicon carbide, gallium arsenide, or cadmium sulfide in transistors for high-temperature operation. Or consider the fabrication of transistors by evaporating or plating in which case the short lifetime in the semiconductor does not permit bipolar principles to be used. A final example is that use of the thin-film

Fig. 10. Integrated circuit using four rows of interconnected field-effect transistors.



structure permits fabrication of high-frequency performance transistors from semiconductors with extremely high mobility, such as InSb or InAs, without the need for a reduction of dimensions.

One factor not discussed, though of central importance in insulated gate field-effect transistors, is the surface. Whether all the listed semiconductors can be given a surface sufficiently free of traps for satisfactory transistor performance is unknown.

Thermal stability. The temperature dependence of the field-effect transistor characteristics is related to the majority-carrier mobility. For silicon in the resistivity range used for field-effect transistors, the mobility is proportional to the (absolute temperature)$^{-3/2}$ characteristic of lattice scattering. This relation is shown in Fig. 9 as a dashed line. In the same figure are curves of g_m vs. temperature taken from data sheets for four different makes of silicon field-effect transistors that, within the accuracy of the data, all fall on this line. The same temperature dependence is obtained for the current at constant voltages.

Figure 9 also depicts the data for a thin-film transistor of evaporated cadmium sulfide. In this case the temperature dependence is much larger and the temperature coefficient is positive instead of negative. The evaporated cadmium-sulfide layer is known to consist of many small crystallites with a large number of defects and grain boundaries. Therefore, in addition to lattice scattering, there is a considerable amount of surface and defect scattering which explains the different temperature dependence of the evaporated cadmium sulfide field-effect transistor.

In the case of the insulated gate field-effect transistor, also shown in Fig. 9, the temperature dependence is very small. In this transistor, the current passes very close to the surface where the mobility is reduced by surface and, perhaps, defect scattering; hence, it is tempting to ascribe the small temperature dependence to a fortuitous balance of two effects with opposite temperature dependence, namely, the lattice scattering with negative temperature coefficient and surface scattering with positive temperature coefficient. If this should turn out to be a fact, it should be possible to accomplish an even closer balance for specific purposes, perhaps to the point where active devices may be obtained with the same small temperature coefficient that usually characterizes passive components; i.e., a few hundred parts per million per degree centigrade.

Another aspect of thermal stability is freedom from thermal runaway in field-effect transistors. In bipolar transistors the collector current increases with increasing temperature to the point where thermal runaway takes place and the transistor is destroyed. This is particularly troublesome in power transistors. In field-effect transistors (though not at present in thin-film transistors) the current decreases with increasing temperature, reducing the dissipated power and preventing thermal runaway.

Characteristics in integrated circuits

Geometry. Bipolar transistors are difficult to incorporate in integrated circuits partly because the current flow is perpendicular to the surface while the preferred circuit construction is in the plane of the surface, and partly because the carrier lifetime must be maintained. In contrast, the field-effect transistor is naturally a plane surface device with no requirement on carrier lifetime and can therefore be easily used in integrated circuits. An integrated circuit using 16 field-effect transistors is shown in Fig. 10. The transistors are aligned in four rows of four each and with one source (or drain) in common for each neighboring pair of units. The interconnections are deposited on the surface of the silicon wafer and are insulated from the active parts by an oxide layer. Another attractive feature of the field-effect transistor in this application is the fact that a transistor is in effect a resistor and may with advantage be used as such in circuits. Such resistors are highly nonlinear, a characteristic that is usually advantageous in digital circuits.

Digital circuit features. Another feature useful in digital circuits is the fact that an enhancement-type field-effect transistor is in itself an inverter. This is illustrated in Fig. 11(A) which shows a transistor stage with a "low" input (no or negligible current flowing through the device) and, therefore, a "high" output. With a high input as shown in Fig. 11(B) considerable drain current flows and the output is low. The voltages

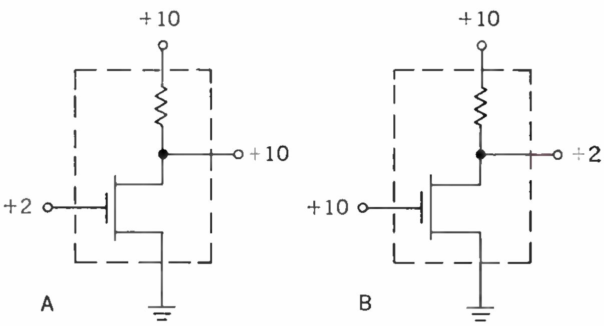
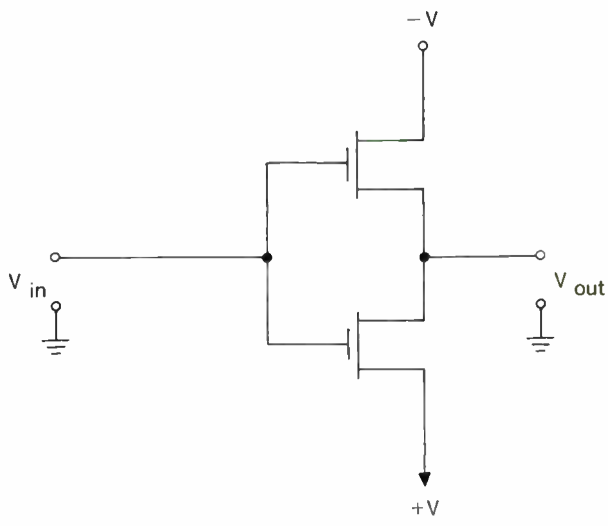


Fig. 11. Field-effect transistor inverter circuit: A—With OFF signal. B—With ON signal on the input.

Fig. 12. Bistable circuit using pairs of field-effect transistors draws no power except when switched.



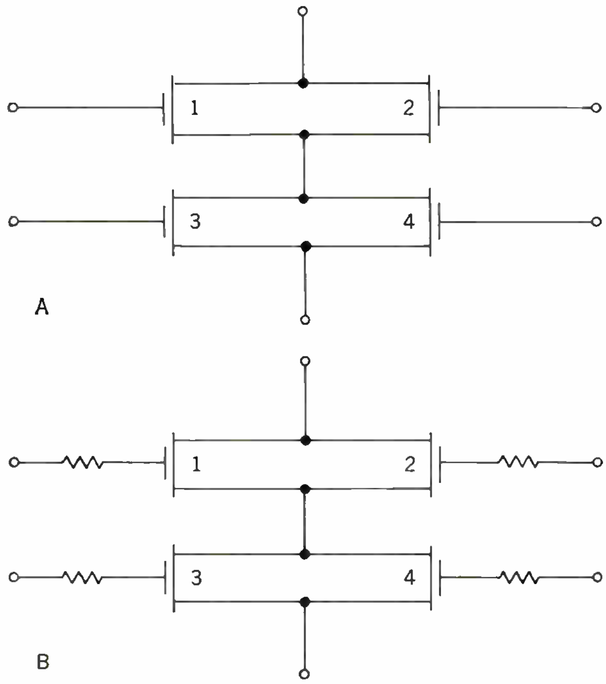


Fig. 13. A—Redundant four-group. B—Redundant four-group with gate resistors (see reference 42).

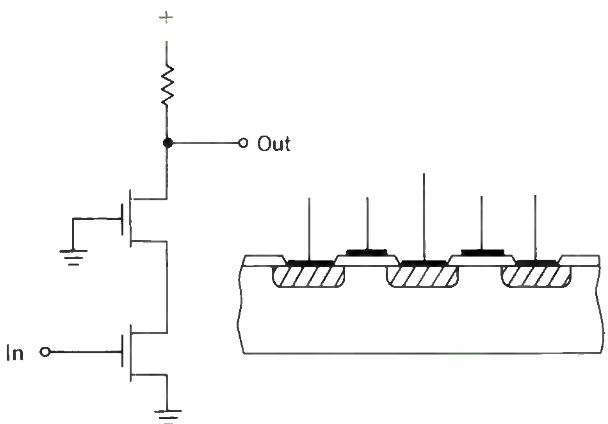
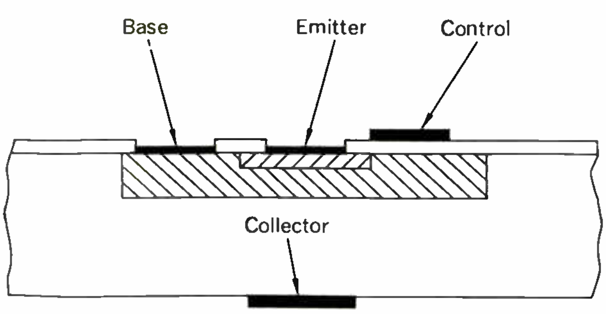


Fig. 14. Drawing of field-effect transistor cascode circuit.

Fig. 15. Semiconductor tetrode using n-p-n transistor combines bipolar and field-effect structures (see reference 22).



are identical and of the same polarity so that direct coupling may be used.

A unique circuit, which uses pairs of field-effect transistors with complementary symmetry and makes logic possible without drawing any current except during switching, has recently been described (Fig. 12). When the input potential is high the top unit is cut off and the output potential is high. When the input is low the bottom unit is cut off and the output is low. In neither position does the pair draw current since one unit in the series chain is always cut off. Current is drawn only in the transition between states.

Redundancy. In large integrated circuits, the use of redundancy becomes more and more attractive the larger the circuit. One of the simplest ways to introduce redundancy is through the use of series-parallel four-groups as shown in Fig. 13(A). Each element is then replaced by a group of four identical elements, and the four-group performs the intended circuit function even if one, two, or even three of the elements in the group become faulty. With conventional bipolar transistors, such four-groups are not very efficient because a short circuit between input and output allows current flow between adjacent four-groups and interferes with the functioning of the redundancy. With field-effect transistors, however, redundancy in the form of four-groups is quite effective. Because of the high input resistance, there can be introduced in the gate lead a resistor large enough to protect against excessive current, but small enough not to reduce the speed of the circuit appreciably. A typical value may be 10^4 ohms. Then the redundant circuit would appear as shown in Fig. 13(B).

Multiple units. Special advantages may be obtained by combining the functions of two or more units in a manner analogous to that in which special advantages may be obtained in electron tubes by introducing more than one grid. Figure 14 shows a simple combination of two series-connected units which reduces the feedback capacitance. Just as extra grids in electron tubes give better performance and lower cost than the use of multiple units, so it appears that the combination of two or more field-effect units in one structure may be cheaper and better than several separate units.

Of special interest is the combination of a bipolar and a field-effect transistor which has been described recently. In this unit, shown in Fig. 15, the extra field-effect electrode controls the surface potential of the base region and thereby the surface recombination velocity. When the potential is positive, the surface potential is also positive and the surface recombination is consequently high. The base bias current is therefore used up for recombination of injected carriers under the field electrode and little is left for biasing the emitter. Therefore, the injected current is low. On the other hand, when the field-electrode potential is negative with respect to the base, the surface recombination is low and all the base bias current is available for injecting carriers from the emitter. Then the current transfer ratio of the tetrode is high.

The tetrode combines the advantages of a bipolar and a field-effect transistor. However, the device requires that the bipolar characteristics and the field-effect characteristics be controlled at the same time on the same unit. This has led to difficulties in the fabrication, and such units are not yet commercially available.

CHRONOLOGICAL BIBLIOGRAPHY

1. Heil, O., "Improvements in or Relating to Electrical Amplifiers and other Control Arrangements and Devices," British Patent 439, 457, Sept. 26, 1939.

2. Shockley, W., and G. L. Pearson, "Modulation of Conductance of Thin Films of Semiconductors by Surface Charges," *Phys. Rev.*, vol. 74, 1948, p. 232.

3. Shockley, W., "A Unipolar Field-Effect Transistor," *Proc. IRE*, vol. 40, Nov. 1952, pp. 1365–1376.

4. Pearson, G. L., "A High Impedance Silicon Field Effect Transistor," *Phys. Rev.*, vol. 90, Apr. 15, 1953, p. 336.

5. Dacey, G. C., and I. M. Ross, "Unipolar 'Field-Effect' Transistor," *Proc. IRE*, vol. 41, Aug. 1953, pp. 970–979.

6. Prim, R. C., and W. Shockley, "Joining Solutions at the Pinch-Off Point in 'Field-Effect' Transistor," *IRE Trans. on Electron Devices*, vol. ED-4, Dec. 1953, pp. 1–14.

7. Dacey, G. C., and I. M. Ross, "The Field-Effect Transistor," *Bell Syst. Tech. J.*, vol. 34, Nov. 1955, p. 1149.

8. Huang, C., M. Marshall, and B. White, "Field-Effect Transistor Applications," *AIEE Communication and Electronics*, vol. 3, July 1956, pp. 323–329.

9. Teszner, S., "A New High Frequency Amplifier" (in French), *Comptes Rendus*, vol. 246, Jan. 6, 1958, p. 72.

10. Aisberg, E., "The Tecnetron-Competitor of the Transistor," *Radio-Electronics*, vol. 29, May 1958, p. 60.

11. Warner, Jr., R. M., W. H. Jackson, G. I. Doucette, and H. A. Stone, Jr., "A Semiconductor Current Limiter," *Proc. IRE*, vol. 47, Jan. 1959, pp. 44–56.

12. Stone, Jr., H. A., "Theory and Use of Field-Effect Tetrodes," *Electronics*, vol. 32, May 15, 1959, p. 66.

13. Wallmark, J. T., and S. M. Marcus, "Integrated Devices Using Direct-Coupled Unipolar Transistor Logic," *IRE Trans. on Electronic Computers*, vol. EC-8, June 1959, pp. 98–107.

14. Wegener, H. A. R., "The Cylindrical Field-Effect Transistor," *IRE Trans. on Electron Devices*, vol. ED-6, Oct. 1959, pp. 442–449.

15. Schwartz, B., and M. Levy, "Field Effect on Silicon Transistors," *Proc. IRE*, vol. 48, Mar. 1960, pp. 317–320.

16. Martin, A. V. J., "The Alcatron." *Electronic Industries*, vol. 19, Oct. 1960, p. 98.

17. Beale, J. R. A., D. E. Thomas, and T. B. Watkins, "Field Effect on Silicon Transistors (letter), *Proc. IRE*, vol. 48, Dec. 1960, p. 2038.

18. Terman, L. M., "An Investigation of Surface States at a Silicon/Silicon-Oxide Interface Employing MOS Diodes," Tech. Rept. No. 1655-1, Stanford Electronics Labs., Stanford University, Stanford, Calif., Feb. 23, 1961.

19. Stone, Jr., H. A., and R. M. Warner, "The Field-Effect Tetrode," *Proc. IRE*, vol. 49, July 1961, p. 1170–1183.

20. Ihantola, H. K. J., "Design Theory of a Surface Field-Effect Transistor," Tech. Rept. No. 1661-1, Stanford Electronics Labs., Aug. 17, 1961.

21. Kulp, B. A., J. P. Jones, and A. F. Vetter, "Electron Radiation Damage in Unipolar Transistor Devices (letter), *Proc. IRE*, vol. 49, Sept. 1961, p. 1437.

22. Sah, C. T., "A New Semiconductor Tetrode—The Surface-Potential Controlled Transistor," *Ibid.*, Nov. 1961, pp. 1623–1634.

23. Martin, T. B., "Circuit Applications of the Field Effect Transistor," *Semiconductor Products*, vol. 5, Feb. 1962, p. 33; and Mar. 1962, p. 30.

24. Weimer, P. K., "The TFT—A New Thin-Film Transistor," *Proc. IRE*, vol. 50, June 1962, pp. 1462–1469.

25. Onodera, G. C., W. J. Corrigan, and R. M. Wagner, Jr., "Silicon Field-Effect Transistor with Internal Epitaxial Channel" (letter), *Ibid.*, vol. 50, Aug. 1962, p. 1824.

26. van der Ziel, A., "Thermal Noise in Field-Effect Transistors," *Ibid.*, Aug. 1962, pp. 1808–1812.

27. Etter, P. J., B. L. H. Wilson, "Inductance from a Field-Effect Tetrode," (letter) *Proc. IRE*, vol. 50, Aug. 1962, p. 1828.

28. Parmer, W. F., "Four Ways to Pair Field-Effect and Conventional Transistors," *Electronic Design*, vol. 10, Aug. 16, 1962, p. 44.

29. Highleyman, W. H., and E. S. Jacob, "An Analog Multiplier Using Two Field Effect Transistors," *IEEE Trans. on Communications Systems*, vol. CS-10, no. 3, Sept. 1962, pp. 311–317.

30. van der Ziel, A., "Shot Noise in Thin Film Transistors" (letter), *Proc. IRE*, vol. 50, Sept. 1962, p. 1985.

31. Alford, D., F. Garrett, and L. J. Sevin, "Germanium Field-Effect Transistors," *IEEE Trans. on Broadcast and Television Receivers*, vol. BTR-8, Nov. 1962, pp. 106–119.

32. Bergstrom, J. W., "CdSe Photoconductive Field-Effect Transistors" (letter), *Proc. IRE*, vol. 50, Nov. 1962, p. 2376.

33. Glover, V., "Using a New Device: Field-Effect Transistor Oscillators," *Electronics*, vol. 35, Dec. 21, 1962, p. 44.

34. Bockemuehl, R. R., "Analysis of Field-Effect Transistors with Arbitrary Charge Distribution," *IEEE Trans. on Electron Devices*, vol. Ed-10, Jan. 1963, pp. 31–34.

35. Latham, D. C., D. J. Hamilton, F. A. Lindholm, "New Modes of Operation for Field Effect Devices" (letter), *Proc. IEEE*, vol. 51, Jan. 1963, p. 226.

36. Olsen, D. R., "Equivalent Circuit for a Field-Effect Transistor" (letter), *Ibid.*, Jan. 1963, p. 254.

37. Cohen, J. M., "Generating Linear Waveforms with Field-Effect Transistors," *Electronic Design*, vol. 11, Jan. 4, 1963, p. 66.

38. Burns, R. C., and E. D. Crawfis, "Try Field-Effect Transistors for Redundance," *Ibid.*, Jan. 18, 1963, p. 74.

39. Grosvalet, J., C. Motsch, and R. Tribes, "Physical Phenomenon Responsible for Saturation Current in Field Effect Devices," *Solid-State Electronics*, vol. 6, Jan.–Feb. 1963, p. 65.

40. Bruecke, W. C., "Noise Measurements in Field-Effect Transistors" (letter), *Proc. IEEE*, vol. 51, Feb. 1963, p. 378.

41. Lindholm, F. A., D. C. Latham, "Junction Capacitance of Field-Effect Transistors" (letter), *Ibid.*, Feb. 1963, p. 404.

42. Wallmark, J. T., A. G. Revesz, "Redundancy in Unipolar Transistor Circuits" (letter), *IEEE Trans. on Electronic Computers*, vol. EC-12, Feb. 1963, p. 23.

43. Kauppila, J. E., "Cadmium Sulfide Unipolar Surface Transistor" (letter), *Proc. IEEE*, vol. 51, Mar. 1963, p. 472.

44. van der Ziel, A., "Gate Noise in Field-Effect Transistors at Moderately High Frequencies," *Ibid.*, p. 461.

45. Evans, A. D., "Characteristics of Unipolar Field-Effect Transistors," *Electronic Industries*, vol. 22, Mar. 1963, p. 99.

46. Bignell, T. R., "How to Get Maximum Input Impedance with Field-Effect Transistors," *Electronics*, vol. 36, Mar. 8, 1963, p. 44.

47. Zuleeg, R., "CdS Thin-Film Electron Devices," *Solid-State Electronics*, vol. 6, Mar.–Apr. 1963, p. 193.

48. Bechtel, G. N. "A Circuit and Noise Model of the Field-Effect Transistor," Tech Rept. No. 1612-1, Stanford Electronics Labs , April 1963.

49. Fleenor, E. G., "Low-Noise Preamplifier Uses Field-Effect Transistors," *Electronics*, vol. 36, Apr. 12, 1963, p. 67.

50. Shallcross, F. V., "Cadmium Selenide Thin-Film Transistors" (letter), *Proc. IEEE*, vol. 51, May 1963, p. 851.

51. Warner, R. M., "Epitaxial FET Cutoff Voltage" (letter), *Ibid.*, June 1963, p. 939.

52. Hoerni, J. A., and B. Weir, "Conditions for a Temperature Compensated Silicon Field-Effect Transistor" (letter), *Ibid.*, July 1963, p. 1058.

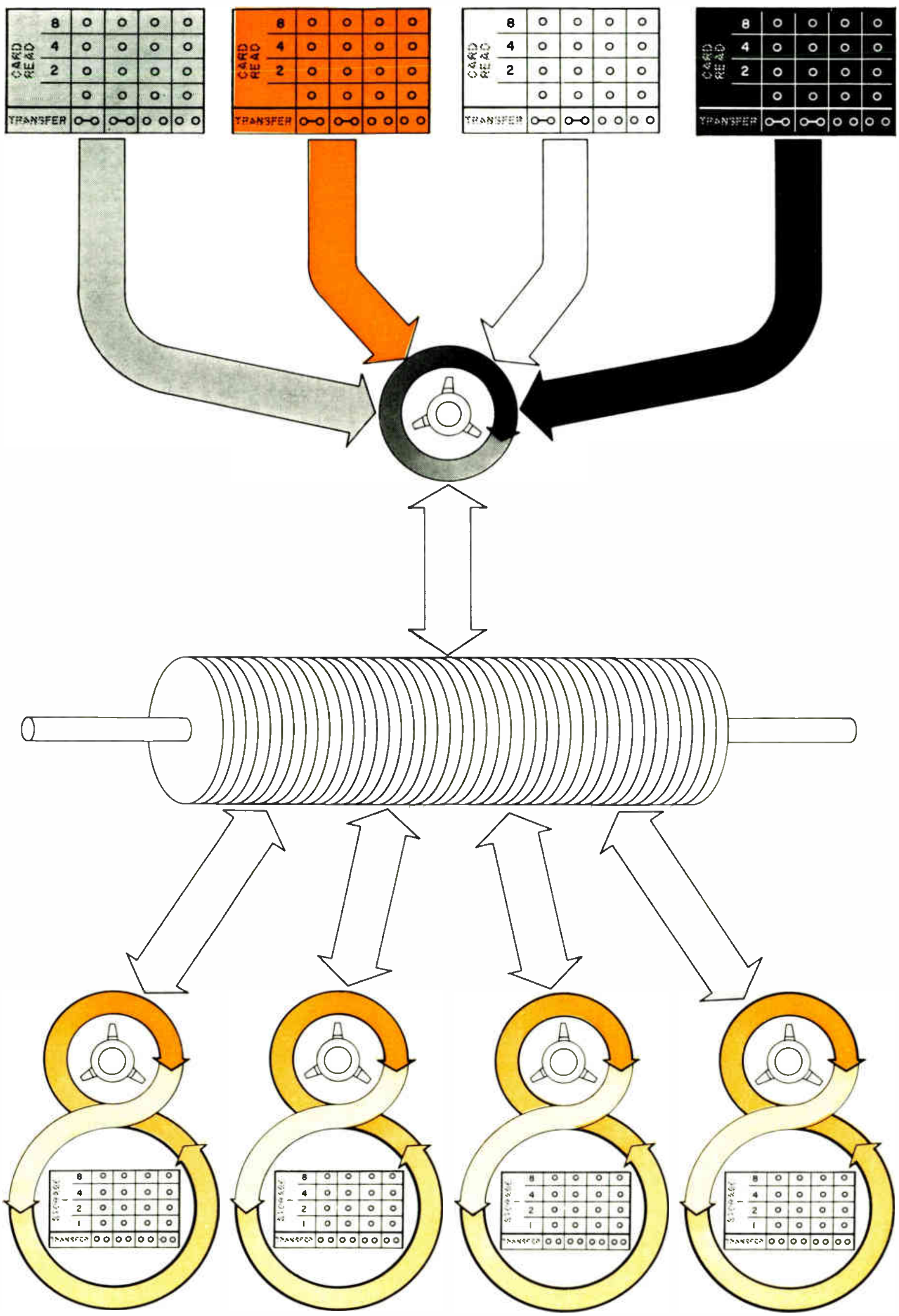
53. Roosild, S. A., R. P. Dolan, Jr., and D. O'Neil, "A Unipolar Structure Applying Lateral Diffusion" (letter), *Ibid.*, p. 1059.

54. Hofstein, S. R., and F. P. Heiman, "The Silicon Insulated-Gate Field-Effect Transistor," *Ibid.*, Sept. 1963, pp. 1190–1202.

Basic material from which this paper is condensed has been contributed by many people, but particularly H. Borkan, D. J. Carlson, G. E. Theriault, F. P. Heiman, S. R. Hofstein, J. A. Stewart, A. Many, and T. O. Stanley. L. A Olson contributed to the bibliography.

This paper is a slightly modified version of the one that appeared in the *RCA Review*, December 1963, under the title "The Field-Effect Transistor—A Review."

MULTIPROGRAMMING



MULTIPROCESSING

Residential underground distribution

Underground power distribution is growing exponentially. New residential customers thus served should increase from 6 per cent to 40 per cent of total by 1973

Robert F. Lawrence *Westinghouse Electric Corporation*

Historically, power systems in the United States have been of overhead rather than underground construction. Exceptions to the rule are the electric distribution systems in downtown commercial areas of cities, special runs of cable transmission circuits, and selected applications of underground distribution in new residential subdivisions. Underground distribution in new residential subdivisions is growing at a rapid rate, however. Improved appearance, new equipment developments and more economical installation methods are all contributing factors to this growth. Building developers' requests have also spurred a new look at associated problems and some electric utility companies now have a policy for the installation of underground distribution systems in new residential subdivisions at little or no increase in cost to the developer of a "total electric" home.

Underground network systems

In the early history of power systems, all circuits were overhead. In downtown areas, high electric load densities required multiple circuits and a highly reliable form of service. It soon became evident that the congestion of overhead lines and distribution transformers could no longer be tolerated. Thus was born the low-voltage ac secondary network system in which all of the circuitry and electric equipment was placed underground. An ac network system is supplied through high-voltage underground cable circuits which feed the network transformers. The network transformers step down to a three-phase four-wire 120/208 utilization voltage and are located in vaults under streets, sidewalks, or occasionally in buildings. Because the transformers are located at a subsurface level, flooding is possible and they must be capable of operation submersed in water. Also, since vault space limits ventilation, network transformers are designed with especially low losses.

The network transformers supply a low-voltage network or grid system through a specially designed circuit breaker called a network protector. The protector opens on reverse power to clear low-voltage backfeed in the event of a primary system fault. The protector will also close automatically when voltage conditions are such as to result in positive flow into the network. The network protector also is built to operate submersed in water.

To operate a network system properly under all normal and emergency operating conditions, appropriate switches

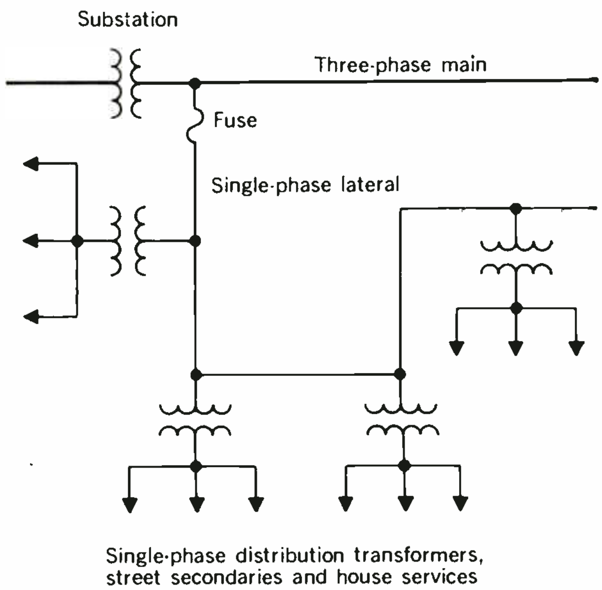


Fig. 1. One-line diagram of a primary main and lateral circuit from a substation. Distribution transformers step down to utilization voltage and secondary mains.

are provided on the high-voltage side of the network transformer. The high-voltage switches permit isolation and grounding of a high-voltage cable for safety reasons during system additions or cable repairs.

The most common primary voltages used in networks are in the 15-kV class. The circuits are three-phase. Both high- and low-voltage cable circuits are almost always located in multiple duct banks buried in the earth. The ducts may be of Transite or similar material and are encased in concrete.

One might be tempted to conclude that the network system, which historically has been the underground system, should be adapted to residential areas. However, the problems and situations found in residential areas are quite different from those that exist in downtown commercial areas.

Area load densities

Downtown commercial areas usually have high load densities. Common values of load density might range from 25 000 to 200 000 kVA per square mile. Office buildings, hotels, stores, apartment buildings, etc., that are found in commercial areas of cities have heavy lighting and air-conditioning loads. "Local" load densities within a single city block or for a given grouping of buildings are as high as 2 million or 3 million kVA per square mile.

A typical load density for a residential area might be as low as 1000 or 2000 kVA per square mile. On the other hand, a new residential subdivision might have a load density of 20 000 kVA per square mile for a built-up area saturated with total electric homes.

Downtown commercial areas use three-phase distribution. Utilization voltage is usually a nominal 120/208 volts three-phase. The three-phase power serves three-phase motors, and single-phase loads are supplied 120 volts line-to-neutral or 208 volts line-to-line. Since the early 1950s, a nominal utilization voltage of 265/460 volts has been used to the economic advantage of both the utility and the user. The higher voltage is particularly advantageous to serve heavy central air-conditioning loads.

Residential distribution system

Residential utilization voltage is almost universally single-phase, 120/240 volts. The primary circuits are both three-phase and single-phase and are usually radial. The portion of the circuit directly out of the substation is the primary main (Fig. 1). Single-phase laterals branch off from the mains into the residential areas to provide electrical coverage of the total area. The primary voltage may be 2.4/4.16 kV, 7.96/13.8 kV, or 14.4/24.9 kV, the most common value being a voltage in the 15-kV class. Small (10 to 100 kVA) single-phase distribution transformers transform voltage from the primary voltage level to the utilization level. To provide additional reliability to the radial overhead system, it is common to use primary-circuit emergency ties. Primary faults can be isolated and service restored by means of switching to obtain an emergency source of supply.

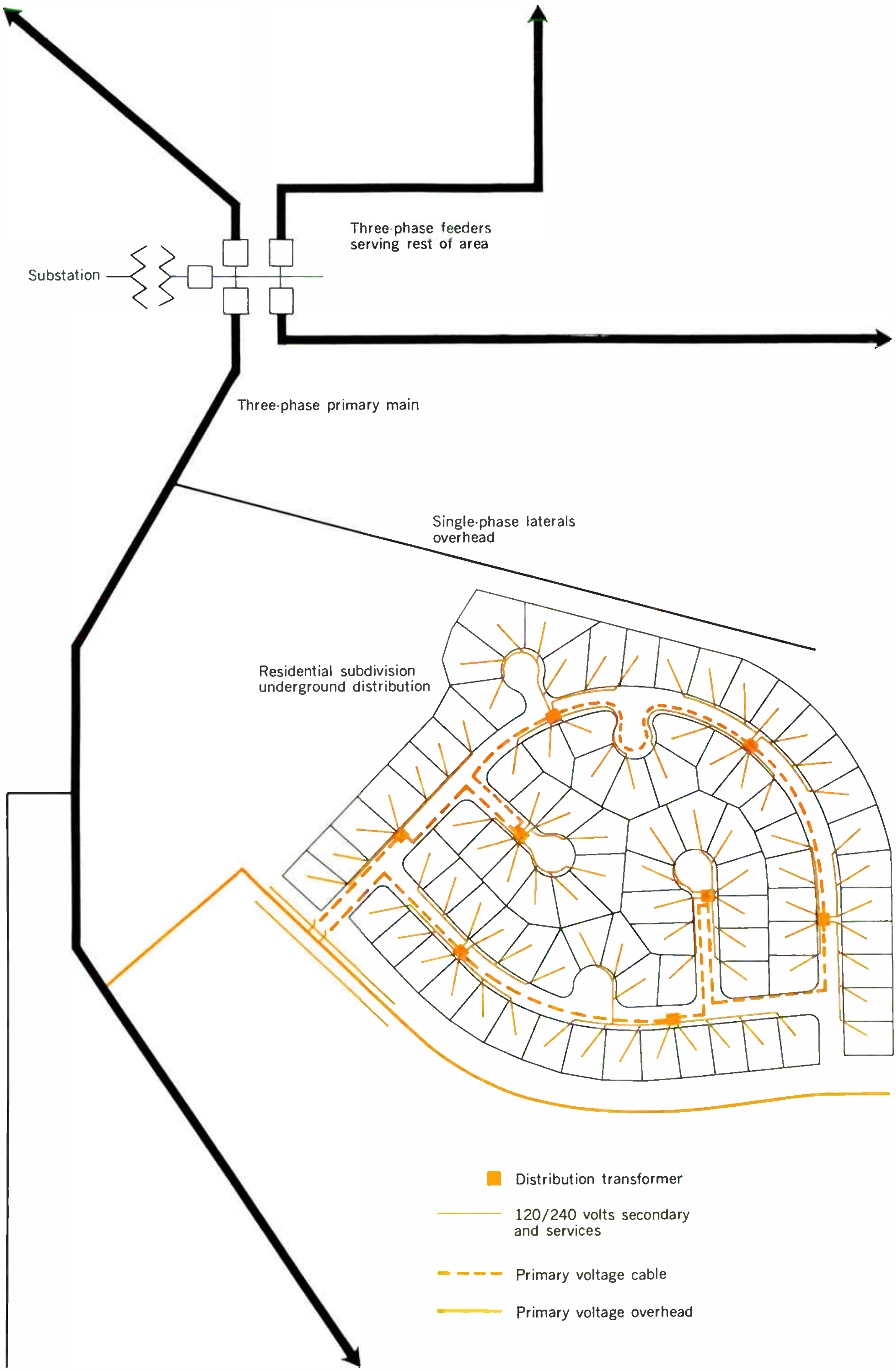
Fig. 2 illustrates a residential area supplied by a distribution substation. Four three-phase primary feeders emanate from the substation to supply power to the entire area. One of these three-phase primary feeder circuits is shown in more detail with its single-phase laterals. The other three primary circuits would likewise cover other parts of the total area fed by the distribution substation. The single-phase laterals are overhead with one exception. In Fig. 2, a new residential subdivision is shown. This area is served by an underground cable circuit in the form of a loop.

Most residential subdivisions served underground are supplied from overhead lines on the periphery of the subdivision area. This practice is largely a result of cost reductions since underground circuits all the way back to the substation would greatly increase the cost of the distribution system. If a subdivision is to be served underground and no overhead line exists, then an overhead line is brought to the edge of the area.

Underground circuit protection

Circuit protection on underground systems is different from that on overhead systems. For an overhead system, the substation protective device and the lateral fuse are usually coordinated to minimize fuse blowings. A fault on a lateral circuit causes the substation circuit breaker to open ahead of the lateral fuse. The substation breaker recloses and, if the fault is temporary, service is restored to the complete circuit including the lateral circuit on which the fault occurred. If the lateral fault was permanent, the substation breaker recloses on the fault, and the lateral fuse clears the fault and isolates the lateral from the primary main circuit. On an underground lateral, however, faults are usually permanent, and the lateral

Fig. 2. One-line diagram of substation and primary mains serving a geographical area. Residential subdivision layout shows distribution transformer locations and primary and secondary circuit routing. Lot widths are 80 feet.


Three-phase feeders serving rest of area
Substation
Three-phase primary main
Single-phase laterals overhead
Residential subdivision underground distribution
Distribution transformer
120/240 volts secondary and services
Primary voltage cable
Primary voltage overhead

fuse is coordinated to clear the fault ahead of the substation breaker.

An underground lateral may be in the form of a simple radial circuit (Fig. 1), a normally open loop, or a normally open circuit with an alternate feed from an adjacent overhead system. The latter two alternatives are shown in Fig. 3(A) and (B), respectively. Maximum flexibility of operation can be obtained with either of these latter arrangements if load break sectionalizing switches are used at each distribution transformer.

Consider a fault at point *X* on the underground lateral; see Fig. 3(A). The fuse *F*1 protecting the lateral clears the fault and de-energizes the lateral circuit. Consumers served from distribution transformers *A*, *B*, and *C* lose power; but those served from transformers *D*, *E*, and *F* note no power outage. The first corrective step is the dispatching of a lineman to the site to open switches *A*1 and *B*1. Fuse *F*1 is re-fused, then reclosed; and power is restored to distribution transformer *A*. The normally opened switch in the loop can be closed, restoring service to customers supplied from *B* and *C*. These switching operations can be done under energized line conditions because of the use of load break switches. Thus service is completely restored. The cable between *A*1 and *B*1 may be grounded for safety reasons and repair of the damaged cable can be accomplished. A common switching requirement is the use of a visible disconnect. If switches *A*1 or *B*1 are open, a lineman can see that an open circuit exists to the underground cable. After cable repairs are made, switches *A*1 and *B*1 can be reclosed and the "normally open" switch can be opened with no further interruption to service. This switching operation is possible when the switches at the distribution transformers have load-break ability.

Figure 3(C) is a variation of the system described in Fig. 3(B). This system has less flexibility but lower cost, using cables connected directly to the transformer high-voltage bushing. Suppose a fault occurs at point *X*. A fuse *F*1 clears the fault and opens the circuit which is operating radially. A lineman dispatched to the site must disconnect transformer *A* and *B* and isolate the fault. To meet the usual operating requirements, a standoff bushing or sleeve protection on the cable is used to isolate the faulted cable circuit. Switch *F*2 is opened so that both of the radial underground circuits are now de-energized. At this point, the normally opened switch can be closed. Fuses *F*1 and *F*2 are reclosed restoring service to all customers. After the cable is repaired, *F*1 and *F*2 are opened. Transformers *A* and *B* are reconnected and the normally opened switch is opened under de-energized line conditions. Then *F*1 and *F*2 switches can be closed and all service restored. All of the switching must be done under de-energized line conditions.

Underground system reliability

Figure 4 shows the expected outage rate on a primary distribution voltage underground cable circuit through time. The outage rate prevailing during the construction period is high because of "dig-ins" from construction equipment. From the limited data available, it appears that the outage rate during construction is about seven times that during the "normal life" period. Somewhat coincidentally, the outage rate of an overhead circuit is of the same order of magnitude as that for a residential underground lateral during the construction period. At the end of the normal life period, the number of outages would increase in a manner similar to that shown.

Let us now consider an underground lateral circuit served from an overhead line. For Figs. 5 through 7 it is assumed that the number of outages per year is proportional to line exposure. The outage rate on overhead laterals is assumed the same as for overhead mains. Figure 5 shows the outage rate experienced by a customer served from an underground lateral in per cent of the outage rate if served by an overhead lateral. Per cent underground system outage rate is shown as a function of overhead main exposure in per unit of lateral exposure. These results apply to either a radial- or loop-system configuration. Results also apply regardless of the type of manual

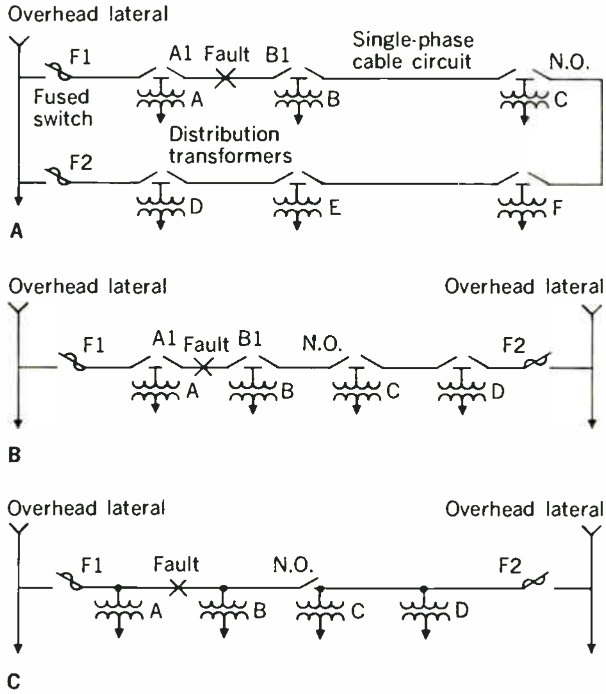
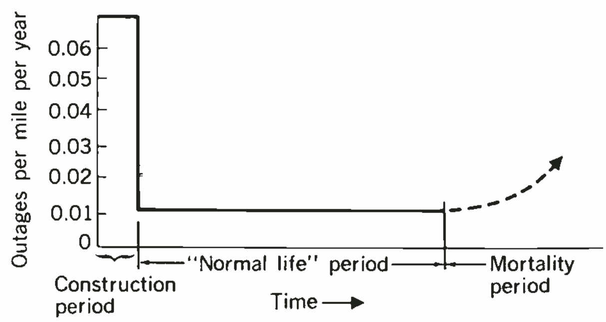


Fig. 3. One-line diagram of lateral underground cable circuit supplying distribution transformers. A—Loop, normally open; B—Normally open circuit with alternate lateral supplies; C—Same as (B) but without individual switches at each distribution transformer.

Fig. 4. Outage rate as a function of time on a primary distribution voltage underground cable circuit.



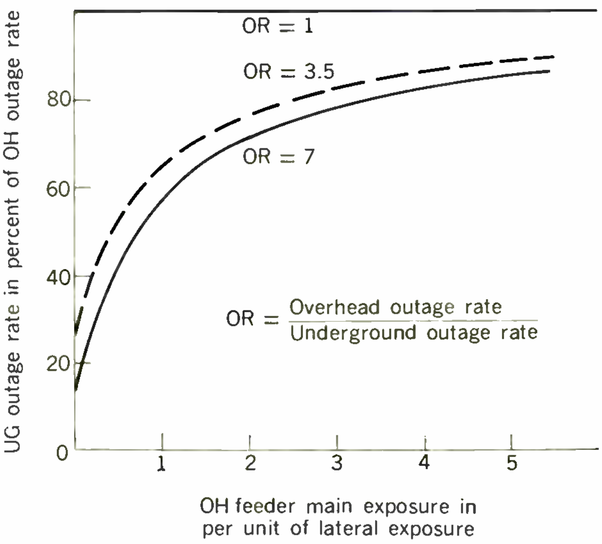
sectionalizing used—load break or otherwise. Based on the author's knowledge of system configuration, a high ratio of overhead main to underground lateral exposure can be expected. Thus, perhaps surprisingly, the outage rates of customers served from underground laterals can be expected to approach overhead system outage rates.

Outage rate, however, is only one measure of system reliability.[1] Another important measure of reliability is outage duration—the length of time a customer is out of service at one time. Customer outage duration is influenced by repair times on overhead and underground supply circuits and by provisions for switching to alternate sources of power. Outage duration is the time required to repair the faulted circuit if a means of switching to an alternate source is not provided. If switching is provided, outage duration caused by faults on that portion of the system that can be isolated is reduced to the time required to perform the switching operation. Limited field data indicate that expected values of repair times are about 2.3 and 3.5 hours for overhead and underground circuits, respectively. Switching time on underground systems seems to average about 1.5 hours. Circuit repair and switching times appear to be approximately exponentially distributed.

Figure 6 illustrates the expected value of outage duration for customers served from overhead and underground laterals as a function of overhead main exposure in per unit of lateral exposure. Two types of underground systems are illustrated: a radial lateral with no switching, like the system in Fig. 1, and a looped lateral with switches at each transformer like that in Fig. 3(A). Note that in either case, radial or looped underground lateral, the expected value of customer outage duration approaches overhead system experience for expected ratios of overhead main to lateral exposure. Thus, it appears that switches at each transformer on an underground system do not significantly reduce expected outage durations during the "normal life" period of the system.

Inasmuch as underground cable failure rates are very much higher during the construction period, or about

Fig. 5. Relative outage rates of underground and overhead as a function of main to lateral exposure.



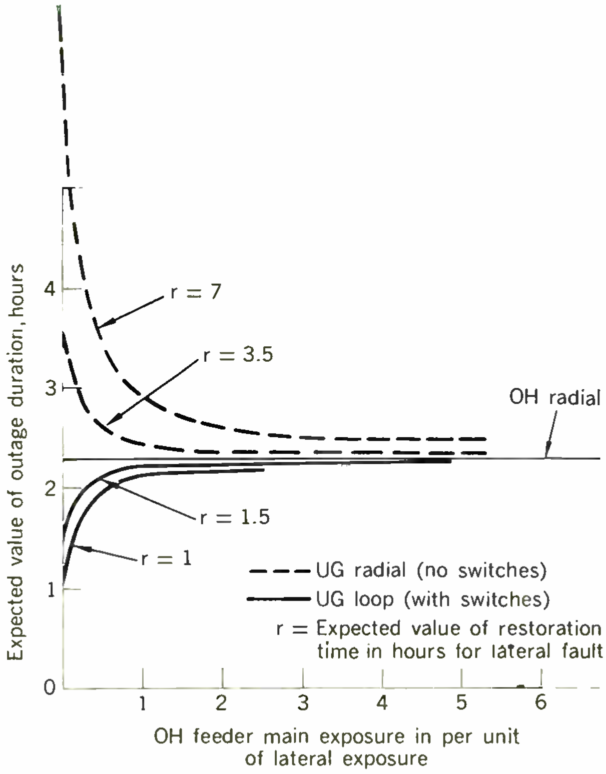
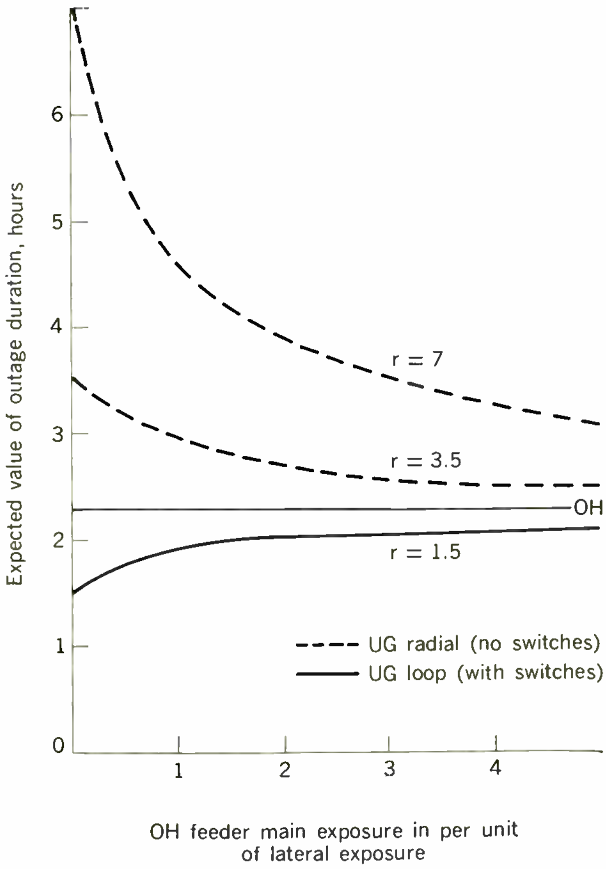


Fig. 6. Expected outage duration as a function of main to lateral exposure: "normal life" period.

Fig. 7. Expected outage duration as a function of main to lateral exposure: "construction" period.



equal to overhead failure rates, let us modify Fig. 6 to reflect equal overhead and underground failure rates. Figure 7 shows the results—and suggests that construction period outage duration rates would be appreciably reduced in a looped underground system with individual switching at each distribution transformer.

Field data of the kind required in the foregoing analyses are limited, but the values used are believed to be representative. In the opinion of the author, individual transformer switching in residential underground systems cannot be justified from the viewpoint of reliability improvement. However, a decision in favor of switches and their associated cost may be justified on the basis of ease and flexibility of operation. A modern underground distribution system without switching but with a new, easy means of cable disconnection will be discussed later.

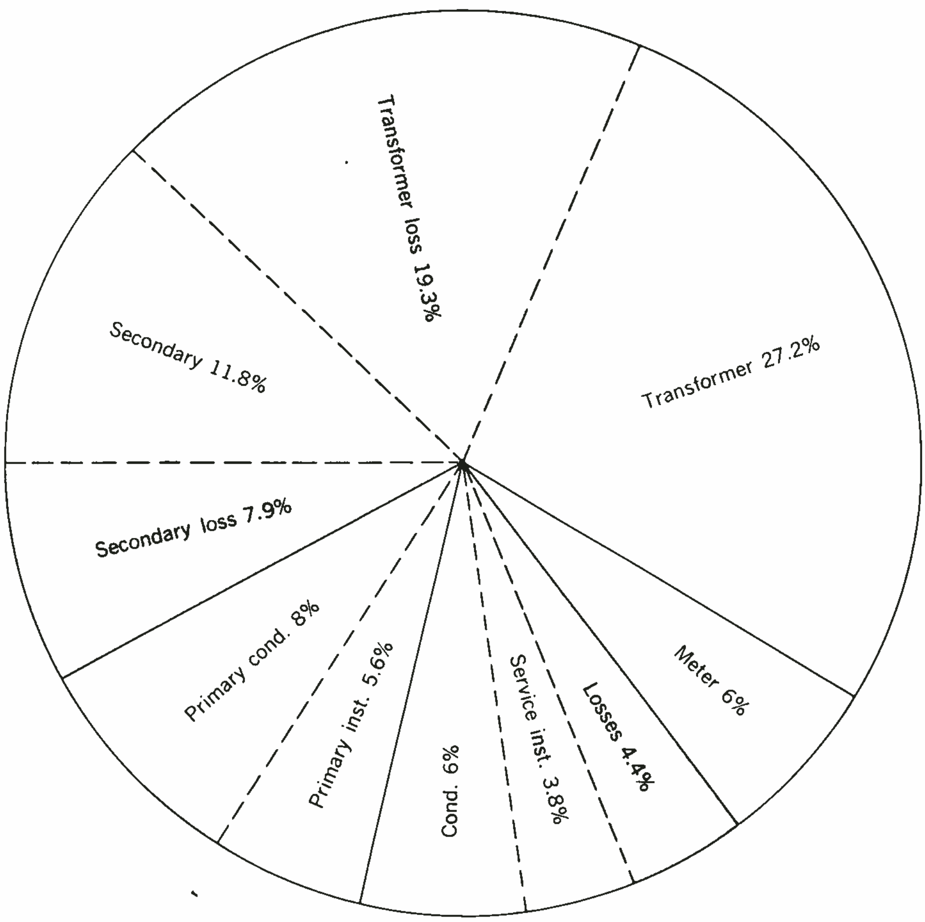
The right transformer-secondary combination

Selection of the right distribution transformer-secondary system is important on an overhead or underground system. Figure 8 shows a breakdown of costs for an underground system from the primary main to the consumer's meter, illustrating the economic importance of the transformer-secondary combination. On an overhead system, the transformer can be readily "changed out" to handle load growth. An alternate economic and technical choice in handling load growth is to split the secondary mains and install new transformers at appropriate locations. Because these flexibilities less often exist in an underground system, it is more important to make the right first choice of transformer rating and secondary conductor size.

Distribution standards must be set up for an underground system as for an overhead system. Computer analyses are a valuable aid and guide for such standards and in the design of the electric system layout. The computer program analyzes the economic choice of transformer-secondary combination, taking into account load growth.[2]

To obtain outputs for a set of standards from which a suitable choice can be made for the particular layout and subdivision under consideration, several values of load

Fig. 8. Pie chart of relative costs of evaluated losses and installed equipments on an underground lateral circuit from the main to consumer's meter. Primary voltage 7.96 kV, secondary 120/240 volts, 70-foot lot width, direct buried cable surface-mounted transformer system. One hundred per cent is $425 per customer served. Load per house is 16.2 kVA noncoincident peak demand.



demands, lot widths, growth rates, etc., are usually considered. Specific information on the installation costs of the transformers and secondaries must be available. A single load class for a total electric home was selected for an example. Because of the air conditioning demanded by the geographical area in this example, peak load occurred during the summer.

Table I shows part of a computer output sheet. System choices are listed in order of increasing present worth of future revenue requirements per customer served. The most economical transformer secondary system based on present worth of future revenue requirements is a 75-kVA transformer serving one secondary span each way, a total of 12 customers per transformer. The secondary conductor is copper, 336 MCM in size. At the end of a 26-year period for the one per cent growth rate studied, the computer results state that the 75-kVA transformer must be changed out to a 100-kVA unit. The voltage drop of VD1 at the end of the changeout period is 4.8 per cent so that changeout load of 160 per cent on the distribution transformer is the limiting design factor. The value of 4.2 per cent for VD2 is the voltage drop at the end of a 30-year study drop. Voltage dip (2.3 per cent) was not a limitation, being less than a 5.6 per cent allowable value. The second economic choice costs slightly more than the first, and uses the smaller secondary conductor size of 266 MCM. This design is the second choice because of increased secondary losses.

How do we interpret the foregoing results into an actual layout? Consider the residential subdivision of Fig. 2. The most economical system of the computer analysis—a 75-kVA transformer and 336-MCM secondary—was used as the basic design for the subdivision. For the most part, ten customers are served by each transformer. Engineering judgment determines the actual primary and secondary layouts, street crossing, and services. Figure 2 shows the complete layout in the form of a lateral loop circuit fed from the peripheral overhead line.

Appearance of underground distribution

One might wonder why underground distribution should need an aesthetic appearance—but it is not completely underground. Primary and secondary cables are "direct buried" or in duct. However, the transformers or housings are either partially or totally above the surface. Until about four years ago, transformers were housed in a "semiburied" installation. A conventional pole-type distribution transformer was mounted in a cylindrical concrete pipe buried in the earth. The superstructure was a steelfabricated housing. Sectionalizing was accomplished by using cutouts mounted in the superstructure above ground (flooding) level.

A direct-buried transformer was given even earlier consideration experiments in 1939. Tests on standard distribution transformers buried in earth indicated that severe corrosion could occur, depending upon soil conditions. Heat transfer properties of the soil varied over an extreme range, depending upon location, soil character and texture, and rainfall. The transformers had to be severely derated.

Another solution to the transformer problem was a housing of "universal construction." This was a prefabricated metal structure, surface mounted on a concrete pad. Inside were a standard pole-type distribution transformer and switching accessories. This "housing" concept never gained acceptance, probably because field assembly of the apparatus was necessary but undesirable. The equipment was large in size and tended to be costly.

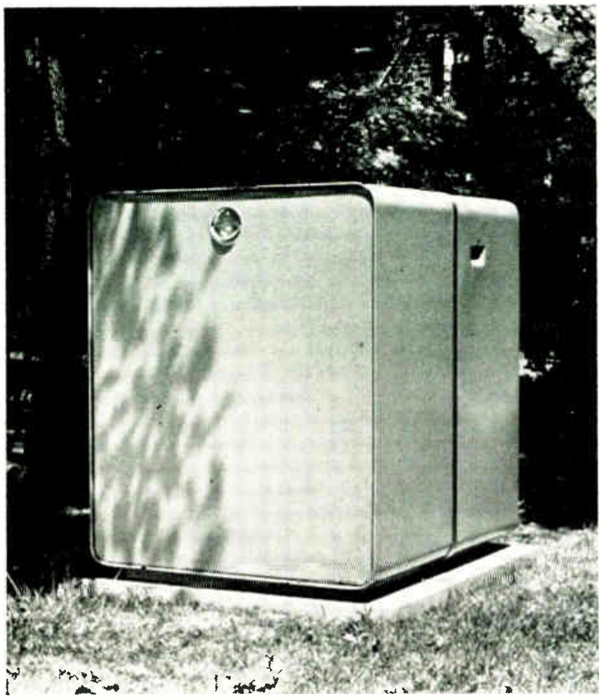
The oldest underground systems reported in an IEEE survey of 150 utilities[4] were installed using cable-connected line-type transformers in subsurface enclosures.

I. Part of computer output sheet showing distribution transformer and secondary optimization

T1	T2	T3	TS	SPANS	TRA1	TRA2	TRA3	TRA4	SEC	VD1	VD2	VD3	VD4	VDIP	PWTRA	PWSEC	PWTL	PWSL	PWTOT	IC
26				1	75.0	100.0			336	4.8	4.2			2.3	148.42	72.68	43.99	24.72	289.81	132.2
26				1	75.0	100.0			266	5.2	4.7			2.7	148.42	67.73	43.99	31.42	291.57	129.27
26				1	75.0	100.0			400	4.4	3.8			2.0	148.42	78.87	43.99	21.37	292.65	136.00
26				1	75.0	100.0			40	5.7	5.2			3.0	148.42	63.39	43.99	39.38	295.19	126.65
26				1	75.0	100.0			500	4.1	3.5			1.8	148.42	88.01	43.99	17.18	297.61	141.53
13				2	100.0	167.5			500	6.0	5.8			2.5	116.68	105.61	37.46	41.87	301.63	125.43

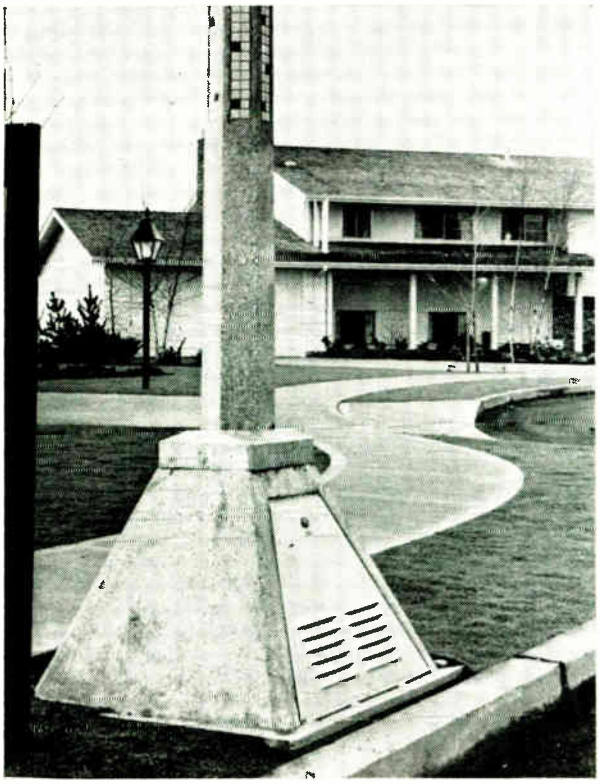
Column Head Definitions:

T (n) = year of nth system modification, transformer changeout or secondary split
TS = year of secondary split, if any
TRA(n) = rating of transformer during nth period
SEC = secondary conductor size
VD(n) = transformer and secondary per cent voltage drop at end of nth period
VDIP = per cent voltage dip with initial transformer and secondary system
PWTRA = present worth of transformer carrying charges and changeout costs per customer served
PWSEC = present worth of secondary carrying charges and splitting costs per customer served
PWTL = present worth of transformer loss costs per customer served
PWSL = present worth of secondary loss costs per customer served
PW TOT = sum of PWTRA, PWSEC, PWTL, and PWSL
IC = initial installed cost of system per customer served



View of a modern surface-mounted distribution transformer installation. Transformer compartment is a welded steel structure containing transformer core, coils, and insulating oil. Individual high- and low-voltage terminal compartments enclose cable terminations and switching in a weatherproof housing.

Combination street lighting and distribution transformer installation in Portland, Ore., installed by the General Electric Company. Area in which system was tried made it possible to combine functions of distribution along with decorative, functional streetlighting.



However, even 35 years ago line-type transformers, without cable entrance, were installed in surface or semiburied enclosures, with this arrangement reaching greatest popularity in the past ten years. The past four years have seen a large number of systems installing the integral (or separable) cubicle, surface-mounted transformer, commonly called "pad-mount" transformer.

Though the survey describes a trend to surface construction, using either line-type transformers in surface or semiburied enclosure, or integral-cubicle transformers, approximately 60 per cent of residential customers served are served from transformers in subsurface enclosures. This percentage is attributable to the greater age of this method of service.

A modern design of surface mounted transformer for residential underground installation has a transformer compartment made of welded steel containing the transformer core, coils, and insulating oil. Individual high- and low-voltage terminal compartments enclose the cable terminations and switching in a weatherproof housing.

Among many considerations of transformer equipments for residential underground distribution systems, equipment which combines the function of power distribution and streetlighting has aroused considerable interest. Such an arrangement is appealing because of the ability to design a transformer enclosure which removes the transformer completely from sight. Such a system[3] has been installed in Portland, Ore. Two primary objectives were to eliminate switching at each transformer but provide easy cable termination and disconnection and improve appearance. The area in which the system was tried fortunately made it possible to combine the functions of distribution along with decorative, functional street lighting.

The distribution transformers are located in precast concrete vaults. The street-light structure is mounted on a transition vault. Primary cable terminations are made with 15-kV right-angle connectors of the type shown in Fig. 9. These connectors are supplied by the Elastic Stop Nut Corp. The male part of the connector is an integral part of the transformer lead and is built into the transformer cover. The connectors require no stress cone or taping; they can be operated under water. In this instance, the transformer would be completely below ground level. Complete disappearance of the surface-mounted transformer can be expected, in this writer's opinion, to be the next step in residential underground distribution.

Forecast of the future

What of the future of underground distribution? At the end of 1963, there were 170,000 individual private homes served by an underground electric system in the United States. Compared to a total of approximately 40 million residential meters, the number of homes served by residential underground distribution is negligible; however, underground distribution in residential areas has almost tripled in the last four years, (Fig. 10). Even more important is the trend that indicates a continually accelerating rate of growth expected in the next ten years.

Who will be served by this presently insignificant but exponentially growing underground distribution? A recent survey by the author's company indicates that the use of underground is confined almost entirely to single-family dwellings costing more than $15000 and located in new subdivision developments. The survey covered 93

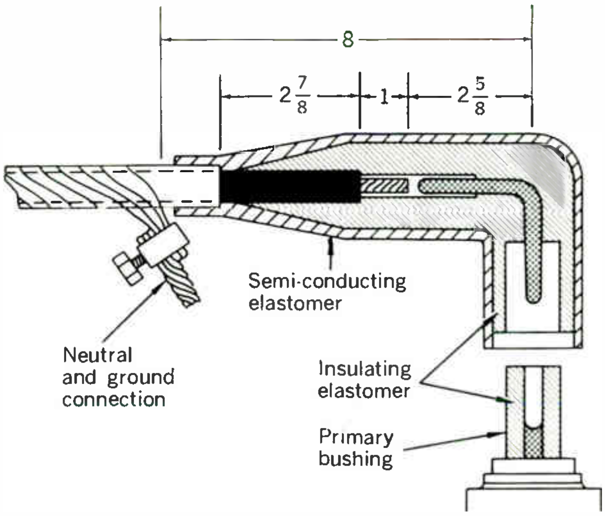


Fig. 9. Special right-angle connector used for primary cable terminations. Connector requires no stress cone.

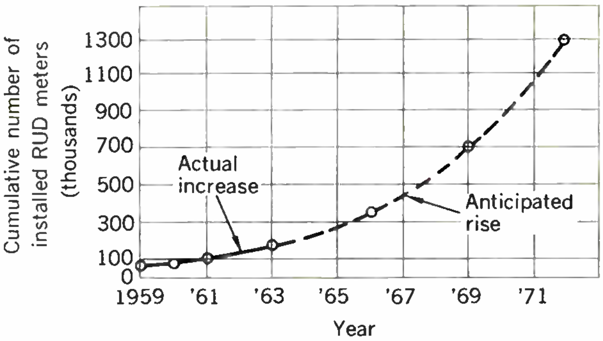
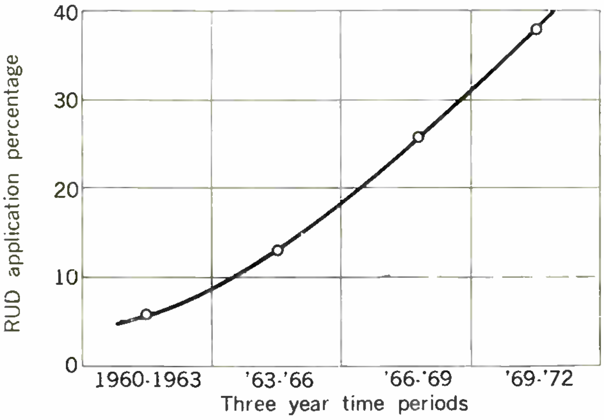


Fig. 10. Residential underground distribution growth 1950–1972. (Actual figures from reference 4.) Projected data are based on reports from 75 major U.S. utilities in a company-sponsored survey.

Fig. 11. Projection of residential underground distribution growth by per cent of metropolitan single-family dwellings costing over $15 000 in new developments that will be served underground. (Approximately 30 per cent of total housing starts.)



electric utility companies with 74 per cent of the total residential meters in the United States. The survey shows that, at present, six per cent of the utilities' new residential customers within this grouping are being served underground. This number is expected to increase to 40 per cent by 1973; see Fig. 11. It is significant that this residential classification is also the major source for the sale of "total electric usage." Some electric utilities are advantageously using residential underground to promote and sell the total electric concept.

Over the years, electric utilities have not favored underground distribution, primarily because underground costs have been too high in relation to overhead construction costs. This disfavor with underground seems now to be disappearing. One indication of increasing acceptance may be found in the many articles in the technical literature. Another indication is contained in the aforementioned valuable IEEE survey.[4] The increase in the number of electric utilities reporting more than 100 residential customers served by underground systems between 1955 and 1960 was more than double the increase over the previous 50 years, even though 19 of the 63 utilities reporting do not yet have 100 served customers served with underground distribution.

The survey also indicates that clarification among utilities of the real estate developer's responsibilities is another factor fostering the growth of underground distribution. The utility consensus is that these responsibilities should be that (1) the developer share the cost of underground distribution in some form; (2) the developer's share be based mainly on the difference between overhead and underground costs; (3) there is no rebate to the developer for promotion of "all-electric living," or any heavy duty loads; (4) the developer provide the service trench; (5) the developer provide the service cable. (The majority of the utilities do not plan to maintain this cable.)

The above survey and other sources indicate that overhead distribution systems will continue to grow and no one should expect their replacement by underground distribution. The economic facts dictate that this utopia is not to become a reality. But it may be predicted that more new homes than ever before can and will be served by underground lines. Electric utilities policy changes, improved equipment developments, lower costs, understanding by the consumer of the availability of underground in new areas, and placement of telephone lines underground all contribute to this eventuality.

REFERENCES

1. Gaver, D. P., F. E. Montmeat, and A. D. Patton, "Power System Reliability I—Measure of Reliability and Methods of Calculation," *IEEE Transactions on Power Apparatus and Systems*, vol. 83, 1964 (TP64-90).

2. Burandt, R. P., J. A. Hughes, A. D. Patton, and D. N. Reps, "Present-Worth Approach for Optimizing Distribution Transformer and Secondary Designs to Serve Growing Loads," *AIEE Transactions*, pt. III, *Power Apparatus and Systems*), vol. 80, Aug. 1961, pp. 345–349.

3. Verheiden, E. P., R. F. Cook, and W. S. Greer, "New Residential Underground Distribution System Improves Appearance," *Electric Light and Power*, vol. 41, no. 12, Dec. 1963, pp. 36–39.

4. "Survey of Residential Underground Practice," IEEE Pub. S-144, sponsored by the AIEE Committee on Insulated Conductors Subcommittee VII—Cable Supply Systems.

Matrix functions and applications

One hears much today about the need for the engineer to continue to learn, to move as the field moves, to enter new fields as challenges arise. Electrical engineering, in its recent progress from dc and ac circuits through the vacuum tube and the waveguide and into the complexities of solid-state devices, well demonstrates the necessity for perpetual learning.

The Editorial Board feels strongly that such continuing education after college must be a major objective of the publications of a technical society. With this intent we present a serial treatment of matrix theory, a form of mathematics that provides a systematic method for the manipulation and solution of systems of equations—those that result from the complex circuitry of today. The method separates the circuit matrix from the independent and dependent variables, and it is found that a great amount of knowledge can be gained by study and manipulation of this impedance matrix.

This series of four articles will begin with the basic rules of matrix algebra, and eventually carry the "student" to a level that should permit him to understand the latest applications to the art. As a method of considerable value, as a foundation for more advanced work, and as a refresher in the methods of modern mathematics, it is well worth study. Stay with it!

—*The Editor*

The purpose of this series of articles is to introduce the engineer who has already studied determinants and has taken at least a first course in differential equations to some of the properties and applications of matrices and matrix functions in the study of linear systems.

Part I is concerned with the basic definitions and operations with matrices, and with methods for the solution of linear systems described in the three subsequent articles. A discussion of generalized inverses for the solution of degenerate systems is included.

Part II introduces differential equations with constant matrix coefficients and shows how these may be solved explicitly by finding the eigenvalues of a matrix and expressing functions of a diagonable matrix in terms of its principal idempotents.

Part III is devoted to some applications of matrices to the construction of models for the solution of problems involved in engineering systems analysis.

Part IV treats the expansion of analytic functions of an arbitary square matrix in terms of its idempotent and nilpotent constituent matrices, and presents computational methods for finding eigenvalues and constituent matrices.

Part I—Matrix operations and generalized inverses

J. S. Frame *Michigan State University*

1.1 The importance of matrices

The theory of matrices is playing a role of rapidly increasing importance in the formulation and solution of problems, not only in mathematics and engineering, but in the biological and social sciences as well. Before the advent of the computer, a mathematician could talk glibly about the existence and uniqueness of a solution of a system of ten linear equations in ten unknowns. Few had ever tried to find the solution of such a system. Now matrix theory not only provides an extremely helpful tool for designing a mathematical model of a system with many variables, but also affords a practical and convenient method of adapting the data for processing by a computer. The theory of functions of a matrix—including polynomial, exponential, and trigonometric functions—provides an extremely powerful tool both for model making and for providing numerical answers. Some feel that any problem that can be solved by Laplace transform methods can be solved with equal or greater ease by using functions of matrices.

1.2 Basic concepts

A system of m linear equations in the n unknowns $x_1, x_2, \ldots, x_n$:

$$\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = y_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = y_2 \\ \cdot \\ \cdot \\ \cdot \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n = y_m \end{array} \qquad (1.2.1)$$

may be represented by the matrix equation

$$\begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{m1} & a_{m2} & \ldots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_m \end{bmatrix}$$

An abbreviated symbolism for this system is the simple matrix equation

$$AX = Y \qquad A = (a_{ij})_{m,n} \qquad (1.2.2)$$

which also may be written

$$\sum_{j=1}^{n} a_{ij}x_j = y_i \qquad i = 1, 2, \ldots, m \qquad (1.2.3)$$

The quantities a_{ij}, x_j, and y_i are all assumed to be elements of some chosen field or ring R, such as the real field, the complex field, or a ring of complex polynomials in some variable λ. All elements of R will be called *scalars*.

Definition 1.2.1 An $m \times n$ *matrix*

$$A = (a_{ij}) = ||a_{ij}||_{m,n}$$

over a field or ring R, is an ordered array of mn scalars a_{ij} from R, arranged in m rows and n columns. The scalar a_{ij} in row i column j is called the *ij entry* of A. It is said to lie *on* the *diagonal* if $i = j$, *off* the diagonal if $i \neq j$, *below* the diagonal (*subdiagonal*) if $i > j$, and *above* the diagonal (*superdiagonal*) if $i < j$. The following example of a 3×4 matrix shows the diagonal entries in italic type, the subdiagonal entries in roman type, and the superdiagonal entries in boldface type:

$$\begin{bmatrix} a_{11} & \mathbf{a}_{12} & \mathbf{a}_{13} & \mathbf{a}_{14} \\ \mathrm{a}_{21} & a_{22} & \mathbf{a}_{23} & \mathbf{a}_{24} \\ \mathrm{a}_{31} & \mathrm{a}_{32} & a_{33} & \mathbf{a}_{34} \end{bmatrix}$$

The sum of the diagonal entries a_{ii} is the *trace* of A.

$$\mathrm{tr}\ A = \sum a_{ii} \qquad (1.2.4)$$

The integers m and n associated with an $m \times n$ matrix are called its *row order* and *column order*, or simply its *dimensions*.

An $n \times n$ matrix is called a *square matrix*

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

A $1 \times n$ matrix is called a *row vector*

$$[a_{11}\ a_{12}]$$

An $m \times 1$ matrix is called a *column vector*

$$\begin{bmatrix} a_{11} \\ a_{21} \end{bmatrix}$$

The ordered set of n entries in row i of A forms the *row vector* $A_{i\cdot}$, the ordered set of m entries in column j of A forms the *column vector* $A_{\cdot j}$.

Equality between two matrices implies equality both of their corresponding dimensions and of their corresponding ij entries.

Thus in defining *sums* $A + B$, *scalar multiples* cA or *linear combinations*

$$\sum c_k A^{(k)}$$

of matrices such as $A = (a_{ij})$, $B = (b_{ij})$, $A^{(k)} = (a_{ij}{}^{(k)})$, where c and c_k are scalars, we write

$$(a_{ij}) + (b_{ij}) = (a_{ij} + b_{ij}) = A + B \qquad (1.2.5)$$

$$c(a_{ij}) = (ca_{ij}) = cA \qquad (1.2.6)$$

$$\sum_k c_k(a_{ij}{}^{(k)}) = \left(\sum_k c_k a_{ij}{}^{(k)}\right) = \sum_k c_k A^{(k)} \qquad (1.2.7)$$

and we imply that all matrices involved have the same dimensions. Clearly these rules imply the distributive laws

$$\begin{aligned} c(A + B) &= cA + cB \\ (c_1 + c_2)A &= c_1A + c_2A \end{aligned} \qquad (1.2.8)$$

Called the *null matrix*, $0^{(m,n)}$, or simply 0, the matrix $A - A = 0 \cdot A$ is an $m \times n$ matrix with every entry 0.

An $m \times n$ *matrix unit* ϵ_{ij} is obtained from the $m \times n$ null matrix by replacing just one entry, the ij entry, by 1. Every $m \times n$ matrix $A = (a_{ij})$ is a linear combination of matrix units ϵ_{ij} with the entries a_{ij} as coefficients.

$$A = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}\epsilon_{ij} \qquad (1.2.9)$$

For example

$$\begin{bmatrix} 4 & -2 & 3 \\ 6 & 5 & -1 \end{bmatrix} = 4\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} - 2\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + 3\begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$
$$+ 6\begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} + 5\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} - \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$
$$= 4\epsilon_{11} - 2\epsilon_{12} + 3\epsilon_{13} + 6\epsilon_{21} + 5\epsilon_{22} - \epsilon_{23} \qquad (1.2.10)$$

Definition 1.2.2 A matrix $A = (a_{ij})$ is called

1. Diagonal if $a_{ij} = 0$ for $i \neq j$.

$$\begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix}$$

2. Superdiagonal or strictly upper triangular if $a_{ij} = 0$ for $i \geq j$.

$$\begin{bmatrix} 0 & a_{12} & a_{13} \\ 0 & 0 & a_{23} \\ 0 & 0 & 0 \end{bmatrix}$$

3. Subdiagonal or strictly lower triangular if $a_{ij} = 0$ for $i \leq j$.

$$\begin{bmatrix} 0 & 0 & 0 \\ a_{21} & 0 & 0 \\ a_{31} & a_{32} & 0 \end{bmatrix}$$

4. Upper triangular if $a_{ij} = 0$ for $i > j$.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{bmatrix}$$

5. Lower triangular if $a_{ij} = 0$ for $i < j$.

$$\begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

6. Tridiagonal if $a_{ij} = 0$ for $|i - j| > 1$.

$$\begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix}$$

Any matrix has a unique decomposition as a sum of matrices of the first three types

$$\underset{}{\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}} = \underset{\text{Subdiagonal}}{\begin{bmatrix} 0 & 0 & 0 \\ 4 & 0 & 0 \\ 7 & 8 & 0 \end{bmatrix}} + \underset{\text{Diagonal}}{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 5 & 0 \\ 0 & 0 & 9 \end{bmatrix}} + \underset{\text{Superdiagonal}}{\begin{bmatrix} 0 & 2 & 3 \\ 0 & 0 & 6 \\ 0 & 0 & 0 \end{bmatrix}} \qquad (1.2.11)$$

A square diagonal matrix with all diagonal entries positive is called *positive* diagonal.

The $n \times n$ *identity matrix or unit matrix*, denoted U_n or U or (δ_{ij}), has its diagonal entries 1 and all other entries 0. Its ij entry is called the Kronecker delta, δ_{ij}.

$$U = \sum \epsilon_{ii} = \begin{bmatrix} 1 & 0 & 0 & \ldots & 0 \\ 0 & 1 & 0 & \ldots & 0 \\ 0 & 0 & 1 & \ldots & 0 \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ 0 & 0 & 0 & \ldots & 1 \end{bmatrix} = (\delta_{ij}) \qquad (1.2.12)$$

$$\delta_{ij} = \begin{cases} 1 \text{ if } i = j \\ 0 \text{ if } i \neq j \end{cases}$$

Scientists who do not reserve I and E for current and voltage commonly denote the unit matrix by I (identity) or E (German "Einheit").

If λ is a scalar, the matrix λU is called a scalar matrix.

Definition 1.2.3 The *transpose* A^T of an $m \times n$ matrix $A = (a_{ij})$ is the $n \times m$ matrix with ij entry a_{ji} whose rows are the columns of A and whose columns are the rows of A. If $A = B + jC$, where B and C are real $m \times n$ matrices and $j^2 = -1$, the $n \times m$ matrix $A^* = B^T - jC^T$ with ik entry a_{ki} is called the *conjugate transpose* of A or simply "A star."

The names in the following tabulation refer to square matrices for which the matrix at the left equals the matrix above the name:

	A	$\bar{A}$	A^T	A^*
A	—	real	symmetric	hermitian
$-A$	null	pure imaginary	skew	skew-hermitian

(1.2.13)

Thus a symmetric matrix A is equal to its transpose A^T, and a skew-hermitian matrix A is equal to $-A^*$.

1.3 Matrix multiplication

The rule for multiplying two rectangular matrices can be derived from two requirements. First, as indicated in (1.2.1) and (1.2.3), the product $Y = AX$ of an $m \times n$ matrix A and an $n \times 1$ matrix X should be the $m \times 1$ matrix Y with entries

$$y_i = \sum a_{ij} x_j$$

Second, matrix multiplication should be *associative*, so that

$$A(BC) = (AB)C \qquad (1.3.1)$$

whenever the products involved are defined. This means that if $X = BC$, where B is $n \times r$ and C is $r \times 1$, we require that

$$Y = AX = A(BC) = (AB)C \qquad (1.3.2)$$

$$y_i = \sum_{j=1}^{n} a_{ij} x_j = \sum_{j=1}^{n} a_{ij} \sum_{k=1}^{r} b_{jk} c_k$$

$$= \sum_{k=1}^{r} \left(\sum_{j=1}^{n} a_{ij} b_{jk} \right) c_k \qquad (1.3.3)$$

Hence the ik entry of the $m \times r$ product AB must be

Definition 1.3.1

$$(AB)_{ik} = \sum_{j=1}^{n} a_{ij} b_{jk} \qquad i = 1, 2, \ldots m \quad k = 1, 2, \ldots r \qquad (1.3.4)$$

Product rule: Multiply the elements of row i of the left factor by corresponding elements of column k of the right factor and add to obtain the ik entry of the product.

If we replace the column vector C by an $r \times s$ matrix $C = (c_{kh})$ and set $X = BC$, $Y = AX$, the product definition just given satisfies the associative law $A(BC) = (AB)C$ in the general case, and we write ABC for either product.

Note that the product AB is defined only when A has as many columns as B has rows. Then AB has as many rows as A, and as many columns as B.

Matrix multiplication is distributive, since

$$A(B + C) = AB + AC \qquad (A + B)D = AD + BD \qquad (1.3.5)$$

whenever both sides of the equations are defined.

The commutative law $AB = BA$ holds for *some* matrix products, *but not all*, as the following example shows. Let

$$A = \begin{bmatrix} 2 & -1 & 3 \\ -4 & 9 & 5 \end{bmatrix} \qquad B = \begin{bmatrix} 6 & 3 \\ 1 & 2 \\ 7 & 4 \end{bmatrix} \qquad (1.3.6)$$

Then

$$AB = \begin{bmatrix} [2\cdot 6 - 1\cdot 1 + 3\cdot 7] & [2\cdot 3 - 1\cdot 2 + 3\cdot 4] \\ [-4\cdot 6 + 9\cdot 1 + 5\cdot 7] & [-4\cdot 3 + 9\cdot 2 + 5\cdot 4] \end{bmatrix}$$

$$= \begin{bmatrix} 32 & 16 \\ 20 & 26 \end{bmatrix}$$

$$BA = \begin{bmatrix} [6\cdot 2 + 3(-4)] & [6(-1) + 3\cdot 9] & [6\cdot 3 + 3\cdot 5] \\ [1\cdot 2 + 2(-4)] & [1(-1) + 2\cdot 9] & [1\cdot 3 + 2\cdot 5] \\ [7\cdot 2 + 4(-4)] & [7(-1) + 4\cdot 9] & [7\cdot 3 + 4\cdot 5] \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 12 & 33 \\ -6 & 17 & 13 \\ -2 & 29 & 41 \end{bmatrix}$$

Although AB and BA are not always equal, they do have the same trace whenever AB is square.

$$\text{tr}\,(AB) = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} b_{ji} = \text{tr}\,(BA) \qquad (1.3.7)$$

Transposing a matrix interchanges rows and columns, so $(AB)^T$ is not generally equal to $A^T B^T$. Instead

$$(AB)^T = B^T A^T \qquad \text{(factors in reversed order)} \qquad (1.3.8)$$

Scalar products of vectors. If X and Y denote $n \times 1$ column vectors, and X^T, Y^T the corresponding $1 \times n$ row vectors, the product

$$X^T Y = Y^T X = x_1 y_1 + x_2 y_2 + \ldots + x_n y_n \qquad (1.3.9)$$

is a scalar (1×1 matrix) called the *scalar product* of X and Y. The related quantity

$$X^* Y = (Y^* X) = x_1 y_1 + x_2 y_2 + \ldots + x_n y_n \qquad (1.3.10)$$

is called the *complex scalar product* of X and Y.

The length, or norm $\|X\|$, of a vector $X \neq 0$ is the positive quantity

$$\|X\| = \sqrt{X^* X} > 0 \quad \text{if } X \neq 0, \qquad \|0\| = 0 \qquad (1.3.11)$$

A vector of unit length is called a unit vector.

Definition 1.3.2 Two column vectors X and Y are called *orthogonal* if $X^T Y = 0$; complex orthogonal if $X^* Y = 0$.

1.4 Powers, inverse, and determinant of a matrix

Positive integral powers of an $n \times n$ matrix A, and the zero power, are defined by

$$A^2 = A \cdot A \qquad A^n = A^{n-1} A \qquad A^0 = U \quad \text{(identity)} \qquad (1.4.1)$$

The matrix A is called *idempotent* if $A^2 = A$. For some, but not all, square matrices A there exists an inverse matrix A^{-1} such that

$$A^{-1} A = A A^{-1} = U \qquad (1.4.2)$$

Definition 1.4.1 A matrix A is said to be *invertible*, or *nonsingular* if it has an inverse, *singular* if it does not. Negative integral powers of an invertible matrix are defined by

$$A^{-n} = (A^{-1})^n \qquad (1.4.3)$$

Fractional powers, such as square roots, will be considered in Part II in a discussion of functions of a matrix.

Theorem 1.4.1 If A and B are invertible $n \times n$ matrices, then

$$(AB)^{-1} = B^{-1} A^{-1} \; \text{(product in reversed order)} \qquad (1.4.4)$$

Proof: We verify directly by the associative law that

$$(B^{-1} A^{-1})(AB) = B^{-1}(A^{-1} A) B = B^{-1} U B = B^{-1} B = U \qquad (1.4.5)$$

$$(AB)(B^{-1} A^{-1}) = A(BB^{-1}) A^{-1} = AUA^{-1} = AA^{-1} = U$$

Q.E.D.

The equation $Y = AX$ in (1.2.2) can be solved uniquely whenever A has an inverse. It has the solution

$$X = A^{-1}(AX) = A^{-1}Y \qquad (1.4.6)$$

The fact is that an $n \times n$ matrix A has an inverse if and only if its determinant $|A|$ is not zero. For a 2×2 matrix,

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \qquad |A| = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{21}a_{12} \qquad (1.4.7)$$

$$A^{-1} = \frac{1}{|A|}\begin{bmatrix} a_{22} & -a_{12} \\ -a_{21} & a_{11} \end{bmatrix} \qquad A^{-1}A = AA^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (1.4.8)$$

Note that an $n \times n$ matrix A is an array of n^2 entries, whereas its determinant is a single scalar function of these entries. Important facts about determinants are as follows:

D1. If $A = (a_{ij})$ is a diagonal matrix, then $|A| = a_{11} \cdot a_{22} \cdots a_{nn}$.

D2. The elementary matrix $L_{ij} = U + ce_{ij}$, where $i \neq j$, has determinant 1.

D3. $|AB| = |A| \cdot |B|$. The determinant of a product of two or more square matrices equals the product of their determinants.

D4. The determinant m_{ji} of the $(n - 1) \times (n - 1)$ matrix obtained from A by deleting row j and column i is called the ji minor of A, and $\tilde{a}_{ij} = (-1)^{i+j}m_{ji}$ is called the ji cofactor of A. The matrix $\tilde{A}$ with ij entry $\tilde{a}_{ij}$ equal to the ji cofactor is called the *adjoint* of A. The determinant is related to the adjoint by the equations

$$|A| = \sum_{i=1}^{n} a_{ji}\tilde{a}_{ij} = \sum_{j=1}^{n} \tilde{a}_{ij}a_{ji} \qquad A\tilde{A} = \tilde{A}A = |A|U \qquad (1.4.9)$$

1.5 Partitioned matrices and direct sums

It is often convenient to denote certain rectangular submatrices of a given $m \times n$ matrix by a single letter, and thus to consider matrices whose elements are themselves matrices. For example, the partitioned matrix equation

$$\begin{bmatrix} U & -Y/c & 0 \\ 0 & 1/c & 0 \\ 0 & -X/c & U \end{bmatrix} \begin{bmatrix} U & Y & 0 \\ 0 & c & 0 \\ 0 & X & U \end{bmatrix} = \begin{bmatrix} U & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & U \end{bmatrix} \begin{matrix} r \text{ rows} \\ 1 \text{ row} \\ s \text{ rows} \end{matrix} \qquad (1.5.1)$$

shows how to write down by inspection the inverse of a matrix of $r + 1 + s$ rows and columns in which only column $r + 1$ is different from that of the unit matrix. If matrices A and B are partitioned into submatrices A_{ij} and B_{jk} so that the products $A_{ij}B_{jk}$ are defined for each j, then the submatrix C_{ik} of $C = AB$ is obtained by the product rule

$$C_{ik} = \sum_{j} A_{ij}B_{jk} \qquad (1.5.2)$$

Assuming that the submatrix A is invertible, we may write a useful factorization of a larger matrix as follows:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{matrix} r \text{ rows} \\ m - r \text{ rows} \end{matrix} \qquad (1.5.3)$$

$$= \begin{bmatrix} U & 0 \\ CA^{-1} & U \end{bmatrix} \begin{bmatrix} A & 0 \\ 0 & D - CA^{-1}B \end{bmatrix} \begin{bmatrix} U & A^{-1}B \\ 0 & U \end{bmatrix}$$

The inverse of each of these factors is easily found, and we reverse the order of inverses, using Theorem 1.4.1 to obtain

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} \qquad (1.5.4)$$

$$= \begin{bmatrix} U & -A^{-1}B \\ 0 & U \end{bmatrix} \begin{bmatrix} A^{-1} & 0 \\ 0 & (D - CA^{-1}B)^{-1} \end{bmatrix} \begin{bmatrix} U & 0 \\ -CA^{-1} & U \end{bmatrix}$$

Thus the inversion of any square matrix can be reduced to the inversion of two matrices of lower order.

Definition 1.5.1 A partitioned matrix A, such as the second factor in (1.5.3), in which the submatrices A_{ij} vanish for $i \neq j$ is called quasidiagonal. It is also called the *direct sum* of its diagonal submatrices, indicated by

$$A = A_{11} \oplus A_{22} \oplus \ldots \oplus A_{rr} \qquad (1.5.5)$$

The determinant $|A|$ of a direct sum A equals the product of the determinants $|A_{ii}|$ of the summands.

Applying this to the factorization (1.5.3) in which the first and last factors have determinant 1 we find

$$\begin{vmatrix} A & B \\ C & D \end{vmatrix} = |A| \; |D - CA^{-1}B| \qquad \text{if } |A| \neq 0 \quad (1.5.6)$$

If A is the scalar $a \neq 0$ this equation describes the pivotal method for evaluating determinants, namely

$$\begin{vmatrix} a & b_1 & \ldots & b_n \\ c_1 & d_{11} & \ldots & d_{1n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ c_n & d_{n1} & \ldots & d_{nn} \end{vmatrix} = a\left|\left(d_{ij} - \frac{c_ib_j}{a}\right)\right|$$
$$= a^{1-n}|(ad_{ij} - c_ib_j)| \qquad (1.5.7)$$

Example 1 Evaluate the determinant and inverse of the following matrix A.

$$|A| = \begin{vmatrix} 2 & 3 & 4 \\ 5 & 7 & 6 \\ 8 & -1 & 9 \end{vmatrix} = \frac{1}{2}\begin{vmatrix} 2\cdot7 - 5\cdot3 & 2\cdot6 - 5\cdot4 \\ 2(-1) - 8\cdot3 & 2\cdot9 - 8\cdot4 \end{vmatrix}$$
$$= \frac{1}{2}\begin{vmatrix} -1 & -8 \\ -26 & -14 \end{vmatrix} = -97 \qquad (1.5.8)$$

$$\begin{bmatrix} 2 & 3 & 4 \\ 5 & 7 & 6 \\ 8 & -1 & 9 \end{bmatrix}^{-1}$$
$$= \frac{-1}{97}\begin{bmatrix} 7\cdot9 + 1\cdot6 & -3\cdot9 - 1\cdot4 & 3\cdot6 - 7\cdot4 \\ -5\cdot9 + 8\cdot6 & 2\cdot9 - 8\cdot4 & -2\cdot6 + 5\cdot4 \\ 5(-1) - 8\cdot7 & 2\cdot1 + 8\cdot3 & 2\cdot7 - 5\cdot3 \end{bmatrix}$$
$$= -\frac{1}{97}\begin{bmatrix} 69 & -31 & -10 \\ 3 & -14 & 8 \\ -61 & 26 & -1 \end{bmatrix} \qquad (1.5.9)$$

$$A^{-1} = \frac{1}{|A|}(\text{adjoint } A) \qquad (1.5.10)$$

1.6 Linear independence and rank

Definition 1.6.1 A finite set of $m \times n$ matrices $A^{(k)}$ is called *linearly dependent* or *linearly independent* according to whether there exists or does not exist a set of scalars c_k, not all equal to zero, such that

$$\sum_{k} c_kA^{(k)} = 0 \qquad (\text{the } m \times n \text{ null matrix}) \qquad (1.6.1)$$

Linear independence of vectors is a special case of this definition.

Definition 1.6.2 The *column rank* r and row rank r^T, of an $m \times n$ matrix A are respectively the maximum number of columns and rows of A in a linearly independent set. Only the null matrix has rank 0. We shall call the column rank of a matrix its *rank*, and later show it to be the same as its row rank.

Definition 1.6.3 The *distinguished columns* of A are the r nonzero columns, no one of which is a linear combination of its predecessors.

Definition 1.6.4 An $m \times n$ matrix of rank $r \leq m$ is a *row echelon matrix* if its last $m - r$ rows are zero, its distinguished columns are the first r columns of the unit matrix U_m, in order, and the 1's in these columns are the first nonzero entries of their respective rows. If $m = r$, there are no rows of 0's and the $r \times n$ matrix is a *reduced echelon matrix*.

Theorem 1.6.1 Every $m \times n$ matrix A of rank r has the rank echelon factorization

$$\underset{m\times n}{A} = \underset{m\times r}{B}\ \underset{r\times n}{C} \qquad (1.6.2)$$

where B is a matrix whose columns are the distinguished columns of A, and C is a reduced echelon matrix. For example,

$$\underset{A}{\begin{bmatrix} 0 & 1 & 2 & 8 & 3 & 1 \\ 0 & -4 & 5 & 7 & 6 & 12 \\ 0 & -7 & 6 & 4 & 8 & 15 \\ 0 & 0 & -1 & -3 & -2 & 0 \end{bmatrix}}$$

$$= \underset{B}{\begin{bmatrix} 1 & 2 & 3 \\ -4 & 5 & 6 \\ -7 & 6 & 8 \\ 0 & -1 & -2 \end{bmatrix}} \underset{\text{Reduced echelon } C}{\begin{bmatrix} 0 & 1 & 0 & 2 & 0 & -1 \\ 0 & 0 & 1 & 3 & 0 & 4 \\ 0 & 0 & 0 & 0 & 1 & -2 \end{bmatrix}} \qquad (1.6.3)$$

In this example, columns 2, 3, and 5 are the distinguished columns of A and of C, and B is formed from the distinguished columns of A.

Proof: Let B_i be the ith distinguished column of A, and the ith column of B. Then each column $A_{\cdot j}$ of A can be written

$$A_{\cdot j} = \sum_{i=1}^{r} B_i c_{ij} \qquad (1.6.4)$$

where the constants of combination c_{ij} form the matrix C. Since each column of A that is not a distinguished column is a linear combination of preceding distinguished columns, C has a reduced echelon form.

Theorem 1.6.2 An $m \times n$ matrix has the same row rank and column rank.

Proof: Let the given $m \times n$ matrix have the rank echelon factorization $A = BC$. Then the reduced echelon matrix C contains the unit $r \times r$ matrix U_r as a distinguished submatrix, so it has row rank and column rank r. Since each row of A is a linear combination of rows of C, not more than r rows are linearly independent, and $r^T \leq r$. Since A^T has row rank r and column rank r^T, the same argument gives $r \leq r^T$. Hence equality holds; that is, $r = r^T$.

Definition 1.6.5 An $m \times n$ matrix A of rank r is said to have *maximum rank* if $r = m$ or $r = n$.

In the first case, A has a *right inverse* R such that $AR = U_r$, and in the second case A has a *left inverse* L such that $LA = U_r$. If $m = n = r$, then $L = R = A^{-1}$.

1.7 Inversion or solution by row operations

The m linear equations (1.2.1), or the equivalent matrix equation $AX = Y$ of (1.2.2), may also be written using partitioned matrices as follows:

$$(A,\ Y)\begin{bmatrix} X \\ -1 \end{bmatrix} = 0 \qquad (1.7.1)$$

$$(A,\ U)\begin{bmatrix} X \\ -Y \end{bmatrix} = 0 \qquad (1.7.2)$$

If the matrix A has rank r, this system can be simplified to an equivalent system with the same set of solutions (if any), in which each of r "distinguished variables" x_j appears with coefficient 1 in a corresponding one of the first r equations, and is eliminated from all other equations. Each other variable x_k that may appear in any of the simplified equations is preceded by one or more distinguished variables. All variables x_k are eliminated from the last $m - r$ equations if $r < m$, but these $m - r$ equations may impose conditions on the y's that determine whether or not the system has a solution.

In the simplified system, the matrix A is replaced by a *row echelon matrix* LA whose r distinguished columns are the first r columns of the unit matrix U and whose "distinguished 1's" in these columns are the coefficients of the "distinguished variables" that can be expressed linearly in terms of the y's, and of the remaining variables x if $r < n$. If A has an inverse, all variables x_j are distinguished, and $LA = U$, $L = A^{-1}$, $X = A^{-1}Y$. The following elementary operations will simplify a set of m linear equations without changing the solution set (if any solutions exist):

E1. Add c times equation j to a lower equation i (where $j < i$).
E2. Add c times equation j to an upper equation i (where $j > i$).
E3. Multiply equation i by a scalar $c \neq 0$.
E4. Interchange equations i and j.

In actual computations, however, it is much simpler to work with the coefficient matrix (A, Y) in (1.7.1) when y_i are numerically given constants, or with the matrix (A, U) in (1.7.2) when Y is a variable vector, and to reduce the matrix (A, Y) or (A, U) to a row echelon matrix by a succession of elementary operations on rows. These have the same effect on the rows as the operations just described have on the equations. Each operation is effected by a left-sided multiplication by a corresponding elementary matrix, of one of the following types:

E1. Lower elementary: Add c times row j to lower row i

$$\text{Matrix } L_{ij}(c) = U + c\epsilon_{ij} \qquad j < i$$

E2. Upper elementary: Add c times row j to upper row i

$$\text{Matrix } L_{ij}(c) = U + c\epsilon_{ij} \qquad j > i$$

E3. Elementary diagonal: Multiply row i by $c \neq 0$

$$\text{Matrix } L_i(c) = U + (c - 1)\epsilon_{ii}$$

E4. Transposition: Interchange rows i and j

$$\text{Matrix } L_{ij} = U - \epsilon_{ii} - \epsilon_{jj} + \epsilon_{ij} + \epsilon_{ji}$$

Products of any number of matrices of one type only are as follows:

E1 products: *Subunit matrix*. A lower triangular matrix with diagonal entries 1.

E2 products: *Superunit matrix*. An upper triangular matrix with diagonal entries 1.

E3 products: *Nonsingular diagonal matrix*. Diagonal with nonzero diagonal entries.

E4 products: *Permutation matrix*. Rows are any rearrangement of rows of unit matrix.

Both the appearance of these elementary matrices and the fact that any transposition (type E4) is a product of elementary matrices of types E1, E2, E3 is illustrated by the easily verified matrix equation.

$$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\underset{\text{(Transposition)}}{L_{13}} = \underset{\text{(Diagonal)}}{L_3(-1)} \; \underset{\text{(Upper elementary)}}{L_{13}(1)} \; \underset{\text{(Lower elementary)}}{L_{31}(-1)} \; \underset{\text{(Upper elementary)}}{L_{13}(1)} \tag{1.7.3}$$

Determinants of elementary matrices are

$$|L_{ij}(c)| = 1 \qquad |L_i(c)| = c \qquad |L_{ij}| = -1 \tag{1.7.4}$$

The matrix L that converts A into the row echelon matrix LA is the right-to-left product of the elementary factors $L_1, L_2, \ldots, L_k$:

$$L = L_k \ldots L_2 L_1 \tag{1.7.5}$$

but it is usually unnecessary to write out these products separately. Indeed, by operating on (A, U) instead of A, we obtain (LA, L) as the reduced echelon matrix, so if $LA = U$, then $L = A^{-1}$ appears as the right-hand block. This is a practical method for computing an inverse of any nonsingular matrix.

Example 2 Invert a given 2×2 matrix A by row operations, where

$$(A, U) = \begin{bmatrix} 6 & 5 & 1 & 0 \\ 4 & 3 & 0 & 1 \end{bmatrix} \tag{1.7.6}$$

Solution: Perform $L_1(^1/_6)$ and then $L_{21}(-4)$ to reduce column 1.

$$\begin{bmatrix} 6 & 5 & 1 & 0 \\ 4 & 3 & 0 & 1 \end{bmatrix} \to \begin{bmatrix} 1 & ^5/_6 & ^1/_6 & 0 \\ 4 & 3 & 0 & 1 \end{bmatrix} \to \begin{bmatrix} 1 & ^5/_6 & ^1/_6 & 0 \\ 0 & -^1/_3 & -^2/_3 & 1 \end{bmatrix} \tag{1.7.7}$$

Then perform $L_2(-3)$ and $L_{12}(-^5/_6)$ to reduce column 2.

$$\begin{bmatrix} 1 & ^5/_6 & ^1/_6 & 0 \\ 0 & -^1/_3 & -^2/_3 & 1 \end{bmatrix} \to \begin{bmatrix} 1 & ^5/_6 & ^1/_6 & 0 \\ 0 & 1 & 2 & -3 \end{bmatrix} \to \begin{bmatrix} 1 & 0 & -^3/_2 & ^5/_2 \\ 0 & 1 & 2 & -3 \end{bmatrix} \tag{1.7.8}$$

The result is the echelon matrix (LA, L) where $LA = U$ and

$$L = A^{-1} = L_{12}(-^5/_6)L_2(-3)L_{21}(-4)L_1(^1/_6) = \begin{bmatrix} -^3/_2 & ^5/_2 \\ 2 & -3 \end{bmatrix} \tag{1.7.9}$$

The matrix $L = A^{-1}$ is not computed as a product, but is read directly from the right-hand block of the final echelon matrix (LA, L) in (1.7.8).

In the general case, elementary operations can be used to reduce the kth distinguished column of (A, U), linearly independent of its predecessors, to the kth column of the unit matrix, after the preceding distinguished columns have been reduced. By a transposition of rows (if needed) a nonzero entry in row $j > k$ of the kth distinguished column is brought to row k, and the row is divided by the entry to produce a "distinguished 1" in row k. If no such nonzero entry exists, the column is not distinguished, and we proceed to the next column. The kth distinguished column is then cleared of its other nonzero entries by adding suitable multiples of row k to the other rows. In performing these operations, we first write the new kth row (indicated by encircling its distinguished 1), and then modify the other rows before rewriting them.

Example 3 Invert the following 4×4 matrix A by row operations.

$$(A, U) = \left[\begin{array}{cccc|cccc} 2 & 4 & 8 & 6 & 1 & 0 & 0 & 0 \\ 2 & 4 & 7 & 8 & 0 & 1 & 0 & 0 \\ -3 & -3 & -4 & -5 & 0 & 0 & 1 & 0 \\ 0 & 2 & 4 & 2 & 0 & 0 & 0 & 1 \end{array}\right]$$

$$\to \left[\begin{array}{cccc|cccc} \textcircled{1} & 2 & 4 & 3 & .5 & 0 & 0 & 0 \\ 0 & 0 & -1 & 2 & -1 & 1 & 0 & 0 \\ 0 & 3 & 8 & 4 & 1.5 & 0 & 1 & 0 \\ 0 & 2 & 4 & 2 & 0 & 0 & 0 & 1 \end{array}\right]$$

$$\to \left[\begin{array}{cccc|cccc} 1 & 0 & 0 & 1 & .5 & 0 & 0 & -1 \\ 0 & \textcircled{1} & 2 & 1 & 0 & 0 & 0 & .5 \\ 0 & 0 & 2 & 1 & 1.5 & 0 & 1 & -1.5 \\ 0 & 0 & -1 & 2 & -1 & 1 & 0 & 0 \end{array}\right]$$

$$\to \left[\begin{array}{cccc|cccc} 1 & 0 & 0 & 1 & .5 & 0 & 0 & -1 \\ 0 & 1 & 0 & 5 & -2 & 2 & 0 & .5 \\ 0 & 0 & \textcircled{1} & -2 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 5 & -.5 & 2 & 1 & -1.5 \end{array}\right]$$

$$\to \left[\begin{array}{cccc|cccc} 1 & 0 & 0 & 0 & .6 & -.4 & -.2 & -.7 \\ 0 & 1 & 0 & 0 & -1.5 & 0 & -1 & 2 \\ 0 & 0 & 1 & 0 & .8 & -.2 & .4 & -.6 \\ 0 & 0 & 0 & \textcircled{1} & -.1 & .4 & .2 & -.3 \end{array}\right]$$

$$= (U, \; A^{-1}) \tag{1.7.10}$$

At any stage the matrix has the form (BA, B), so the computation can be checked by multiplying the second block B by the original matrix A, and comparing with the first block BA.

The final matrix should be checked in this way, in any case; and if it fails to check, earlier ones should be checked until the error is located.

A modification to this method is, first, to reduce A to an upper triangular matrix by operations of types (E1, E3, E4) that avoid altering any row that has already been given a "distinguished 1," and then to clear the entries above the distinguished 1's, beginning at the last distinguished column and proceeding in reverse order of columns.

If the vector Y is given numerically, and the solution $X = A^{-1}Y$ is required without computing the inverse matrix A^{-1}, the same row operations will reduce (A, Y) to $(U, A^{-1}Y)$ if A has an inverse. Otherwise, LA must have the same rank as (LA, LY) or no solution will exist.

1.8 Generalized inverses for the solution of degenerate linear systems

The linear system $AX = Y$ is called *degenerate* if the $m \times n$ coefficient matrix A of rank r is not both square and invertible. Either many or no solutions may exist. If the vector $Y - AX$ is not zero for any X, either $Y - AX$ or some left multiple thereof may still be minimized in length by some vector X_0, using least squares, and the set of solutions X (if any) or "best fit" vectors X will have the form

$$X = X_0 + A_0 Z \qquad \text{with } AA_0 = 0 \text{ and } Z \text{ arbitrary} \tag{1.8.1}$$

A matrix A_0 of rank $n - r$, such that $AA_0 = 0$, is a complete *right annihilator* of A. It is zero if $n = r$.

Both the particular vector X_0 and a complete right annihilator A_0 of A can be read from the partitioned echelon matrix (LA, L) computed from (A, U) by row operations. Let

$$(LA,\quad L) = \left[\begin{array}{c|c} L_1A & L_1 \\ \hline L_2A & L_2 \end{array}\right] = \left[\begin{array}{c|c} C & L_1 \\ \hline 0 & L_2 \end{array}\right] \tag{1.8.2}$$

where L_2A is the $(m - r) \times n$ null matrix, and where L_1A is an $r \times n$ reduced echelon matrix

$$C = L_1A = (U_r, V)P = (U_r, V)\begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = P_1 + VP_2 \tag{1.8.3}$$

The $n \times n$ matrix P is a permutation matrix with inverse $P^* = (P_1^*, P_2^*)$. Its upper $r \times n$ submatrix P_1 has as its nonzero columns all the r distinguished columns of C, which are the first r columns of U_r.

The $(n - r) \times r$ matrix V is formed from the remaining columns of C. The rows of the lower submatrix P_2 of P are all the rows of the unit matrix that do not appear in P_1, arranged so that $C = P_1 + VP_2$.

If $r > 0$, the $m \times r$ matrix $B = AP_1^*$ contains the r distinguished columns of A, and A has the rank factorization

$$A = BC = AP_1^*L_1A \tag{1.8.4}$$

The equations

$$U_r = P_1P_1^* = (P_1 + VP_2)P_1^* = CP_1^* = L_1AP_1^* = L_1B$$

show that L_1 is a left inverse of B and P_1^* is a right inverse of C. The $n \times m$ matrix $P_1^*L_1 = A^s$ will be called a *semi-inverse* of A. Since $L_2A = 0$, a solution X of $AX = Y$ can exist only if

$$L_2Y = L_2AX = 0 \tag{1.8.5}$$

In any case, a minimizing vector that reduces the length of $L(Y - AX)$ to that of L_2Y is a solution X_0 of $L_1(AX - Y) = 0$ given by

$$X_0 = P_1^*L_1Y \tag{1.8.6}$$

Any right annihilator of $A = BC$ also annihilates $C = (U, V)P$. Hence it can be written in the form A_0Z, where

$$A_0 = P^*\begin{pmatrix} -V \\ U \end{pmatrix} = (P_1^*, P_2^*)\begin{pmatrix} -V \\ U \end{pmatrix} = P_2^* - P_1^*V \tag{1.8.7}$$

The solutions of $AX = Y$ or minimizing vectors X for $L(Y - AX)$ are

$$X = P_1^*L_1Y + (P_2^* - P_1^*V)Z \qquad \text{with } Z \text{ arbitrary} \tag{1.8.8}$$

A numerical example will illustrate these submatrices before we proceed further with the general theory.

Example 4 Solve the system of four equations in five unknowns given by $AX = Y$ where A is 4×5 matrix of rank 3, and (A, U) has the following reduction to row echelon form

$$(A,U) = \left[\begin{array}{ccccc|cccc} -2 & 16 & 12 & -6 & 6 & 1 & 0 & 0 & 0 \\ 3 & -11 & -5 & 6 & -2 & 0 & 1 & 0 & 0 \\ 4 & -11 & -3 & 7 & -1 & 0 & 0 & 1 & 0 \\ 1 & -4 & -2 & 2 & -1 & 0 & 0 & 0 & 1 \end{array}\right]$$

$$\to \left[\begin{array}{ccccc|cccc} 1 & -4 & 2 & -2 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & -3 \\ 0 & 5 & 5 & -1 & 3 & 0 & 0 & 1 & -4 \\ 0 & 8 & 8 & -2 & 4 & 1 & 0 & 0 & 2 \end{array}\right]$$

$$\to \left[\begin{array}{ccccc|cccc} 1 & 0 & 2 & 2 & 3 & 0 & 4 & 0 & -11 \\ 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & -3 \\ 0 & 0 & 0 & -1 & -2 & 0 & -5 & 1 & 11 \\ 0 & 0 & 0 & -2 & -4 & 1 & -8 & 0 & 26 \end{array}\right]$$

$$\to \left[\begin{array}{ccccc|cccc} 1 & 0 & 2 & 0 & -1 & 0 & -6 & 2 & 11 \\ 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & -3 \\ 0 & 0 & 0 & 1 & 2 & 0 & 5 & -1 & -11 \\ \hline 0 & 0 & 0 & 0 & 0 & 1 & 2 & -2 & 4 \end{array}\right]$$

$$= \left[\begin{array}{c|c} P_1 + VP_2 & L_1 \\ \hline 0 & L_2 \end{array}\right]$$

$$\text{where } P = \left[\begin{array}{ccccc} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ \hline 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{array}\right] = \begin{pmatrix} P_1 \\ P_2 \end{pmatrix} \text{ and } V = \begin{bmatrix} 2 & -1 \\ 1 & 1 \\ 0 & 2 \end{bmatrix} \tag{1.8.9}$$

Solutions X of $AX = Y$ exist if and only if

$$L_2Y = y_1 + 2y_2 - 2y_3 + 4y_4 = 0 \tag{1.8.10}$$

The *general solution* vector X is then given in terms of an arbitrary $(n - r)$ vector Z by (1.8.8), namely

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} 0 & -6 & 2 & 11 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 0 & 0 \\ 0 & 5 & -1 & -11 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} + \begin{bmatrix} -2 & 1 \\ -1 & -1 \\ 1 & 0 \\ 0 & -2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}$$

$$= A^sY + A_0Z \tag{1.8.11}$$

Theoretical discussions of degenerate linear systems are aided by the concept of the semi-inverse of a matrix.

Definition 1.8.1 A *semi-inverse*, or *generalized inverse* of an $m \times n$ matrix A of rank r is any $n \times m$ matrix A^s of rank r such that

$$AA^sA = A \tag{1.8.12}$$

If $A = 0$, we define $0^s = 0^*$. Both A^sA and AA^s are idempotent matrices, equal to their own squares, since

$$\begin{aligned} (A^sA)^2 &= A^s(AA^sA) = A^sA \\ (AA^s)^2 &= (AA^sA)A^s = AA^s \end{aligned} \tag{1.8.13}$$

We note from (1.8.4) that $P_1^*L_1$ is one semi-inverse of A. A special semi-inverse $A^\dagger$, called the Moore-Penrose generalized inverse (or pseudo-inverse) is uniquely determined by requiring that both idempotents $A^\dagger A$ and $AA^\dagger$ be hermitian matrices; see (1.8.27). Whenever A is nonsingular, we have $A^s = A^\dagger = A^{-1}$.

Theorem 1.8.1 The $n \times m$ matrix A^s of rank $r > 0$ is a semi-inverse of the rank factored $m \times n$ matrix $A = BC$ of rank r if and only if

$$CA^sB = U_r \tag{1.8.14}$$

Proof: Multiplication of (1.8.14) on the left by B and on the right by C gives (1.8.12). Furthermore, multiplication of (1.8.12) on the left by $(B^*B)^{-1}B^*$ and on the right by $C^*(CC^*)^{-1}$ gives (1.8.14).

Theorem 1.8.2 Every semi-inverse A^s of a matrix $A \neq 0$ with rank factorization $A = BC$ has the form

$$\underset{n \times m}{A^s = A^{N\dagger M}} = C^{N\dagger}B^{\dagger M} = N(MAN)^\dagger M \tag{1.8.15}$$

where $CC^{N\dagger} = U_r$, N is nonsingular $n \times n$, and

$$C^{N\dagger} = NN^*C^*(CNN^*C^*)^{-1} = N(CN)^\dagger \quad \text{(right inverse of } C) \tag{1.8.16}$$

and where $B^{\dagger M}B = U_r$, M is nonsingular $m \times m$, and

$$B^{\dagger M} = (B^*M^*MB)^{-1}B^*M^*M = (MB)^\dagger M \quad \text{(left inverse of } B) \tag{1.8.17}$$

The idempotents A^sA and AA^s have the form

$$A^{N\dagger M}A = C^{N\dagger}C \qquad AA^{N\dagger M} = BB^{\dagger M} \tag{1.8.18}$$

Finally A is a semi-inverse of A^s, since

$$A^sAA^s = A^s \qquad (A^{N\dagger M})^{M^{-1}\dagger N^{-1}} = A \tag{1.8.19}$$

Proof: If N_1, R, M_1 denote nonsingular matrices of dimensions n, r, m, and C^*B^* is a rank factorization of the $n \times m$ matrix A^* of rank $r > 0$, then every $n \times m$ matrix of rank r has the form

$$N_1C^*RB^*M_1 \tag{1.8.20}$$

This will be a semi-inverse A^s of A if $CA^sB = U$. Thus the matrix R can be determined from the condition

$$C[N_1C^*RB^*M_1]B = U \qquad R = (CN_1C^*)^{-1}(B^*M_1B)^{-1} \tag{1.8.21}$$

Here N_1 and M_1 must be chosen so that CN_1C^* and B^*M_1B are nonsingular $r \times r$ matrices. Letting C_1 denote a nonsingular $n \times n$ matrix such that $CC_1 = (U, 0)$, the following factorization can be assumed for arbitrary nonsingular N_1 such that CN_1C^* is also nonsingular:

$$N_1 = C_1\begin{bmatrix} U & 0 \\ W & U \end{bmatrix}\begin{bmatrix} X & 0 \\ 0 & Y \end{bmatrix}\begin{bmatrix} U & Z \\ 0 & U \end{bmatrix}C_1^* \tag{1.8.22}$$

where X and Y are nonsingular $r \times r$ and $(n - r) \times (n - r)$ matrices. Then

$$N_1C^* = C_1\begin{bmatrix} U & 0 \\ W & U \end{bmatrix}\begin{bmatrix} X \\ 0 \end{bmatrix} \qquad CN_1C^* = X \tag{1.8.23}$$

$$C^{N\dagger} = N_1C^*(CN_1C^*)^{-1} = C_1\begin{bmatrix} U \\ W \end{bmatrix} \tag{1.8.24}$$

Thus the matrix $C^{N\dagger}$ is independent of X, Y, Z. Taking $Z = W^*$ we may assume $N_1 = NN^*$, and likewise $M_1 = M^*M$. Each solution A^s of (1.8.12) has the form

$$\begin{aligned} A^{N\dagger M} &= NN^*C^*[(CNN^*C)^{-1}(B^*M^*MB)^{-1}]B^*M^*M \\ &= C^{N\dagger}B^{\dagger M} \end{aligned} \tag{1.8.25}$$

The remaining formulas in Theorem 1.8.2 follow directly.

The Moore-Penrose generalized inverse $A^\dagger$ is obtained for $M = U_m$, $N = U_n$. It may be written

$$A^\dagger = C^\dagger B^\dagger = [C^*(CC^*)^{-1}][(B^*B)^{-1}B^*] \tag{1.8.26}$$

In terms of the partitioned echelon matrix (1.8.2) it is

$$A^\dagger = (L_1A)^*(U + VV^*)^{-1}(P_1A^*AP_1^*)^{-1}P_1A^* \tag{1.8.27}$$

The simpler semi-inverse $A^s = P_1^*L_1$ of (1.8.4) is found when

$$\begin{aligned} M &= L & B^{\dagger M} &= L_1 \\ N &= (P_1^*P_2^* - P_1^*V) & C^{N\dagger} &= P_1^* \end{aligned} \tag{1.8.28}$$

Theorem 1.8.3 For given A, Y, nonsingular N, M, and arbitrary Z, the vectors

$$X = A^{N\dagger M}Y + (U - A^{N\dagger M}A)P_2^*Z \tag{1.8.29}$$

or

$$X = P_1^*B^{\dagger M}Y + (P_2^* - P_1^*V)Z \tag{1.8.30}$$

minimize the squared length of the vector $M(Y - AX)$ and reduce it to $(MY_0)^*(MY_0)$, where

$$Y_0 = (U - AA^{N\dagger M})Y \tag{1.8.31}$$

Solutions X of $AX = Y$ exist only if $Y_0 = 0$.

Proof: First take $M = U$, $Y_0 = Y - AA^\dagger Y = (U - AA^\dagger)^*Y$. Then express the squared length of $Y - AX$ as the sum of the squared lengths of Y_0 and $Y - AX - Y_0$ as follows:

$$\begin{aligned} &(Y - AX)^*(Y - AX) - Y_0^*Y_0 - \\ &\quad (Y - AX - Y_0)^*(Y - AX - Y_0) \\ &\quad = Y_0^*(Y - AX - Y_0) + (Y - AX - Y_0)^*Y_0 \\ &\quad = Y^*(U - AA^\dagger)A(A^\dagger Y - X) + \\ &\quad [Y^*(U - AA^\dagger)A(A^\dagger Y - X)]^* = 0 \end{aligned} \tag{1.8.32}$$

The last two expressions vanish because $A = AA^\dagger A$. Thus $(Y - AX)$ is minimized in length when $AX = Y - Y_0$ or

$$BCX = AA^\dagger Y = BB^\dagger Y \tag{1.8.33}$$

Left multiplication by $B^\dagger$ gives the r equations

$$CX = B^\dagger Y \tag{1.8.34}$$

To minimize the length of $M(Y - AX)$ instead of $Y - AX$, replace Y by MY and $A = BC$ by MBC. Condition (1.8.34) becomes

$$CX = (MB)^\dagger MY = B^{\dagger M}Y \tag{1.8.35}$$

The vector $X = A^{N\dagger M}Y = P_1^*B^{\dagger M}Y$ is seen by direct substitution to be a solution of (1.8.35). Using $V = CP_2^*$ the complete right annihilator for C found in (1.8.7) can be written

$$(P_2^* - P_1^*V) = (U - C^{N\dagger}C)P_2^* = (U - A^{N\dagger M}A)P_2^* \tag{1.8.36}$$

Hence the vectors (1.8.29) or (1.8.30) give the complete solution of (1.8.35) and reduce the squared length of $M(Y - AX)$ to its minimum value $(MY_0)^*(MY_0)$. The vector $Y - AX$ can vanish only if $Y_0 = 0$, and the theorem is proved.

(The second article in this series will appear in April.)

BIBLIOGRAPHY

Aitken, A. C., *Determinants and Matrices*, 9th ed. New York: Interscience Publishers, Div. of John Wiley & Sons, Inc., 1956.

Dwyer, P. S., *Linear Computations*. New York: John Wiley & Sons, Inc., 1951.

Faddeeva, V., *Computational Methods of Linear Algebra*. New York: Dover Publications, Inc., 1959.

Gantmacher, F. R., *Elementary Matrix Algebra*. New York: The Macmillan Co., 1958.

Greville, T. N. E., "Some Applications of the Pseudo-inverse of a Matrix," *Rev. Soc. Ind. Appl. Math.*, vol. 2, 1960, pp. 15–22.

Hohn, F. E., *Elementary Matrix Algebra*. New York: The Macmillan Co., 1958.

Penrose, R., "On the Best Approximate Solutions of Linear Matrix Equations," *Proc. Cambridge Phil. Soc.*, vol. 52, 1956, pp. 17–19.

Perlis, Sam, *Theory of Matrices*. Reading, Mass: Addison-Wesley Publishing Co., Inc., 1952.

more economical than unfoamed plastic because the gas bubbles substitute for relatively expensive plastic. The fine-celled plastics foamed by the hot-spot technique have better dielectric properties than large-celled plastics, or than fine-celled plastics foamed by "blowing" agents. Furthermore, it is mechanically and electrically impractical to use a large-celled plastic insulation on fine wire gauges.

Seismic disturbance data are transmitted by telephone

The Office of Aerospace Research announced recently that scientists at its Air Force Cambridge (Mass.) Research Laboratories have achieved a significant "first" in seismography. They have been able to transmit accurate information from earth disturbances by long-distance telephone line.

The technique permits comparison of data from the relatively quiet New England area with data from the active Aegean, west coast of North and South America, and Japan regions. Differences in various events will be evaluated in terms of distance from the source of the disturbance.

The problem, which has concerned scientists involved in developing a method of accurately detecting underground nuclear tests, is that disturbances on and beneath the earth's surface create similar patterns on a seismograph. Underground nuclear explosions in distant areas create the same seismographic signals as relatively mild local disturbances such as the pounding of the ocean surf, the movement of trains or trucks, sonic boom, and quarry explosions.

Air Force scientists have placed three unmanned stations in Maine—Caribou, Michias, and Milo—and one in Berlin, N. H., which regularly transmit seismic data by land lines to the Weston Observatory in Massachusetts.

There is an average of 12 500 earthquakes of severe to moderate intensity recorded each year. The greatest number of these events occur in the Aegean region.

Lensless optics system makes clear photographs

An optical system in which a sharp, clear image is formed entirely without the use of lenses has been demonstrated by researchers at the University of Michigan's Institute of Science and Technology.

With the use of this technique it may be possible to construct optical instruments such as microscopes, cameras, and photographic enlargers entirely without lenses. The process may be especially useful with X-ray cameras and electron microscopes, since good lenses in these systems are not attainable. The technique may also be used in combination with lenses to improve performance, thus converting a poor optical system into one of high quality.

Perhaps the chief application of the technique will be in the laboratory, as the equipment is expensive—except for the cost of the light source if a mercury-arc lamp is used instead of a laser.

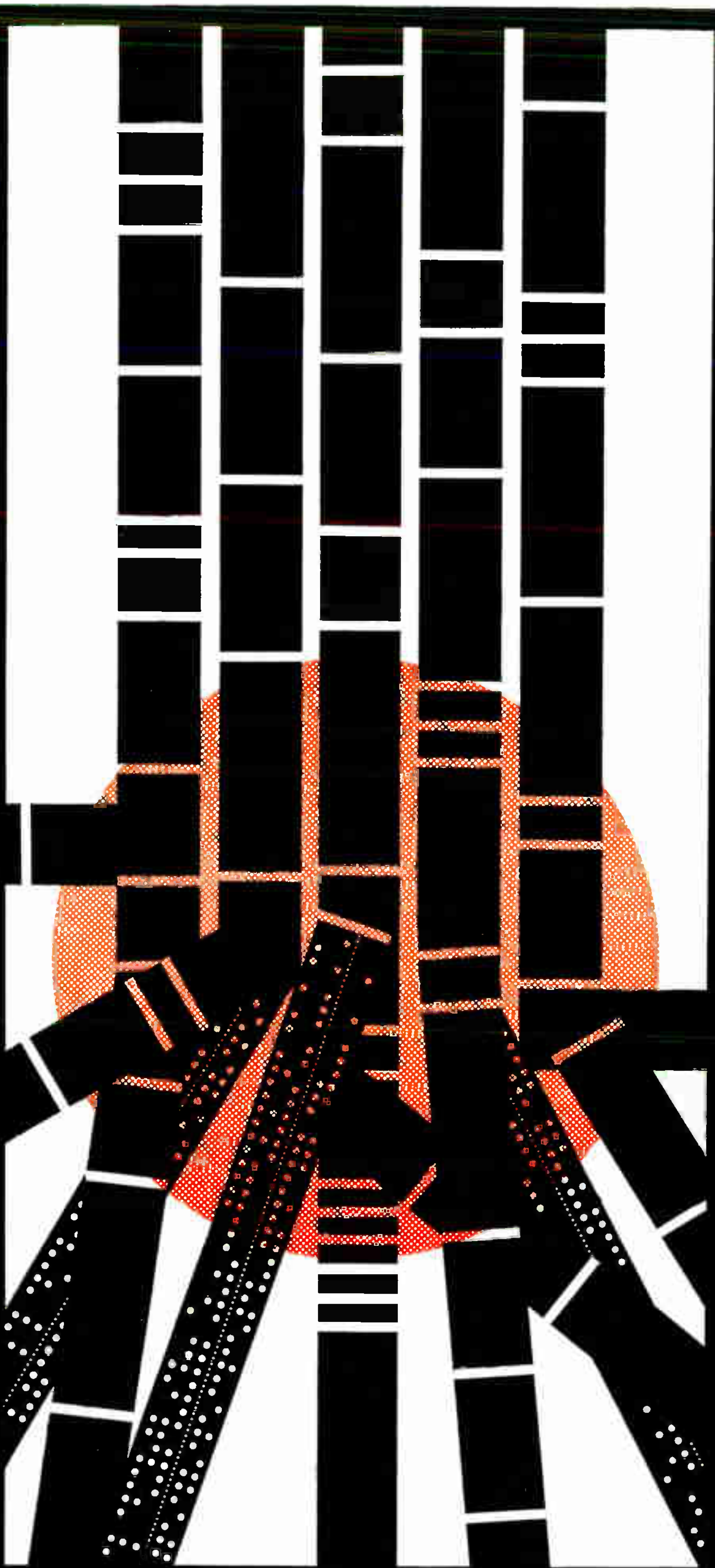
The imaging is done by a two-step process. The first step produces a blurred, unintelligible negative. In the second step, this smudge is converted into a recognizable image.

In the initial part of the process, the object is illuminated by a point-source beam of light. Then, a camera-like device photographs the object. Since no lenses are employed, the resulting photographic negative is blurred and completely unrecognizable. However, when this negative is placed in a special, lensless projector-like device, a sharp, clear image appears on the projection screen.

Each of the rays that comprise the beam has its own intensity. But the rays also have a phase characteristic so that some rays precede and some lag behind. It is this phase data that is lost in recording. Unless the phase of the rays can be recorded on the blurred negative, reconstruction of the image is impossible. Photographic film is completely insensitive to these phase relations.

In the new technique, the camera-like device converts this phase data into intensity variations, which then can be recorded on ordinary photographic film. To effect the conversion, a portion of the laser light is made to bypass the object and is beamed directly into the camera. This is called a *reference* beam. It combines with the light reflected from the object, producing interference. It is the interference between the two components of light which converts the phase data into intensity variations, which are then recorded by the film.

To reconstruct the image, the projector-like device shines a beam of coherent light through the blurred negative. An interaction between the film and the light causes the light rays to be grouped into patterns similar to those



Norelco®

MEETING TODAY'S COMMUNICATION NEEDS WITH TOMORROW'S EQUIPMENT

Here is equipment designed in one of the world's leading communications laboratories, performance-proven in vital communications centers throughout the world. This unique Norelco telegraph and data communication equipment fulfills a wide range of needs with a broad selection of components. Flexibility permits future expansion with add-a-unit ease.

STORE AND FORWARD TELEGRAPH SWITCHING SYSTEMS
Automatic switching systems, designed to simplify message transmission problems for any organization.

DATA TRANSMISSION EQUIPMENT
High speed, accurate performance with error-detection system built in for automatic corrective action.

MAGNETIC TAPE STORAGE UNITS
Compact, long term storage device for use alone or in telegraphic switching systems. Eliminates paper tape—completely self-contained and virtually maintenance-free.

FIVE-ELEMENT AND CCITT SEVEN-ELEMENT ARQ EQUIPMENT
Fully transistorized automatic error detection and correction equipment.

AUTOMATIC FORMAT GENERATOR EQUIPMENT
Automatically generates in encoded form, selected pilot line, priority, routing indicators and origin line, for telegraph messages originating at a transmission point.

ELECTRONIC CODE DETECTORS
A solid state unit which automatically initiates action commands upon detection of pre-set telegraph character and function combinations.

May we assist you in solving your communications problems . . . call or write

Norelco | TELEGRAPH AND DATA SYSTEMS DIVISION

100 East 42nd Street, N. Y. 17, N. Y.

Correspondence

Beginning of broadcasting

I was particularly interested in Mr. Espenschied's letter, "Beginning of Broadcasting" in the December PROCEEDINGS. I would like to quote from a letter addressed to me, dated September 26, 1942, on a printed letterhead "WHA, The Oldest Station in the Nation, University of Wisconsin," and signed by Harold A. Engel, Public Relations.

"The University of Wisconsin station, under the experimental call of 9XM, put its first telephonic broadcasts of voice and music on the air 'early in 1917.' At that time, several other experimental transmitters were in operation. However, of all these only the one at the University of Wisconsin has continued to operate. The others were abandoned for one reason or another. Most of them went out of existence July 1, 1918, when all transmitters were ordered dismantled as a war-time precautionary measure. 9XM was ordered to continue its work on the air. At that time it had been carrying on experiments with the Great Lakes Naval Training Station located nearby.

"KDKA was started in November, 1920. WWJ, Detroit, preceded it by several months, having gone on the air in August, 1920. By that time, the University of Wisconsin station had maintained for three years successful operations. The call letters WHA were assigned on January 13, 1922."

Cecil K. Johnson
Roswell, N.M.

Mr. Johnson's letter of 23 December is a reminder of the fact that many pioneers participated in the initiation of broadcasting. The question that comes to mind is: what station can be credited with having started the snowball a'rolling, if any?

The broadcasting of voice and music "early in 1917" by the University of Wisconsin experimental station 9XM is similar to the fits and starts of others I have mentioned, 1907, 1915, 1916, in which should have been included Fessenden, 1907. In the three years from 1917 to 1920, was there continuous broadcasting of entertainment from station 9XM with a public following? Obviously not; for, during World War I, in 1918, the station was "carrying on experiments with the Great Lakes Naval Training Station." Hence, the 1942 letterhead claim: "WHA, The Oldest Station in the Nation . . . " can hardly be read upon broadcasting. It would be interesting to know just when there did start from this station broadcasting of such programs and continuity as to have engendered a listening public of any size. Not that the very "firsty" first is actually so very important!

Lloyd Espenschied
Kew Gardens, N.Y.

Addendum: My letter evidently has rung the bell of memory on the part of old timers, for two others have taken the trouble to write (privately to the writer) on behalf of their local stations, claiming a "first" in broadcasting, namely:

1-XE, later WGT, of Medford Hills, Mass. said to have been broadcasting as early as 1919;

(call letters?) Grove City College, Pa., said to have broadcast football games and such before KDKA.

All of which is a reminder of how naturally broadcasting arose once there was solved the problem of radio telephony as distinct from wireless telegraphy. That solution came in two steps: first in 1906–1907 the partial solution afforded by the acquiring of continuous waves by means of the Poulsen arc, etc.; second, the complete solution found in the electron amplifier, more especially in the high-vacuum triode, in the roles of amplifier, oscillator, and modulator, as well as detector. The first such all-electronic radio telephone system was that of the American Telephone & Telegraph Co. used in 1915 to broadcast (for narrow-cast purposes) across the continent and overseas for the first time (note two "firsts"!).

But only after World War I arose con-

ditions favoring the continuance of broadcasting and the building of an audience. Among those who found themselves tumbling into this situation was A.T.&T., whereby it almost "started broadcasting," in a manner too amusing and too significant not to tell! On the Atlantic Coast, in developing radio telephony for reaching ships at sea as an extension of the wire telephone network, the company engineers "played ball" with the amateurs, getting reports from them as to the effectiveness of the transmitters, in exchange for the playing of phonograph records, heralding greetings, etc., starting in 1919. But to the big bosses this seemed undignified, and about May 1920 there came the order to stop such frivolity! Naturally that just about broke the hearts of the telephone engineers who were thus exploring by following their noses (and ears). It later developed that the telephone company was negotiating with the General Electric Co. an exchange of patent rights concerning the new vacuum-tube technology, in which exchange the G.E. (and RCA) was to have the field of amateur radio. Broadcasting as such was unrecognized as yet, and that occasioned subsequent trouble with the Cross License Agreement of July 1, 1920—a story in itself.

About the same time, 1920, the telephone company installed a radio telephone link between the mainland and Santa Catalina Island, Calif., intended for private public telephone service. Well, the Island was quite a sexual hunting ground, and some of the conversations were red hot. The listening amateurs were quick to "lend an ear," and before long this broadcasting of public service telephony on the Pacific Coast (heard as far as Australia!) became most embarrassing. A "privacy" system was hurriedly installed, and thus there was stopped another chance for the telephone company to have claimed a "first" in broadcasting!

With incipient broadcasting springing up all over the country in 1920, in the form of a host of little radio telephone transmitters, and with a rising and expectant audience, who can be sure of identifying the "first"? The credentials of effective transmission, a real program, continuity of service down through the years, plus an "up-welling" audience, need to be shown by contemporary evidence. This I've tried to do for the Detroit News station simply because I happen to have known about it.

Lloyd Espenschied
Kew Gardens, N.Y.