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IEEE spectrum

features

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

Scan of a microimage 1.02 cm wide is accomplished by a flying-spot scanner system operating at a 10× optical reduction. The size of the small "e" on the original was 1780 by 1780 μm. There is no discernible horizontal jitter in the letter edges, even though the system is resolving approximately 1500 elements across the field. These scanner systems are described in an article beginning on page 73.

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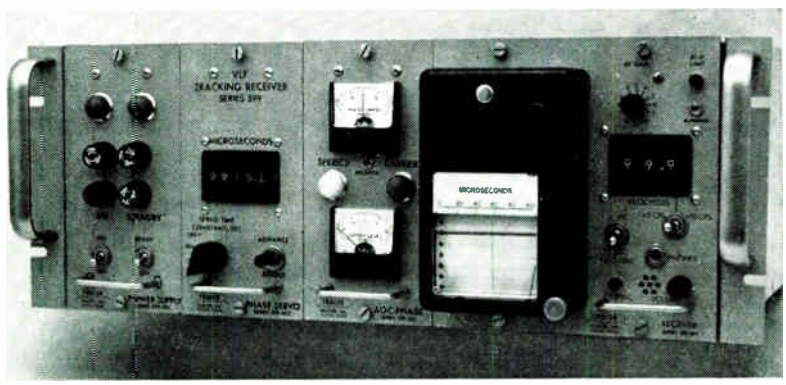

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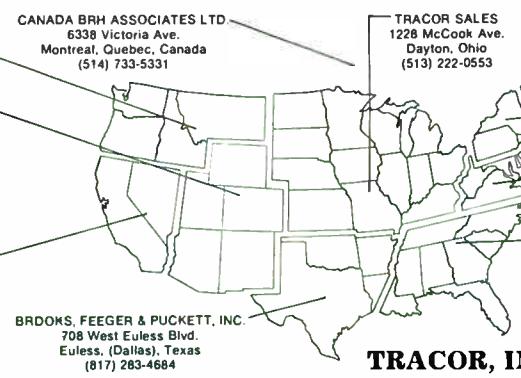

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Lloyd V. Berkner—a commentary by Vannevar Bush

Lloyd V. Berkner was undoubtedly one of the best liked men in the whole field of science and engineering. The reason for his popularity is not hard to find. He liked his fellow men, and obviously enjoyed working with them. From this flowed his many fine accomplishments in originating and molding organizations. This same attitude accounted for his generous collaboration during all of his creative scientific research.

As President of IRE in 1961 he initiated the move to consolidate IRE and AIEE into the present IEEE, and he left his mark on many other undertakings. In an association spanning nearly thirty years, I knew him first as an able investigator and senior staff member of the Carnegie Institution of Washington and later as a key figure in the scientific effort of World War II and the early postwar period.

When I came to the Carnegie Institution as president in 1939, Berkner was chairman of the Section on Upper Atmospheric Physics of the Department of Terrestrial Magnetism. He had come into the Institution in 1933 from the Bureau of Standards when the Bureau could no longer fund his ionospheric studies. While there he had verified and studied the F_1 layer of the ionosphere and developed the rationale of predicting and scheduling long-distance, short-radio-wave propagation on the basis of ionosphere measurements.

Breit and Tuve, who a few years earlier had been doing their pioneer echo investigations of the Kennelly–Heaviside layer, using techniques different from Appleton's, had persuaded John A. Fleming, then head of the Department of Terrestrial Magnetism, that if the Department were to resume work on the problem, they should bring in Lloyd Berkner. His early work with the CIW included the creation and engineering of the first "Ionosonde," the now standard technique used for studying the spectral characteristics of radio waves propagated through the outer ionized regions of the atmosphere, and for defining and describing the ionized layers of the ionosphere.

With Harry Wells, also of CIW, he worked on multifrequency transmissions from stations they had erected in College, Alaska, in Huancayo, Peru, and in Watheroo, Australia. Later they used the pulse method to study the effect of solar storms on the ionosphere.

Berkner was an early and enthusiastic naval aviator, having enlisted in the newly organized Naval Aviation Reserve while he was attending the University of Minnesota. He quickly related his interests in radio and flying, and devised, installed, and flight-tested a small VHF radio communication system for small naval aircraft.

In the first months of World War II, Berkner and Wells set up the western hemispheric network of ionosphere stations, about fifteen in all, in the United States, Canada, the Pacific, and South America. The purpose of the network was to meet the emergency in communications created by the large number of sunspots and the inability of the Army and Navy radios to go to sufficiently high frequencies.

In 1941, Berkner was called to active duty and assigned to the Bureau of Aeronautics, where as chief electronics officer he became responsible for the engineering design of all naval airborne electronics equipment throughout the war. As such equipment proliferated and became more complex, he introduced the systems concept to the management of electronic installations. An important aspect of his contribution was his continued insistence on personally flight-testing new equipment. During the war period he also served as a consultant to Section T of the National Defense Research Committee, which under Merle Tuve was responsible for the proximity fuse, and as consultant to Division C, which under Frank B. Jewett had primary cognizance of communications.

Berkner was one of the original members of the highly important *ad hoc* subcommittee on Radar Research and Development of the Joint Committee on New Weapons and Equipment of the Joint Chiefs of Staff. As noted by Baxter in his book, *Scientists Against Time*, the radar subcommittee of JNW which was headed by Karl T. Compton, was the most important planning group in radar for a significant part of the war.

At the close of the war, Berkner returned to his research at CIW. When I was invited by the Army and Navy in 1946 to head the Joint Research and Development Board, Berkner was my natural choice to fill the important post of executive secretary. He had a highly developed grasp of the interaction of new weapons with both strategy and tactics and, more important, the vision and imagination to look well into the future and to anticipate the potential impact of many new developments. Under his guidance, the Board produced a number of significant studies including, among others, a study of the problem of air navigation and traffic control and one on the problem of evaluating the relative importance to national security of the various competing weapons systems.

In 1951, he left the Carnegie Institution of Washington to become the president of Associated Universities, Inc., with responsibility for the Brookhaven National Laboratory and, subsequently, for the National Radio Astronomy Observatory. He was responsible for the creation of the system of scientific attaches in the State Department. All these and other later accomplishments have been reviewed elsewhere, and are well known, so that I have commented primarily on his earlier years. Through it all, however, runs a notable thread: the ability to work smoothly and harmoniously with others, to overcome obstacles, and to produce results for science and his country.

He had a fine mind and represented a rare combination of research ability and administrative talent. Much of his mature life was devoted, in one way or another, to the service of his fellow men. His death at 62 years of age was premature: the nation has been deprived of what should have been another dozen years or so of productive thought and work.

Spectral lines

Man, a subsystem? "... *the important need is for a full and thoughtful comparison of manned and unmanned systems to accomplish the various objectives.*" This is the tenor of the recent report[1] of the U.S. President's Science Advisory Committee.

We have come a long way from early science fiction concepts, where an astronaut was a modified sailor. Man's part in space adventure is not less crucial but will certainly be different than that imagined by a previous generation. The report is a welcome change from the early emotionalism that called for an American on the moon *first*; though, of course, the story is not yet finished.

The ship's captain has exchanged his bridge for a swivel chair and his belaying pin for a light pen. Through the use of modern electronics he has extended his senses and controls to an unprecedented degree. He may not be as colorful as his 18th century counterpart, but he is a lot more reliable.

With a capability remotely to observe and control,[2,3] and in fact the necessity enforced by the space environment to observe and control at least through tools and windows, it is appropriate to reassess the real usefulness of man in space. More to the point for electrical engineers is to assess and advance technological substitutes for a spaceman.

The report makes a good case for the scientific value of the U.S. space program and suggests post-Apollo activity with primary emphasis on exploitation of our present capability. Who does not thrill at the prospect of exploring planetary surfaces, searching for extraterrestrial life, operating astronomical observatories outside the atmosphere? Man has not lost his imagination nor space its glamour.

In due time, interplanetary travel should be easy and popular, and we may even have extraterrestrial colonies and vacation resorts; but will man be more than a passenger or a poor alternative for a sophisticated telemetry system?

Where does the astronaut fit into the space program? His place has been nicely described[4]: "We believe that man should be used in space flight only when his presence contributes in an important way to the exploratory and scientific objectives."

It is argued[5] that in orbiting astronomical laboratories he should be used only occasionally to repair and replace equipment; that in other systems he may be needed only for occasional maintenance rather than as an operator; and that[6] in spite of the great difficulty and hazard, "man's presence may ultimately be required to provide full and satisfactory answers" regarding extraterrestrial life.

This is an interesting contrast to a section in an earlier report[7] that wisely recommends: "Under no circumstances should man be viewed as a subsystem that does what is left over after the design engineers have reached the end of their current technological rope. Nor should man be inserted as an afterthought and handed a few superficial duties simply to keep him busy. ... Once it has been decided that he is needed, it is advisable to reanalyze the entire mission with this fact in mind ... to use his talents in other ways ..."

Is it not better to build machines for the service of man rather than man for the service of, or as a substitute for, machines? Is there really anything that a man can do in a lethal environment that he cannot do as well and more safely through remote or automatic controls? He now works, through tools and machines, in the scale of the gigantic world and of the microminiature world, with delicate control, and with ease. He does chemical experiments in radioactive chambers and in vacuum chambers through remote observation and control. Is there anything so incredible about doing even more by remote sensing and control through the vast reaches of the solar system?

As a subsystem, man leaves much to be desired. What other system has no significant prospect of miniaturization or ruggedization, can work at full capacity only one quarter of the time, must be treated as nonexpendable, requires a critical psychological and physical environment, cannot be decontaminated, and is so unpredictable?

On earth we are doing much to relieve man of weird and dangerous tasks. Surely we can do as much for him in space. It seems illogical that with present-day telemetry, visual transmission, computer-controlled factories, and remote manipulators, it should be proposed to use a heavy, nonexpendable man for maintenance of space hardware; and in place of automated and remote controlled laboratories for planetary exploration. Send the man because he has judgment and discrimination, but *not* as a subsystem.

Here then is a challenge for engineers. Can we not produce remote observation means and manipulators that perform as well as a man on a tether, and thus relieve our astronauts of the necessity of working in space and on the other planets?

C. C. Cutler

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Authors

Analyzing flying-spot scanner system resolution (page 73)

Caroll J. Brown (M) received the bachelor of science degree in electrical engineering from the University of Southern California, the master of science degree in electrical engineering from the University of Wisconsin, and the engineer's degree from Stanford University, Calif.

He joined the International Business Machines Corporation in 1954, where he worked on the design of circuits and the establishment of testing circuits and procedures for the IBM Ramac. More recently, he has been involved in research and development of CRT remote display systems, high-speed servos, special memories, and high-resolution scanners for image retrieval systems.

Mr. Brown's work with flying-spot scanner technology has contributed to a number of IBM projects in such areas as character recognition, microimage dissection, and data conversion. At the present time, he is serving in the capacity of advisory engineer in IBM's Advanced Systems Development Laboratory, Los Gatos, Calif.

Waveform generation by enzymatic oscillators (page 79)

Britton Chance (F) is chairman of the Department of Biophysics and Physical Biochemistry at the University of Pennsylvania School of Medicine and Director of the Johnson Research Foundation for Biophysics. He received the Ph.D. degree in physical chemistry from the University of Pennsylvania in 1940, and he later was awarded a doctorate in physiology and a D.Sc. degree from Cambridge University, England; he also studied at the Moore School of Electrical Engineering. Between 1941 and 1945 he was a member of the Radiation Laboratory at Massachusetts Institute of Technology, where he served as leader of the Precision Circuit Group, associate director of the Receiver Components Division, and as a member of the steering committee. He received the President's Certificate of Merit for his contributions to the development of radar. His recent interests include the application of solid-state lasers through the measurement of ultrarapid biochemical reactions. He is the author of over 300 published papers.

Kendall Pye is presently a postdoctoral fellow in the Johnson Research Foundation at the University of Pennsylvania, Philadelphia, Pa., where he is engaged in research on oscillating biochemical reactions, using yeast as a model system. Although he is now studying the control mechanisms operating in such systems, his interests also include periodic phenomena occurring in other areas of biology.

Dr. Pye received the bachelor of science degree in biochemistry with honors from the University of Manchester, England, in 1961. Three years later, he was awarded the doctor of philosophy degree, also in biochemistry, from the same school. His doctoral thesis was concerned with research into the mechanism of the Pasteur effect in yeast. His published scientific papers have been in the general area of metabolic control.

He joined the Johnson Research Foundation in 1965, and this fall he will join the Biochemistry Department of the University of Pennsylvania Medical School.

Joseph Higgins is an associate professor of biophysics at the University of Pennsylvania. Since 1949 he has been associated with Professor Chance in the development and application of computers for the study of chemical kinetics and cellular dynamics.

He was awarded the master of arts degree from Harvard University in 1955, and he received the doctoral degree in physics from the University of Pennsylvania in 1959. His postdoctoral studies were carried out with Prof. I. Prigogine (University Libre de Brussels) and Prof. Thor A. Bak (University of Copenhagen, Denmark) on the theory of irreversible processes.

In 1961 Dr. Higgins returned to the University of Pennsylvania, where he became principal investigator for the development of the Mark II computer—a hybrid computer specifically designed for the investigation of chemical reaction kinetics. This work has led to several papers on control and dynamics in cellular chemistry.

Multiple-access discrete-address communication systems (page 87)

Arnold M. McCalmont (A) is president of Technical Communications Corporation, Lexington, Mass. He completed his undergraduate and most of his graduate work at the University of Redlands, Calif., and he also studied aerological engineering at the U.S. Navy Post Graduate School. After his service in the Navy, he became an instructor in physics, meteorology, and photography at Bakersfield College. He also served as a consultant in operations planning, meteorology, and documentation. Subsequently, as a member of the staff of Air Force Cambridge Research Laboratories, he served as chief of the Research Applications Branch and then as chief of the Research Information Division. In the latter capacity, he directed the information management program, technical intelligence, and photographic functions. Since forming TCC, Mr. McCalmont has directed studies of Navy communications (Somada), the design of a meteorological/oceanographic buoy system, and the design of an automated meteorological data-handling and display system; he has also served on programs dealing with data transmission between computers and between automated subscribers.

He is a member of AMS, AAAS, and AGU, and a contributing member to both Navy and FCC working committees on communications.

Educating for the new technology (page 99)

Howard W. Johnson joined the Massachusetts Institute of Technology in 1955 as an associate professor of industrial management and as director of the Sloan Fellowship Program. He became associate dean of the Sloan School of Management in 1958 and, in the following year, he became dean. Under his leadership, the school's scope and depth in education and research were greatly expanded. Major research programs in finance, organization, information and control systems, industrial dynamics, and the management of large-scale technology-based enterprises were inaugurated. In 1966 he assumed the presidency of M.I.T.

He received the A.B. degree in economics with honors from Central College, Chicago, in 1943, and then served in the infantry and in military government in Europe and Africa. After study at the University of Glasgow, Scotland, he became a graduate student at the University of Chicago, where he received the M.A. degree in economics in 1947. Between 1948 and 1955 he served on the faculty of the University of Chicago.

Mr. Johnson is a member of the U.S. President's Advisory Committee on Labor–Management Policy. He is a Fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science, and a member of the Council on Foreign Relations.

Thyristors and rectifier diodes—the semiconductor workhorses (page 102)

F. W. Gutzwiller (F) is manager of application engineering for the Semiconductor Products Department of the General Electric Company, Auburn, N.Y.

He was graduated from Marquette University, Milwaukee, Wis., with a bachelor of electrical engineering degree. A veteran of over 12 years of service with GE, Mr. Gutzwiller has been active in the application of power semiconductors. He was responsible for the applications work on the team that developed the first commercial silicon-controlled rectifiers. He was also involved in the inception and development of the controlled avalanche rectifier diode and the triac bidirectional switch.

He has published over 30 technical papers and articles and is one of the authors of *Semiconductor Controlled Rectifiers: Principles and Applications of p-n-p-n Devices*. He is the editor of the General Electric SCR Manual, and he has been granted 11 United States patents in the semiconductor field.

Mr. Gutzwiller is presently serving as Papers Chairman of the Power Semiconductor Committee of the IEEE Industry and General Applications Group; also, he was on the Program Committee for the IEEE Industrial Static Power Conversion Conference (1965).

"Mathematics 10" (page 112)

E. S. Purington (F), who presently serves as vice president for Hammond Research Corporation, Gloucester, Mass., received the A.B. degree (summa cum laude) from Bowdoin College in 1912, the A.M. degree in physics and mathematics from Harvard in 1913, and the Sc.D. degree (honoris causa) from Bowdoin in 1965.

Between 1915 and 1920 he was in the Electrical Division of the National Bureau of Standards. In its Resistance Section and its Inductance and Capacitance Section, he was extensively engaged in ordnance researches and developments for and with the Armed Services. As a member of the Radio Section, Dr. Purington was engaged in the revision of the "Signal Corps Pamphlet 40."

He joined Hammond Laboratories in 1920, and has participated in most of its electrical and electronics research for governmental, commercial, and educational purposes. For his work, he has been granted 77 U.S. patents. In 1966 he retired from the post of chief engineer and acting president of the Hammond Research Corporation.

He is a member of Alpha Delta Phi and Phi Beta Kappa. He served for nine years as an IRE representative to the American Standards Association.

Michael Faraday—a centennial (page 114)

Bern Dibner (F) presently is serving in the capacity of chairman of the board of directors for the Burndy Corporation, Norwalk, Conn. He received an electrical engineering degree from the Polytechnic Institute of Brooklyn in 1921 and, subsequently, he studied at Columbia University, New York, and the University of Zurich, Switzerland. He served with the Adirondack Power & Light Corporation and the American & Foreign Power Company prior to founding Burndy in 1924. He is a veteran of both world wars and served as a lieutenant colonel with the Air Forces in Europe.

Dr. Dibner is a trustee of the University of Bridgeport and of the Yale Medical Library, and a Fellow of Brandeis University and of the Pierpont Morgan Library. In 1936 he founded the Burndy Library, which is devoted to the history of science. Presently, he is the library's director.

He is the author of several works on the history of science, including more than a dozen published books and papers in the field of electricity and magnetism.

Dr. Dibner is the recipient of an honorary doctorate from the Polytechnic Institute of Brooklyn.

Economics of indoor climate control (page 120)

Herbert L. Laube is past president of and senior consultant to Remington Air Conditioning, the Climate Control Division of the Singer Company, Auburn, N.Y. He received the B.Sc. degree in mechanical engineering from Iowa State University in 1923 and then joined the Parker Ice Machine Company, serving first as a design engineer and then in sales work. In 1927 he joined the Export Department of the Brunswick Kroeschell Company and, in 1934, after the firm had merged into the Carrier Corporation, he became vice president of the International Division.

Immediately after Pearl Harbor, he became vice president for research and product development in the Engineering Division. He joined Remington Corporation as president in 1946, serving in that capacity until Remington became a Singer Division in 1964, at which time he became its general manager. A year later, he assumed the position of senior consultant.

Mr. Laube holds a number of patents, and is a member of the American Society of Heating, Refrigerating and Air Conditioning Engineers.

Resolution of flying-spot scanner systems

The flying-spot scanner system has become a precision device that offers high scanning speeds with good resolution. It can reduce a 1.3-meter stack of earnings reports to a single reel of magnetic tape in eight hours

Caroll J. Brown *International Business Machines Corporation*

Optical reader systems can condense data at the rate of 650 lines per minute, using the flying-spot scanner technique. Flying-spot systems are not new, but they have been held back by component limitations. Excellent system components are now available, and FSSS is being used to convert images into electrical signals for high-speed transmission of complex scientific, business, and defense information to remotely located computers or readers. Recently, photographs of the moon were made by Orbiter I and stored on film, to be retrieved and transmitted on command to an earth receiving station by a flying-spot scanner system.

The U.S. Government's largest bookkeeping operation uses an advanced optical scanning system to read reports typed or printed in over 200 different typefaces. Operating at more than 650 lines per minute, the IBM 1975 Optical Page Reader scans earnings reports posted quarterly for the Social Security Administration by 3.5 million U.S. employers. Before the system went into operation in Baltimore, billions of bits of information in each employee wage report were manually punched into cards for transfer to magnetic tape and computer processing.

The flying-spot scanner device condenses a 1.3-meter stack of earnings reports onto a single magnetic tape reel in eight hours—a hundredth of the time formerly required. The system at the Social Security Administration exemplifies the trend to finding better ways to communicate and to store vast hoards of data in small spaces. It becomes increasingly likely that many more systems will be built around flying-spot scanners to take advantage of their high-speed, high-resolution capabilities.

Although FSSS is an old means of converting images into electrical signals for remote transmission, it offers a good solution to the modern problem of transmitting complex scientific, business, and defense information to remote viewing devices or to computers. Widespread use of FSSS has been held back, however, by component limitations. Now, within the past decade, most of these limitations have been overcome. Many companies are producing excellent system components for off-the-shelf purchase, and FSSS has become a precision device that offers high resolution, high scanning speed, and asynchronism (the ability to stop anywhere during a scan; to jump to selected areas and begin scanning; to do location or servoing actions; to perform variable-speed scanning; to scan blank areas extremely rapidly). The FSSS has become a promising and hardly touched resource. Imagine, for example, a system storing thousands of microimages for instantaneous scanning and conversion to electrical signals for transmission over a network of remote viewing and facsimile stations.

A flying-spot scanner already has been used successfully to send pictures back to earth from Orbiter I on its journey around the moon. Photographs of the moon were made and stored on film aboard the spacecraft. Then, on command, the flying-spot scanner rapidly scanned the film images, and the video signal was transmitted to the receiving station. Among the many possible FSSS applications, consider these:

1. Character-recognition devices based on high-resolution flying-spot scanners and modern logic circuitry to produce high-speed data inputs directly from machine-printed documents with varied typefaces. Machines built for the Post Office Department already recognize city-state locations for all states and hundreds of major cities, reading tens of thousands of addresses per hour. Reading rates range from 5000 to 10 000 characters per second.

2. Optical readers, which read 15 handwritten characters (ten digits and the letters C, S, T, X, and Z) to enter credit-card printed numbers, sales checks, meter readings, and other documents directly into a computer. The need to translate into punched cards or other machine-language form is eliminated for such users as department stores and utilities.

3. A flying-spot store, which provides a semipermanent information storage system and has been used by Bell Telephone Laboratories in an electronic switching system.[1] The store utilizes cathode-ray-tube (CRT) access to information stored on photographic emulsion. Telephone switching requires ready access to control and translation information. The semipermanent memory has stored basic operational routine and number translation information, taking directory numbers used by customers and transforming these into equipment numbers. A small tele-

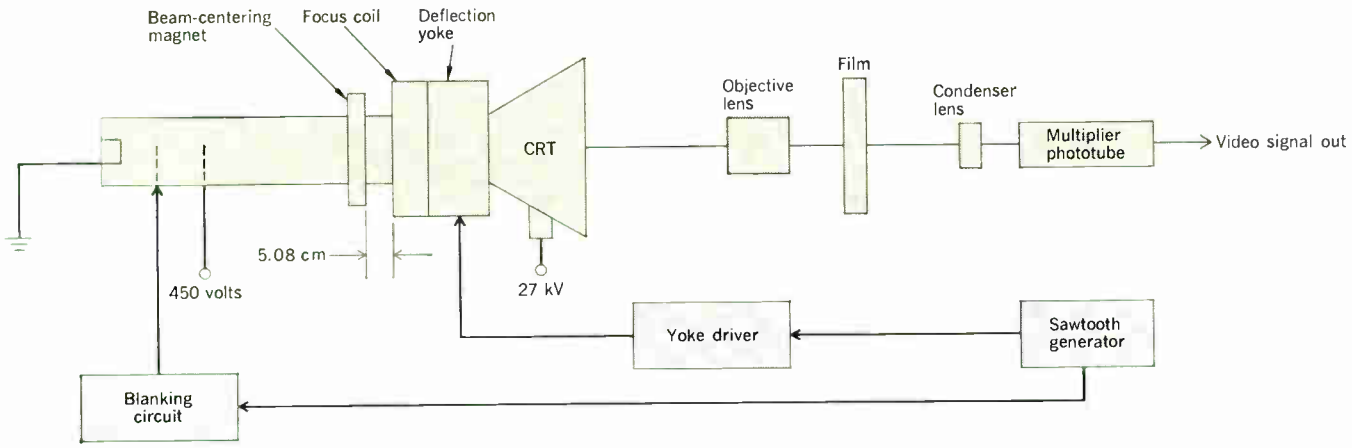


FIGURE 1. Diagram of a flying-spot scanner.

phone-switching system requires from 500 000 to one million bits for translation information alone.

4. A film recorder, which stores graphic and alphanumeric data on 35-mm film for scanning by an FSSS. Through the use of computer control, three-dimensional views from any angle are presented, and drawings can be modified and updated.

These few recognized applications for flying-spot scanner systems are only a beginning; many potential applications remain undeveloped or unrecognized. But before the potential of the FSSS can be realized, a better understanding of the problems encountered in constructing and applying such a system is essential.

A basic flying-spot scanner system consists of a CRT, objective lens, transmitting film, condensing lens, and phototube (Fig. 1). A light spot sweeping across the CRT face is focused on the transmitting film. A multiplier phototube behind the film receives the light modulated by the film image and converts the image into an electrical signal. An alternate system for scanning opaque documents has the opaque document in place of the transmitting film, and phototubes suitably arranged to collect reflected light. For a digital reading system, the phototube signal is appropriately clipped, shaped, and entered into a computer. For a display system, the signal is sent to a nearby or remote display station where it is reconstructed as a picture.

The system used as an example in this article scans a transparent film microimage about 1 cm wide with a resolution of 1500 television lines at about 40 percent modulation. A transparent image 21.6 cm wide can be scanned with a resolution of 2700 television lines at about 40 percent modulation.

System resolution is a function of CRT spot size (or resolution), lens resolution, film image contrast and sharpness (related to the film granularity as well as to the quality of the lens used to place the original image on the film), and phototube signal-to-noise ratio (SNR). The SNR becomes small at low light levels, reducing the number of bits that can be resolved adequately. These factors, which influence system resolution, will be described.

Cathode-ray-tube spot size resolution

In studies at the IBM Advanced Systems Development Laboratory at Los Gatos, Calif., system cathode-ray tubes, using magnetic focus and deflection, had a 10.8-cm maximum usable face diameter. Data presented were taken at 27-kV anode voltage and 450-volt second-grid voltage. By the shrinking raster method, CRT spot sizes measured 25.4 μm and 20.3 μm at 5-μA beam current. In this discussion, line or spot width is taken as the width at the half-amplitude point of the CRT spot line spread function (energy distribution). The best experimental relation obtained was that the actual spot width was about 1.5 times the width determined by the shrinking raster method. The CRT spot size increases with beam current,[2] since the effective cathode emitting area is increased and focusing lens aberrations increase. The spot does not stay in focus as it moves across the CRT face because the electron beam has a center of curvature at the yoke whereas the tube face is flat. Since the magnetic deflecting field is not uniform, the spot changes shape; to keep the spot in focus, focus coil current can be adjusted. The phosphor is a P16 type, with a rapid decay time (0.05 μs to 37 percent amplitude), so that light will not continue to be emitted from areas the spot has passed, thus eliminating the scanning effect of a wide spot.

Lens resolution

There are four ways in which the lens may deteriorate system resolution: resolution limitation caused by diffraction effects; limitations because of aberration effects; off-axis resolution loss resulting from increased aberration effects; and light-gathering capability.

Diffraction effects. Diffraction spreads an infinitesimal object point of light into a finite disk of light surrounded by fainter rings in the image plane. Resolution, as limited by diffraction, is given by

$$\text{Resolution} = \frac{d}{1.22\lambda F(1 + m)} \qquad (1)$$

where

F = focal length of the lens
m = magnification at which the lens is being operated
d = diameter of the lens aperture
λ = wavelength of light

Aberrations. Lens aberrations produce spreading of a point of light into a mound of light at the film similar to

that produced by diffraction. When the mound of light is scanned with a slit, the CRT spot size enlargement at the film is considerable when low-resolution lenses are used, when a lens is operated at a large field angle, or when large optical reductions are used in the flying-spot scanner system. If the lens line spread function is known, the lens effect on the CRT spot size (seen at the film) can be determined by convolving the lens line spread function with the CRT line spread function. Mathematically, this is[3]

$$F(x) = \int_{-\infty}^{\infty} A(\xi)G(x - \xi)\, d\xi \qquad (2)$$

where

$F(x)$ = CRT spot line spread function at the film modified by the lens
$A(\xi)$ = lens line spread function
$G(x)$ = CRT spot line spread function

The lens resolving power is the maximum number of light and dark line pairs per millimeter that can be resolved visually with sufficient magnification. As shown in an IBM internal report, the frequency response function $Y(f)$ of a lens is related to the lens line spread function by

$$Y(f) = \left[\left(\int_{-\infty}^{\infty} A(\xi) \cos 2\pi f\xi\, d\xi\right)^2 + \left(\int_{-\infty}^{\infty} A(\xi) \sin 2\pi f\xi\, d\xi\right)^2\right]^{1/2} \qquad (3)$$

where

$A(\xi)$ = lens line spread function
f = spatial frequency, Hz/mm
$Y(f)$ = (the contrast of the image)/(the contrast of object), when the object luminance varies sinusoidally in one direction.

$$\text{Contrast} = \frac{F_{max} - F_{min}}{F_{max} + F_{min}}$$

where F represents illuminance.

If a typical lens response $Y(f)$ is plotted against lines per millimeter, the lens resolving power will be roughly equal to the line frequency at which response is zero. Almost zero image contrast is obtained at the point of maximum resolution.

Where a typical lens resolution is plotted as a function of aperture size, highest resolution occurs between maximum and minimum aperture. At maximum aperture, diffraction is minimized but lens aberrations are usually large. At minimum aperture, aberration effects are reduced but the diffraction effect is larger.

Off-axis lens characteristics. A lens usually will exhibit lower resolution at an off-axis point as the off-axis incident rays strike the lens at a wider angle with respect to the lens axis. Lens aberrations are a function of this field angle.

Test data on different lenses presented in Fig. 2 were taken with the system using the test lens to scan a 10 101-bit pattern on film at 3× optical reduction. The bit size chosen gave 10 percent to 30 percent modulation, where modulation is defined as the ratio of the phototube signal swing for a scan of 10101 series of bits to the phototube signal swing for full black to white light, and where bits one (1) and zero (0) are of equal width. Only the scan at the CRT center was used, as the lens and film were moved to obtain proper off-axis distances. The lens focus was adjusted for maximum signal from 10 101 bits at each off-axis position.

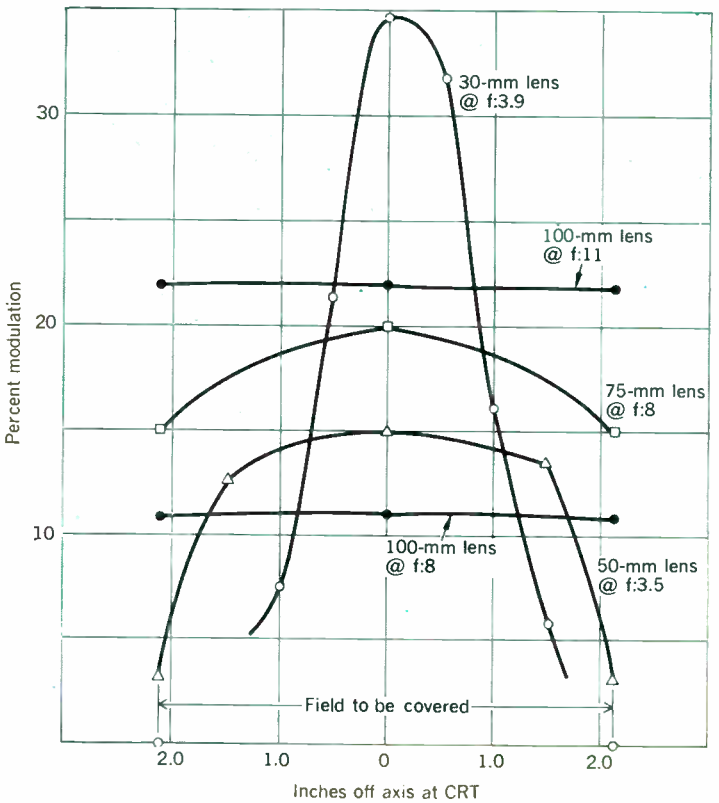


FIGURE 2. Performance of various lenses at 3× optical reduction with lenses scanning a 10 101-bit pattern.

Light-gathering ability. When collected light flux is plotted relative to 1:1 magnification for a group of constant-aperture lenses, less light is gathered by lens as it is moved further away from the CRT. This is a function of the reduction or magnification. For the lenses tested it also was found that at very large apertures lens resolution decreases. Lens resolution also decreases with distance off-axis; and light transmitted at off-axis points is reduced by the $\cos^4$ law and by vignetting.

Phototube

The signal-to-noise ratio for a phototube is given by

$$\text{SNR} = \sqrt{\frac{i_k}{2qB}} \qquad (4)$$

where

q = 1.6×10^{-19} coulomb
B = bandwidth, in hertz
i_k = average photocathode current, in amperes; directly proportional to the light to the phototube

The light striking the phototube is reduced in six cases and will give a poorer SNR for operation

1. At larger optical reduction.
2. Of lenses at higher f number (smaller aperture) to overcome lens aberrations.
3. At lower CRT beam currents for smaller spot size or for phosphor preservation.
4. When the system for scanning images contains a

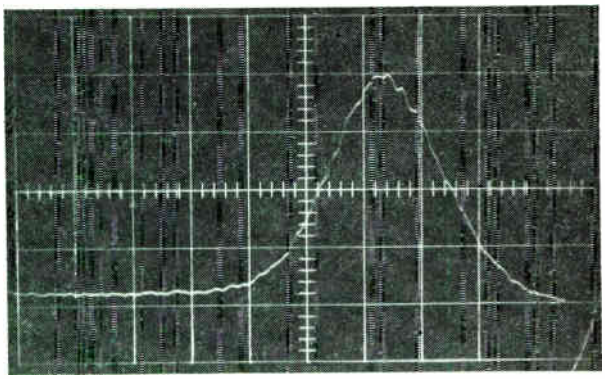


FIGURE 3. CRT spot line spread function at 3-μA beam current (sweep speed = 6.35 μm/μs at the CRT face).

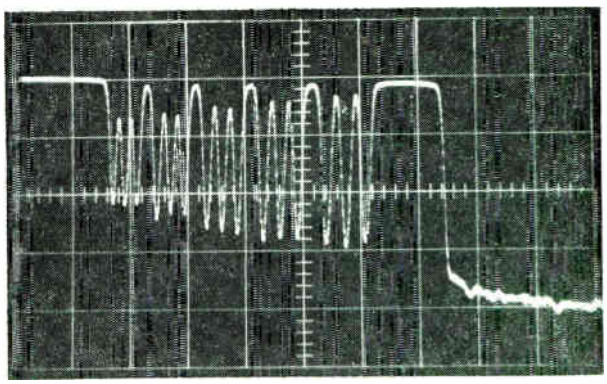
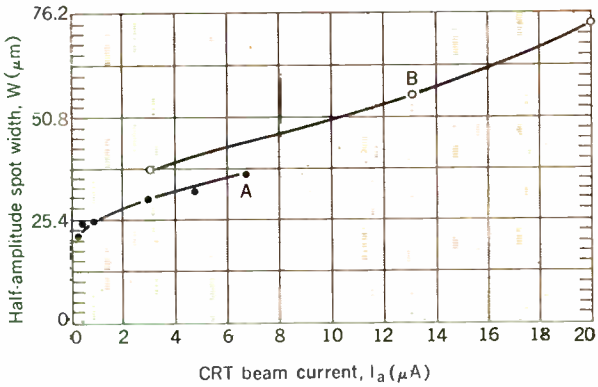


FIGURE 5. Modulation obtained by actual scan of bits equal to CRT spot half-amplitude width.

FIGURE 4. Spot size vs. beam current. A—CRT with 20.3-μm spot by shrinking raster. B—CRT with 25.4-μm spot by shrinking raster.



larger total number of bits or elements on the film so that individual bits are smaller than the CRT spot on the film.

5. Of the system at higher information rates required for repetitive television-type display with high resolution, increasing the bandwidth and reducing SNR.

6. Of the system at even higher information rates, causing CRT sweep speed to be so fast that tailing caused by finite decay time of phosphor occurs.

Film image

One of the most frequent and usually least suspected causes of inadequate performance of a system is the quality of the film image. An example of poor film image may be cited from experience with a 22× reduction of a 21.6- × 27.9-cm printed page to a film image approximately 0.99 cm wide. The image was to be scanned with the FSSS to investigate the scanner system feasibility as a readout device.

In the first attempt the image was reduced 22× in one step to film with a resolution of 170 lines per millimeter, and scanning results were inadequate. As observed under a 400-power microscope, the quality of the image was poor. By reducing in two steps (10× and 2.2×), and using high-resolution film and lens, the results justified scanner resolution of 1500 television lines at 35 percent modulation.

The lens used to produce the film image, and the film itself, must have sufficient resolution for the film image to be sharp and have reasonably high contrast. Contrast should be high enough so that areas designated transparent shall be very transparent, and those designated black shall be very dense.

Optimum image size

Defining optimum image size involves a compromise. It is difficult to work at 20× reduction because of lack of light. For microimages, 5× to 10× reduction is better, providing the lens covers the wide field angle; 2.5× or less reduction is even better in cases where small image size is not required.

Experimental results

The following experimental results were obtained for CRT spot size, relation of modulation to undeteriorated spot size, spot size at the film, attainable resolution, and actual microimage scan.

Spot size at the CRT. Two CRT spot sizes were measured, using a lens at f:3.9 to magnify the spot 10× onto a film image consisting of two transparent 43.3-μm slits separated by 1250 μm on an opaque background. The use of two slits instead of one made it possible to calibrate the sweep speed readily. The spot energy distribution (spot line spread function) across one of the slits was photographed, as shown in Fig. 3. This is a spot line spread function of a 38.1-μm minimum half-amplitude spot, which, by the shrinking raster method, produced a 25.4-μm spot size at the same beam current. A beam-centering magnet 5.09 cm behind the focus coil was adjusted for minimum spot width.

Data concerning spot size as a function of beam current for two different cathode-ray tubes are shown in Fig. 4. At 3-μA beam current, minimum half-amplitude points are 38.1 μm and 30.5 μm. Spot height (that is, the y dimension of the spot) was measured for one tube; the half-amplitude height was 96.5 μm when the width was 30.5 μm. By adjusting the beam-centering magnet the spot height was reduced to 55.9 μm, but the spot width increased to 35.6 μm.

A symmetrical spot is desirable. Misalignments in the CRT gun and between the electron beam and the focus coil exact center, and a nonuniform deflection coil field cause the spot to assume an elliptical or other noncircular shape.

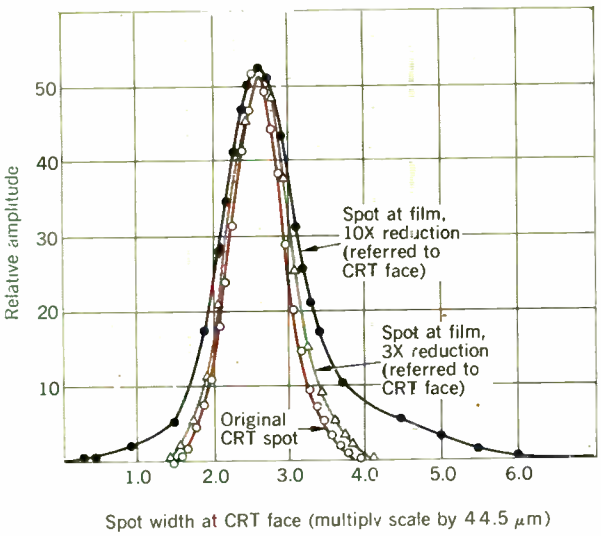


FIGURE 6. Distribution of original cathode-ray-tube spot as modified by lens at f:3.9 on axis.

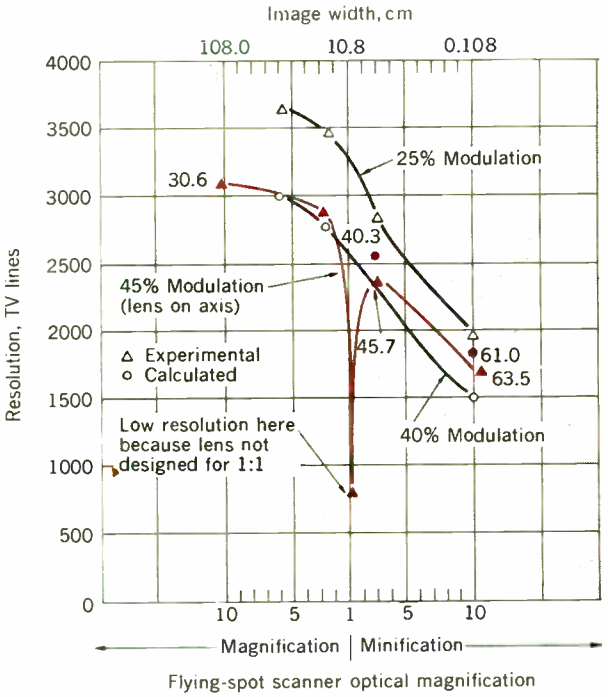
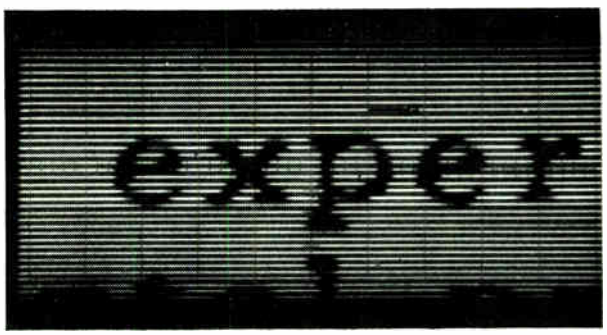


FIGURE 7. Experimental and theoretical resolution of FSSS using lens on axis at f:3.9, with 35.6-μm spot half-amplitude width and 3-μA beam current (black curve). Attainable resolution, with spot half-amplitude width = 30.5 μm, using selected lenses for each magnification (colored curves).

FIGURE 8. Scan of typewritten page (reduced 22× onto film; FSSS operated at 10× optical reduction).



Relations of modulation to undeteriorated spot size

Usually the fundamental design question is, "If closely spaced marks are scanned, what will be the relative amplitude of the output signal?" Assuming an ideal lens, this study approached the problem in three ways. The first method assumed that the spot has a Gaussian distribution from which the modulation (that is, the relative output signal) was calculated. When a single, isolated transparent bit equal in width to the CRT spot half-amplitude width is scanned at the film, 76 percent modulation is obtained. When a series of opaque and transparent bits, each equal in width to the CRT spot half-amplitude, is scanned, 52 percent modulation is obtained. Results are not exact because the actual spot does not have perfect Gaussian distribution.

The second method used the convolution equation. The CRT spot line spread function was measured by scanning a slit at 10× optical magnification. This was convolved with a series of bits, $G(x)$, on a computer to solve the equation (2) relating the CRT spot line spread function at the film to the lens line spread function and the CRT spot line spread function at the CRT. When the resulting signal $F(x)$ is plotted, the average modulation is about 45 percent.

In the third method, the flying-spot scanner system was used to scan the resolution chart at 10× optical magnification; see Fig. 5. Individual bits in the second bit group from the left are equal in width to the CRT half-amplitude width at the film. In the second group bit width was 312 μm, and these bits were scanned with a 30.5-μm half-amplitude spot width optically magnified ten times. These bits yield about 45 percent modulation. Thus, both the experimental method and the computer convolution method yield 45 percent modulation when a series of identical bits is scanned.

Spot size at the film

In an actual system spot size at the film is modified by a nonideal lens. The nature of this effect was determined mathematically by using the previously mentioned convolution program. Figure 6 illustrates the original CRT spot size and the resulting convolutions for 3× and 10× optical reduction.

The original half-amplitude width is 35.6 μm. At 3× reduction, half-amplitude spot width, at the film, is 40.6 μm referred back to the CRT. Optical reductions or magnifications refer to CRT spot reduction or magnification, not to image or original document reduction or magnification. At 10× reduction, the spot at the film is wider and contains a larger amount of energy in the long tail near the base, as though scanning with a very large spot.

It is desirable to find what bit size produces 45 percent modulation at the film in order to provide a basis for comparison with a scan by an undeteriorated spot where 45 percent modulation was produced, when bits equal in width to the spot half-amplitude width were scanned with

the original undeteriorated CRT spot. This problem was resolved experimentally by using the flying-spot scanner system to scan resolution charts at various optical magnifications. Figure 7 illustrates experimental and theoretical resolution using a lens on axis at *f*:3.9; spot half-amplitude width was 35.6 μm with the chosen lens not suitable at the 1:1 magnification.

The question to be answered now is: "What bit size at the film produces 45 percent modulation when scanned with the spots shown in Fig. 7?" This question was answered by convoluting the spot line spread function at the film with a bit pattern. Forty-five percent modulation is produced by approximately 6.1-μm bits at the film at 10× reduction and by approximately 15.2-μm bits at the film at 3× reduction. Referred to the CRT face, bit sizes are 61 and 45.7 μm respectively.

The analytical solution presented shows what modulation is possible in the case of an ideal film image, thus enabling the user to ascertain if a poor-quality film image may be limiting the actual flying-spot scanner resolution. Using the analytical solution, improved CRT and/or lens performance can be predicted.

In general, CRT spot enlargement is more pronounced at large optical reductions as the spot is reduced to about the same size as the lens line spread function, which is different for different lenses and even for the same lens at different magnifications. This effect cannot be predicted accurately unless the lens line spread function and the CRT spot distribution are known.

Attainable resolution

Resolution, as used in this article, means the total number of bits, or elements (number of television lines, not optical lines), that will produce a certain modulation across an entire field. Using a "best" lens for each magnification, the experimentally attained resolution is shown as a function of magnification in Fig. 7. Groups of opaque and transparent bits or bars of equal width were scanned. Figure 7 also shows the maximum number of elements scanned in a single sweep with a 25 percent or 40 percent modulation.

Resolutions represent the number of resolvable bits across the 10.8-cm CRT face. When a 4:3 aspect ratio raster scan is used the resolution across the image is reduced, so the resolutions given describe the image diagonal. The CRT spot width is 30.5 μm; the maximum theoretical number of television lines resolvable with 45 percent modulation is 10.8 cm/30.5 μm, or 3540 lines.

If a Gaussian distribution is assumed for the spot at the film, an isolated bit can be defined as a bit separated by about 2.5 times the spot width or more from the nearest neighbor. With a Gaussian distribution assumed for the spot at the film, the theoretical modulations obtainable can be calculated as 76 percent for an isolated bit and 52 percent for a series of opaque and transparent bits of equal size.

Microimage scan

Figure 8 depicts the result of scanning a 1.02-cm-wide microimage with the system operating at 10× optical reduction. The image was produced by reducing the 21.6- by 28-cm original 10× and again 2.2× onto high-resolution film.

In the scan of the typed page (Fig. 8), the size of a small "e" on the original was 1780 by 1780 μm. The thin horizontal bar of the "e" was 178 μm thick and the letter's thickest part was 382 μm. The small "e" on the typed page was 1.4 times as wide and the small horizontal bar was 2.3 times as wide as that on a magazine page. There is no discernible horizontal jitter in the letter edges, even though this system resolved approximately 1500 elements across the field.

Conclusions

This article has specified flying-spot scanner system resolution when used to scan images from 1.02 to 61 cm wide. A transparent film microimage 1.02 cm wide can be scanned with 1500-television-line resolution at about 40 percent modulation; a transparent image 21.6 cm wide can be scanned with 2700-television-line resolution with the same modulation.

Resolution variances with image size are caused by the system lens and film. The reasons for this are:

1. Lens aberrations cause a point of light to be imaged on the film as a disk of light with an energy distribution called the lens point spread function. When small images are scanned, the point spread function effect on the spot size at the film becomes appreciable.
2. Light that the lens can gather depends on the optical reduction used. At large reduction, the light gathered will be small, and the signal-to-noise ratio will be poor. Signal-to-noise ratio can be improved by making the bits larger at the expense of fewer bits that can be resolved in one sweep.
3. Resolution is reduced by a lens operating at off-axis points as compared with operation at an on-axis point.
4. System resolution is affected by the scanned film image resolution. A very small image usually will be poor in quality as compared with a large image, because the lens line spread function producing the image and the film line spread function remain constant in spite of the size of the image. Hence, the spread functions account for a proportionately greater degradation as the image is made smaller.

If a series of bits equal in width to the CRT spot half-amplitude width are scanned with the CRT spot undeteriorated by a lens, resulting modulation is approximately 45 percent. For comparison, the CRT spot line spread function was convolved with the lens line spread function to obtain the spot line spread function at the film at 3× and 10× optical reduction. In turn, this result was convolved with a bit pattern and the effective CRT spot enlargement at the film due to the lens aberrations was determined by finding the bit size producing 45 percent modulation.

At 10× reduction, a relatively high resolution lens at *f*:3.9 on axis caused the effective spot size at the film to be approximately 1.7 times as wide as the original spot.

The author is indebted to his various associates at IBM for their constructive thoughts and encouragement in completing this project, most notably R. C. Schneider, R. C. Treseder, and M. E. Rabedeau.

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Waveform generation by enzymatic oscillators

Of the many phenomena that have come to the forefront of biomedical research, the control of cell chemistry and physics is the one that would seem most capable of linking the interests of the electrical engineer and the biological scientist

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The control of cell chemistry is being investigated through a multipronged approach combining the techniques of physics, chemistry, and biology with the development of electronic instrumentation and the application of analog and digital computers. An example of such metabolic control phenomena is provided by biological oscillators involving enzymatic reactions. These oscillators, which may exist in nearly every kind of cell and even in several forms in a single cell, reveal basic instabilities in biochemical reactions and metabolic control that may be of significance to health and disease. In addition, the high-frequency oscillations observed in simple enzyme systems may be models for the longer-period rhythms that regulate the activities of nearly all biological systems.

Many bodily functions are subject to periodic control, and such rhythmic phenomena have been studied in human beings by a number of workers, particularly Curt Richter and Frans Halberg. Their observations indicate that humans are subject to many biological clocks of three general types: those located in the blood-forming tissues, those located in the brain, and those involving target organs such as the endocrine glands. The variety of periods of which a human is capable ranges from the obvious short-period beat of the heart and the 24-hour cycle of body temperature fluctuation through the weekly cycle of 17-ketosteroid urinary excretion in man, studied by Halberg,[1] to the well-known 28-day ovarian cycle. In addition, many investigators, particularly Richter,[2] point to periodicity in states of health and disease, ranging from 48 hours to two or three weeks; many of these rhythms are evoked only by appropriate synchronizing disturbances.

Recent studies of clocks in single cells have entailed the development of methods for continuous biochemical readout from cells and tissues that have shown persistent short-period oscillations in the concentrations of essential biochemical constituents. The oscillations have been observed in intact cells, particularly yeast,[3,4] in intact organs of small animals,[5] and in soluble enzyme systems extracted from both materials.[6-8] An analog computer representation of the physical chemistry on which the oscillatory mechanism is based provides a simplified explanation of the nature of the feedback causing the oscillations.[9] The equivalent electronic circuit may translate the biochemical oscillator into the terms of reference of the electronic engineer; it somewhat resembles a phantastron.[10]

The nerve messages worked on so elegantly by our predecessor at the Johnson Foundation, Dr. D. W. Bronk,[11] provide one of the few examples of continuous extracellular readout of intracellular events, in this case in terms of electric potentials. Biochemical quantities are much more difficult to read out directly, and the object of much of our research has been the transduction of underlying physical, chemical, and biochemical processes to continuous readout. Since essentially nondestructive readout is desired, attention has been focused upon the nature of optical signals from cells and tissues. One biochemical component, diphosphopyridine nucleotide, is particularly well suited for nondestructive readout since it is highly fluorescent in its reduced form, known as DPNH. Ultraviolet irradiation produces a visible blue DPNH fluorescence peaking at about 470 nm and as few as 10 000 DPNH molecules can be detected by a highly sensitive microfluorometer.[12]

It is also possible to read out with great sensitivity the small absorbancy changes due to changes of DPNH level in cells or excised strips of solid tissues.[13] This is essentially a time-sharing technique, in which the tissue is alternately illuminated by the light of two wavelengths, initially adjusted so that a balanced output is read out of the photomultiplier. This balanced waveform, fed into a phase detector, rejects any small changes common to both wavelengths but sensitively responds to differential changes. As in electrophysiology, where it is necessary to reject large changes common to both electrodes and yet detect sensitively a small differential change of potential, here nonspecific effects such as movements of the tissues during contraction must be rejected and small differential signals of one part in 100 must be recorded with precision and speed. The common-mode rejection for certain types of nonspecific effects is high, over a thousandfold. The sensitivity is limited usually only by the shot noise from the photosurface.

We first applied this differential absorption technique in 1954 to the biochemical events that follow the feeding of a suspension of starved yeast cells (*Saccharomyces cerevisiae*). The results,[14] which are indicated in Fig. 1(A), show that feeding caused increased absorbancy at 340 nm (upward deflection of the trace) and obviously led to an unstable situation with long overshoot and recovery. Thus the first recording of intracellular events identified the biochemical system as inherently instable.

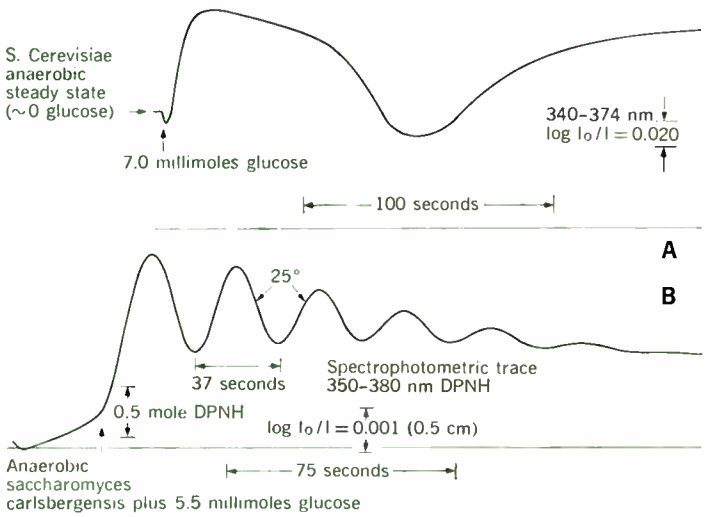
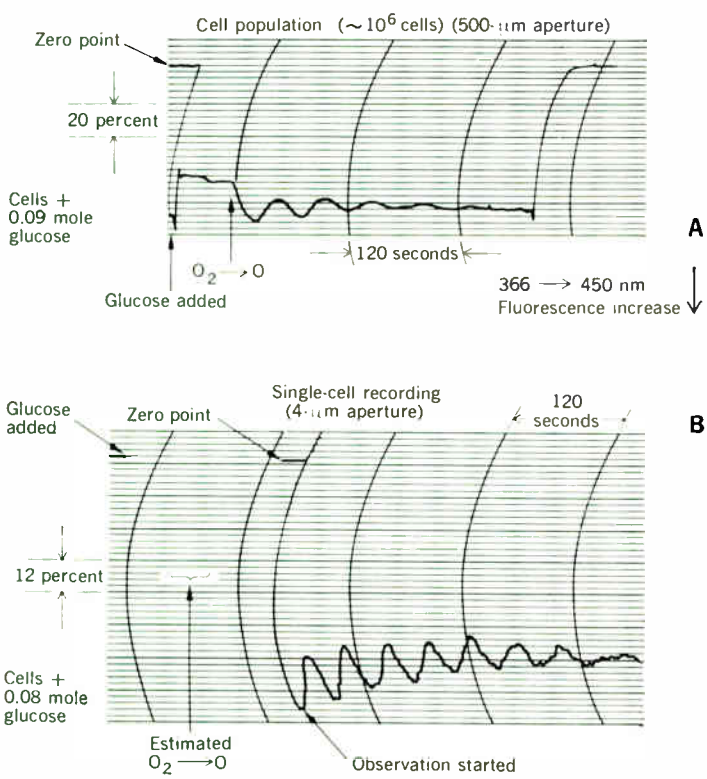


FIGURE 1. A—Dual-wavelength spectrophotometric recording of DPNH overshoot following addition of glucose to starved yeast cells (Saccharomyces cerevisiae). B—Damped sinusoidal oscillations in a suspension of yeast cells (S. carlsbergensis) on anaerobiosis.

FIGURE 2. Fluorometric recording of oscillations of the DPNH level in (A) a suspension of 10^6 cells, and (B) a single cell of S. carlsbergensis.



This observation lay fallow for a number of years until A. K. Ghosh obtained the results shown in Fig. 1(B).[15] At the point where oxygen dissolved in the suspension is used up by mitochondrial activity, this yeast, *S. carlsbergensis*, shows a large upward deflection that is the beginning of not just a simple overshoot but a damped sinusoid such as one might have expected from a pulsed *LC* oscillator. Although some chemical oscillators are known, this was the first observation of the generation of a persistent sinusoidal waveform from a biochemical event in living cells recorded in terms of the biochemical constituents involved in the oscillations.

Since, under these conditions, we are dealing with a population of cells, the question arises as to whether the oscillations are an intrinsic property of the single cell or whether and to what extent they depend upon the interaction of individuals in the population. Yeast cells are not large, 2–3 μm at best for the types that we use, and may contain no more than a million molecules, or 10^{-17} mole, of the biochemical constituent under study. Nevertheless, we have been able to take advantage of DPNH fluorescence, coupled with a sensitive phase-detection system, to measure the oscillations of the DPNH level in a single isolated cell observed under high-power magnification. A typical series obtained by G. Williamson is shown in Fig. 2. Here the fluorescence trace, delayed somewhat in order to permit the isolation and mounting of the cell, shows a sinusoidal oscillation very similar to that observed in the cell suspension. It seems as if each cell has the capability of providing a persistent biochemical oscillation for this short period.

The next step was to extract and isolate the oscillator by breaking the cell wall and, surprisingly enough, after a few months of work we were able to obtain an extract of yeast enzymes that showed vigorous oscillations.[16] In Fig. 3 the differential spectrophotometric recordings are made on an enzyme system obtained by breaking the cell, and it is seen that the DPNH concentration oscillates sinusoidally, just as if it were a pulsed crystal or *LC* oscillator capable of high precision in waveform and frequency. These oscillations involve the glycolytic enzymes of the cell; Fig. 4 indicates some of the key enzymes that operate in the series of reactions that converts glucose into alcohol in yeast. Only half a dozen of the 30-odd enzymes and five intermediates (*A*–*E*) in this pathway are included; between them are a number of phosphate derivatives of glucose. The interconversion of one compound to another depends upon a sequence of enzymes whose abbreviations are written above the arrow. In addition, there are a number of coenzymes or cofactors upon which the operation of the enzymes depends, such as adenosine triphosphate, the energy-rich molecule, and DPNH, the substance we measure with our optical methods. There is a feedback in this system, not identical to that of Nyquist,[17] but a feedback in terms of gain control in which a product of one reaction can control the effectiveness of those preceding it. Either inhibition or activation may be observed, and these are indicated by (+) or (−) signs. Where there is product activation or inhibition that directly affects the amount of active enzyme present, the analysis indicates an oscillatory potential in that step; to the biochemist, this is known as a cooperative phenomenon. Therefore, the regions "Oscillator I" and "Oscillator II" are identified. Thus, we have

a complex sequence of steps involving positive and negative feedback, and the possibility of oscillatory response.

An analytical approach

In Fig. 5, the biochemical reactions of Fig. 4 are written as chemical and differential equations. Thus, Eqs. (1)–(3) illustrate the conversion of A to B and B to C. In (4), the inactive enzyme E_i is converted by the product C into active enzyme E_a in a reaction in which C is not expended. The two differential equations, (5) and (6), represent the basic feedback property of the system, and it is seen that the rate of formation of C depends upon the concentration of the intermediate E_aB, which in turn depends upon the concentration of E_a (7). Thus, this particular equation has a good deal of positive feedback in it. An inspection of the differential equation indicates that when B is near zero, there will be a linear relationship between overall rate (dC/dt) and concentration of B. However, when all of E_a is converted to E_aB, there will be no further possibility of increasing the rate unless more E_i is converted into E_a. This characteristic is similar to the mutual characteristic of a pentode. Other formulations are given by Berman and Schoenfeld.[18,19]

The sequence of intermediate $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E$ has been suitably programmed for an analog computer.[20] In Fig. 6, the computer outputs corresponding to B, C, and D show a characteristic oscillatory behavior when A enters the appropriate region. If A is clamped at any particular value during the oscillatory phase, continuous sinusoids of that particular amplitude are generated; it should also be noted that component B gives sinusoids, and C gives pulses. Thus, the analog computer shows that a sufficient requirement for oscillation is the back-activation connection in the sequence indicated in the diagram.

Although the analog provides the mathematical basis for the enzymatic oscillator and is an absolute mechanism in the sense that it is based upon the physical-chemical laws that govern the enzymatic action, it tells the engineer very little about the relationship of this type of oscillator to those with which he is familiar. We have therefore attempted to derive a physical analog for the enzymatic oscillator, based upon the variable transfer characteristic of a vacuum tube.

The transfer characteristic of an enzyme system for converting A to B is nicely represented in Fig. 7 by those of a multivariable element, for example, a multigrid vacuum tube with a sharp cutoff on both g_1 and g_3 such as the 6AS6. The flow of material through the chemical system is represented by the potential of g_3 and the effect

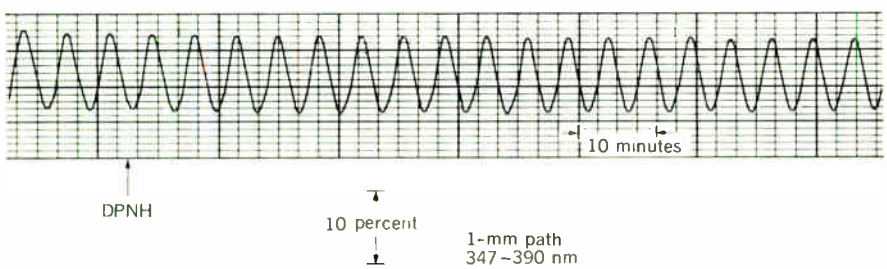
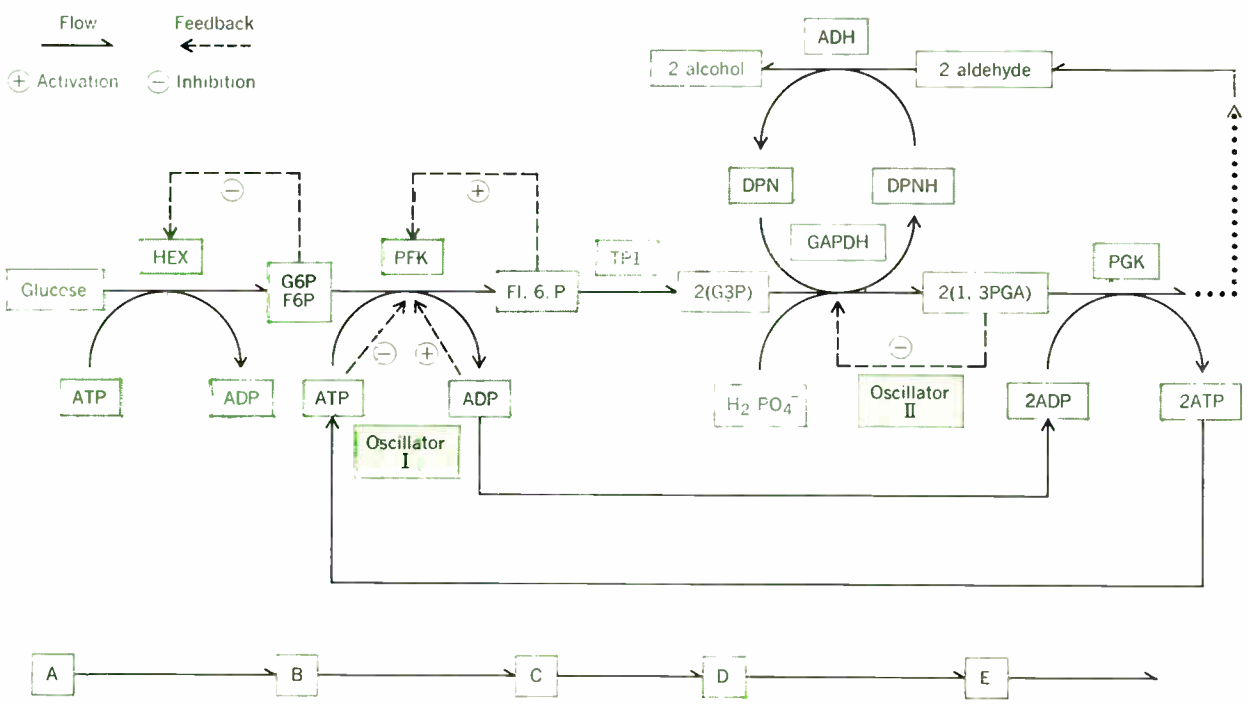


FIGURE 3. Spectrophotometric recordings of sinusoidal oscillations of DPNH in a cell-free extract of the yeast enzyme system.

FIGURE 4. Chemical feedback in glucose metabolism.



$$\begin{array}{c} E_i \\ \downarrow \\ A \longrightarrow B \longrightarrow C \longrightarrow D \\ \uparrow \\ E_a \end{array} \qquad (1)$$

$$B + E_a \xrightarrow{k_1} E_aB \qquad (2)$$

$$E_aB \xrightarrow{k_3} E_a + C \qquad (3)$$

$$E_i + C \underset{k_5}{\overset{k_4}{\rightleftharpoons}} E_a \qquad (4)$$

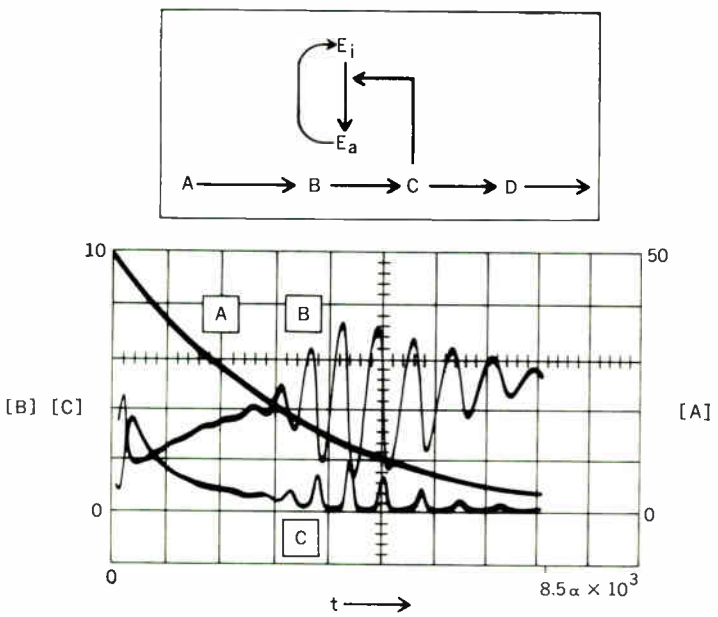
$$\frac{d(E_aB)}{dt} = k_1 B E_a - k_3(E_aB) \qquad (5)$$

$$\frac{dC}{dt} = k_3(E_aB) \qquad (6)$$

$$\begin{cases} E_aB = \text{const.} - E_i - E_a \\ E_i = \dfrac{k_5}{k_4 C} E_a \end{cases} \qquad (7)$$

FIGURE 5. Equations for the chemical oscillator.

FIGURE 6. Simplified enzymatic oscillator and analog computer solution.



of varying amounts of the active form of the enzyme is represented by the potential on g_1. Although in some respects this is an imperfect analog, it may provide a picture in engineering terms of the type of system with which we are dealing.

On this basis we can write, in Fig. 8, a minimum analog for the feedback properties of an enzymatic sequence in which A is converted to B and C; one enzyme is specified to convert B to C. The trick comes in the conversion of the enzyme by its product, C, from an inactive E_i to an active E_a form. This conversion is indicated by feedback of C to G_1 of V_1, to give a positive signal on that grid in proportion to the amount of C that it has formed, so that an activation or increase of gain occurs step by step with

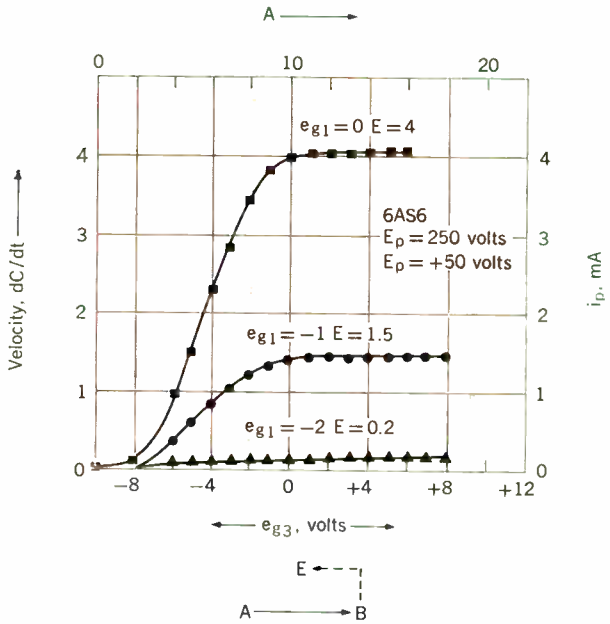


FIGURE 7. Electronic analog as set up to represent the back-activated enzyme step.

the accumulation of C as a potential on the capacitor. Otherwise, the circuit is straightforward and similar to one proposed by MacNichol[21]; the conversion of A to B is represented by the accumulation of charge on G_1, driving G_3 of V_1 positive, and after inversion discharging C_1, and charging a capacitor C_2 to represent the amount of C. Note that the enzyme oscillator does not involve a direct feedback, but rather a feedback of the integral of the output, and thus may be classed as a waveform generator of the phantastron type.[10]

The oscillatory phenomena

It is of interest to determine the operating characteristics of the oscillator. This has been done, not with the computer representation or the physical analog, but with the enzyme system itself.[22] The concentration changes of one of the feedback chemicals, DPNH, can be continuously read out by dual-wavelength spectrophotometry in the yeast cell extract. Three examples obtained from the soluble extract of the Carlsberg yeast are included in Fig. 9: (A) shows a damped sinusoid, as would be obtained from a ringing circuit; (B) shows an amplitude-modulated sinusoid, as would be obtained in communication; and (C) shows a continuous sinusoid, as might be obtained from a pulsed LC oscillator or a pulsed crystal oscillator. In each case the enzyme system is oscillating within a period of several minutes. It is obvious from these records that this is a high-precision oscillator of considerable reproducibility and one also found in mammalian systems where similarly complex waveform generations can be generated in a heart extract.[23]

By suitably altering the chemical composition of the enzyme system, other waveforms can be generated. Figur 10(A) indicates an approximation to a square-wave generator with roughly equal marks and spaces, and Fig. 10(B) an approximation of an unequal-duty-cycle multivibrator waveform. In this case it becomes apparent

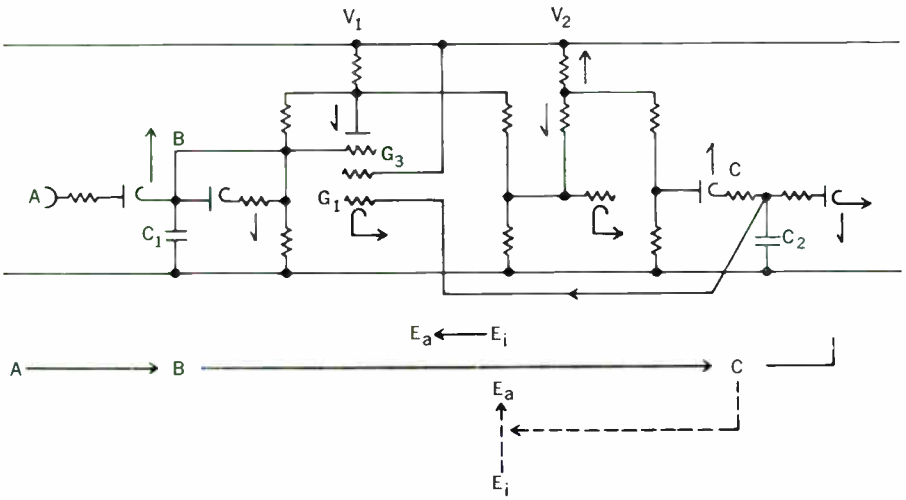


FIGURE 8. Electronic analog for back-activated enzyme.

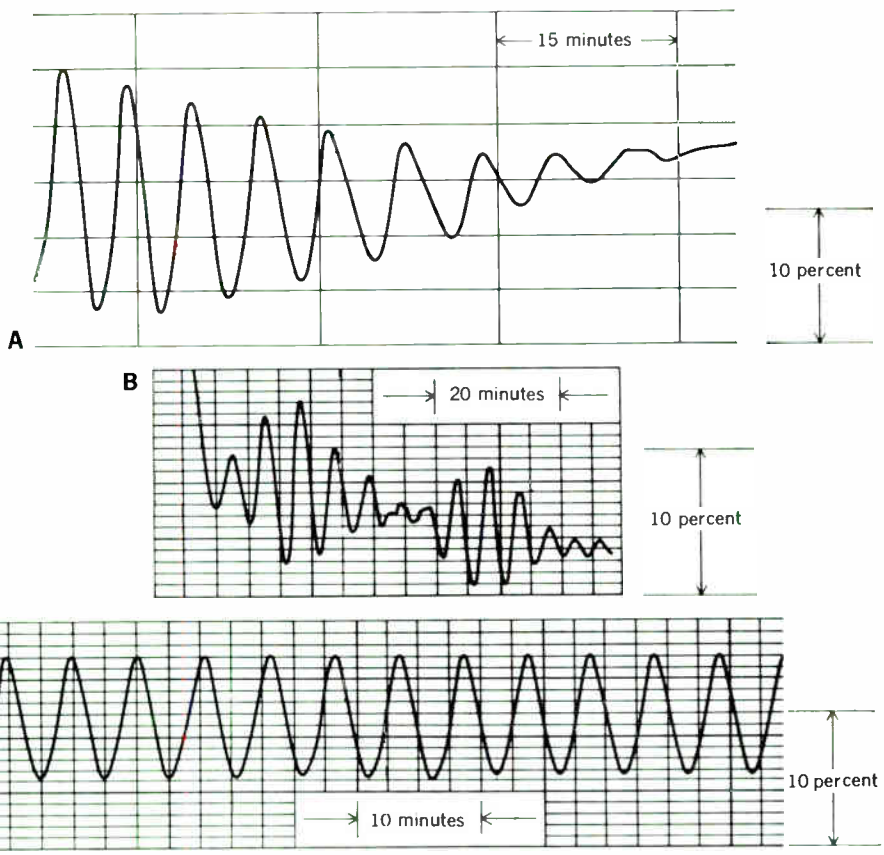


FIGURE 9. Waveforms generated in a cell-free extract of S. carlsbergensis. Spectrophotometric recordings at 347–390 nm; 1-mm optical path. A—Damped sinusoid. B—Amplitude-modulated sinusoid. C—Continuous sinusoid.

that the enzymatic system is capable of generating more than one frequency, as indicated by the higher-frequency modulations on the trace. In Fig. 11 the chemical concentrations have been altered to give single and double pulses from the enzymatic oscillator. In Fig. 11(A) single pulses with spacings of more than 15 minutes are obtained, and in Fig. 11(B) double pulses are obtained.

It is apparent from these data that the system contains more than one oscillator and is capable of nearly any waveform type of generation. It should be emphasized that this sophisticated type of waveform generation occurs in the most primitive cell types and with some of the most elementary steps of metabolism.

The role of the enzyme 'clock'

Quantitative evaluation of oscillatory phenomena requires continuous, or nearly continuous, readout of the phase and amplitude of the waveform. One organism particularly useful for this purpose is the dinoflagellate protozoan *Gonyaulax*, which has been investigated by Hastings.[24,25] When agitated at various times in its oscillation cycle, *Gonyaulax* will emit a flash of light that varies in intensity with a circadian rhythm. In Fig. 12, recordings of the light flashes from these small organisms show sinusoidal waveform generation at approximately constant amplitude and period, which may be compared with the shorter period sinusoidal oscillations of the

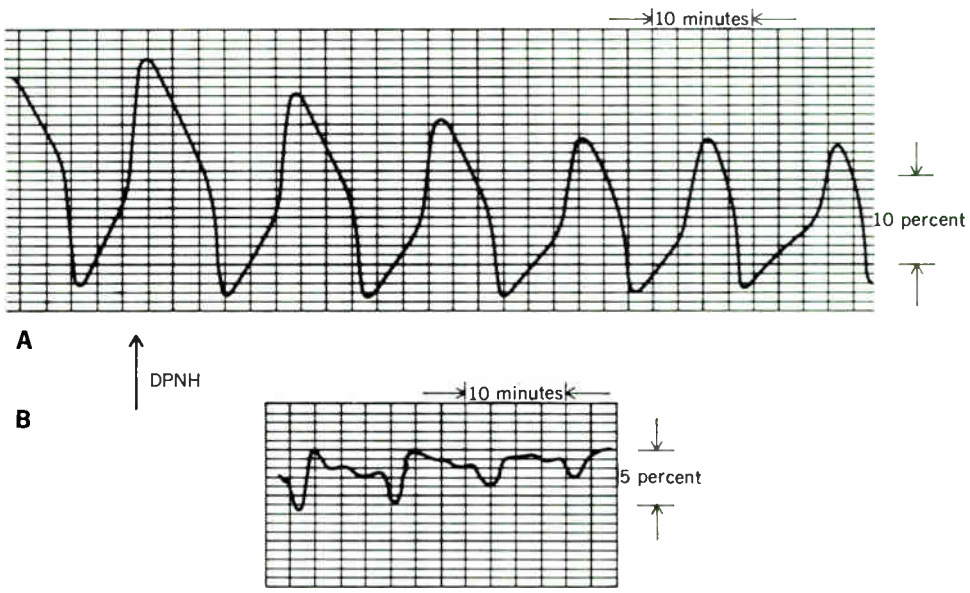


FIGURE 10. Waveforms generated in a cell-free extract of S. carlsbergensis, measured as in Fig. 9; square-wave approximations.

FIGURE 11. Waveforms generated in a cell-free extract of S. carlsbergensis. A—Single pulses, spectrophotometric trace. B—Double pulses, fluorometric trace.

enzymatic system of Fig. 9(C).

The periods of several minutes that we observe in the enzymatic system are obviously much shorter than those of the one-day clock. Although we have made considerable progress in showing that periods of up to a couple of hours can be achieved by decreasing the enzymatic activity, it is probable that the circadian interval is generated either by an entirely different set of rate constants than we observe in the short-period oscillations, or by a frequency division of a character as yet unknown.

The temperature stability of the one-day clock is usually rather high, certainly higher than we observe in the simple enzymatic oscillator.[26] However, a temperature-compensating reaction may operate on the principle that as the enzymatic activity increases with temperature, the effect of an inhibitory reaction increases in a similar way as an *RC* timing element is temperature-compensated. An alternative proposal has been made by Winfree,[27] who has shown mathematically that an ensemble of weakly interacting oscillators has stability properties considerably in excess of that exhibited by a single member of the ensemble. According to this hypothesis, an isolated member of the protozoan population would not exhibit such precise frequency stability as does the en-

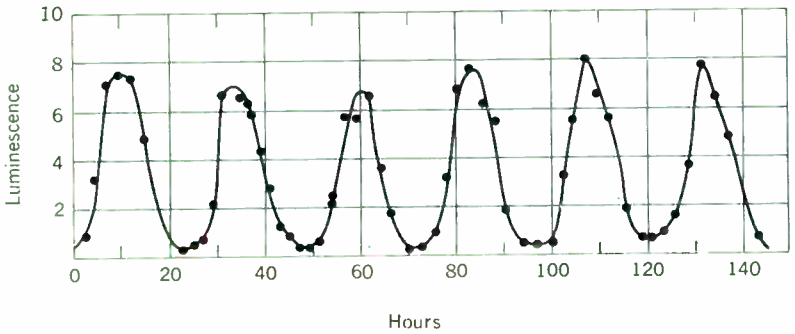
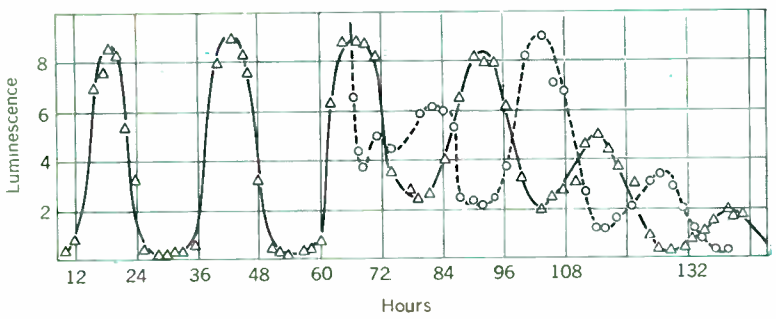


FIGURE 12. Rhythm of luminescence in G. polyedra from cultures maintained in dim light at constant temperature (1292 lux, 21°). Average period, 24.4 hours (from Hastings[35]).



A

B

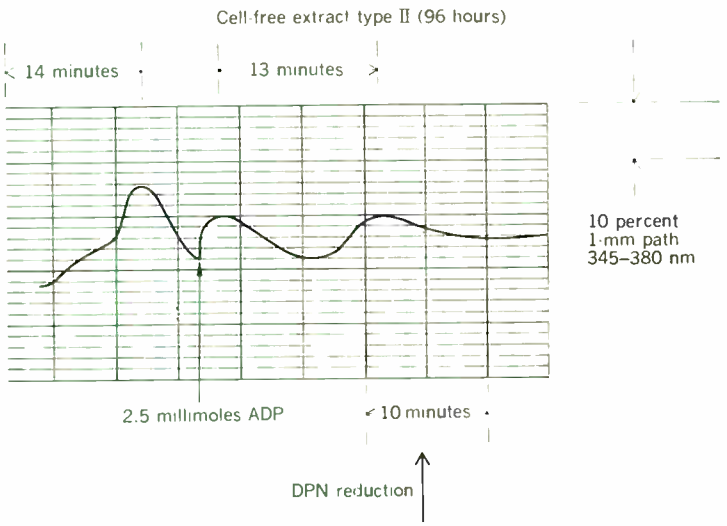


FIGURE 13. Setting the biological clock. A—Effect of a light pulse on phase of oscillator in G. polyedra (dashed trace) (from Hastings and Sweeny[21]). B—Effect of ADP addition on the oscillations in a cell-free extract of S. carlsbergensis.

semble employed in Hastings' experiments.

It is characteristic of most biological clocks that they may be reset, as in traveling from one time zone to another or, in some biological systems, by a shock or pulse. A light pulse will reset the *Gonyaulax* clock, as shown in Fig. 13(A)[24] where the period of the oscillations is advanced by 180°. A similar phenomenon is observed in the enzymatic clocks, where a phase advance of almost 180° can be obtained by a pulse of the control chemical adenosine diphosphate.[28] This chemical is only effective at the time during the cycle when it is in control.

Most biological clocks simply mark a moment in time. For example, any circadian phenomenon, such as the night running of rats or cockroaches, gives no warning until the phenomenon breaks out full-blown. This is shown by the black marks of Fig. 14(A), which indicate the time each day when cockroaches in total darkness start their nocturnal excursions.[29] Their progress (dashes) indicates that their oscillations "run free" in the dark. Whatever waveform is generated by their clock results in a sharp pulse, denoting a particular time. If, indeed, the clock were a sinusoidal waveform generator, it would be necessary to perform the engineer's operation of squaring, differentiating, and pulse generation. However, the enzymatic system that we have studied is also capable of pulse generation, as we have shown in Fig. 14(B). It is possible that this is the way in which the circadian clock denotes a moment in time.

The enzymatic oscillator shares many properties with biological clocks of longer periods, particularly sinusoidal or pulsed output, setting at constant period, and continous oscillation. Although at present we cannot fully

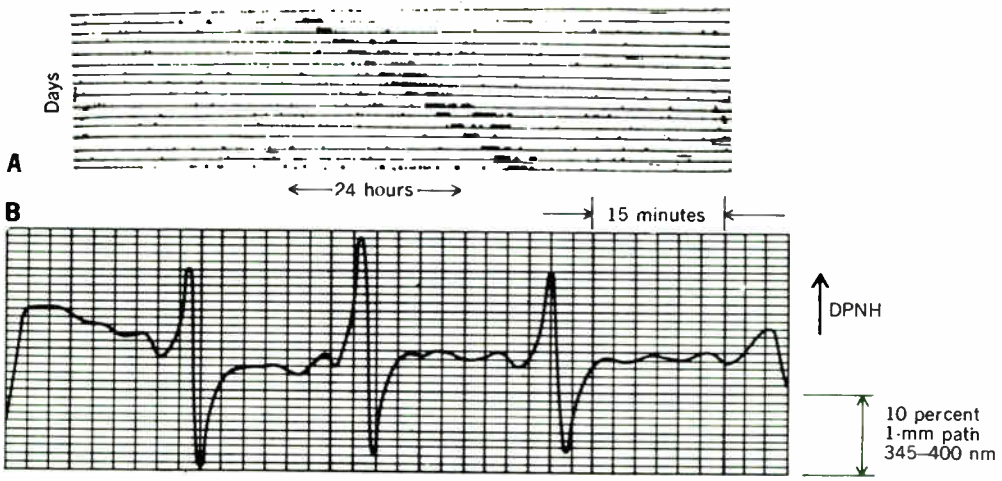


FIGURE 14. Identification of a moment in time. A—Record of the running activity of a cockroach; recordings from successive days appear one below the other (from Harker[29]). B—Pulsed waveform phenomena seen in a cell-free extract of S.carlsbergensis.

justify the speculation that one-day biological clocks operate according to the mechanism that we have demonstrated for the enzymatic oscillator, this hypothesis may be strengthened as we are able to isolate and study the biochemical details of enzymatic oscillators of longer periods. With this increased knowledge, we may embark upon one of the most fascinating of biomedical problems of the future—the regulation of cell chemistry in man to his own advantage.

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Multiple-access discrete-address communication systems

The improvement of spectrum utilization is a constant challenge to the communications industry. Multiple-access discrete-address (MADA) systems may meet this challenge and gain widespread acceptance if their benefits are found to warrant the cost and effort that are involved in their implementation

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A relatively new method for organizing and designing communications systems using MADA and its two variants, RADA (random-access discrete-address) and SOMADA (self-organizing multiple-access discrete-address), are described. In these systems, time and frequency are used in an organized manner. Representative designs, system implementation and selection, and reliability are examined. In general, narrow-band SOMADA is more efficient than conventional operation with respect to spectrum utilization; for larger systems, broadband RADA may be superior.

The multiple-access discrete-address (MADA) approach is a relatively new method for organizing and designing communications systems. Multiple access implies that the system will accept input from any of its subscribers at any time, depending on design capacity. The inputs are made directly as desired by the subscriber without prior authorization, multiplexing, or other forms of organization, except search and scan. Discrete address suggests that each transmission is directed to a specific receiver or group of receivers as desired, setting up a private (in some systems) communication channel between transmitter and receiver.

MADA represents more in the way of a family of communications system concepts than it does a specific modulation or coding technique; however, performance and modulation are related. There are numerous ways to implement MADA and there are different types of MADA systems. Two basic MADA approaches are discussed here: random-access discrete-address (RADA) and self-organizing multiple-access discrete-address (SOMADA).

MADA techniques differ from conventional methods, such as frequency or time-division multiplexing, in that both RADA and SOMADA use time and frequency in an organized and cooperative manner. Communications capacity is allocated on an as-needed basis, and it is the form and degree of control, along with the modulation used, that vary between different systems. In MADA, discrete addressing is accomplished on either a bit-by-bit or a message-by-message basis, but not by fixed channel assignments.

The MADA family of communications system concepts seeks to provide more efficient use of communication capacity along with improvements in the grade of service and in spectrum utilization. Besides the exploration of its use in military communications (particularly radio and satellite) there have been preliminary studies for possible use in vehicular communications[1,2] and time-sharing computer systems.[3]

A common feature of MADA is the unusually close interrelationship between communications traffic characteristics, the degree of mobility of the subscribers, the terrain and other environmental factors in which the users must operate, power limitations, modulation techniques, and overall system control.[4] MADA systems are applicable for use by subscribers who are sporadic users of communications, who require multiple access to both the system and to each other, and who often communicate with one or a small number of other users at one time. The application to military use is obvious and it is the military who have shown the greatest interest in MADA. There have been difficulties in selecting proper system design approaches, mostly because of inadequate definition of requirements and performance in terms of traffic characteristics and service. Selection of MADA design approaches should be based on specific traffic requirements, available spectra, and technical factors such as compatibility, radiated power, and antenna limitations.[5]

In this article we will consider MADA from a systems viewpoint and to a limited degree the modulation and addressing techniques that are practical. Thus, we shall concentrate on alternative system approaches, user requirements, modulation, and coding techniques.

Qualitative description of RADA and SOMADA

Assume a hypothetical RADA system, using a bit-by-bit addressing scheme, where each bit of the transmitted message is represented by a round ball that one subscriber wishes to send to another. Let us use the color of the ball as its address. Each subscriber's transmitter is a device for generating balls of different colors at a given rate (bit rate) and each subscriber's receiver is a device for recognizing and retrieving balls of the color assigned to that subscriber. Assume there are Z subscribers, each with his assigned color (address) that is distinguishable from the colors associated with other subscribers. Let us represent the transmission medium by a box whose capacity N is considerably less than that required to contain a ball from each subscriber ($N \ll Z$).

To communicate, a transmitter deposits colored balls in the box whose capacity is N and the receiver "tuned" to that color retrieves the balls sequentially from the box. The balls have a short life span and disappear before the next ball in sequence is transmitted, so there is no chance for unretrieved balls to accumulate and fill up the box. Additional subscribers may add transmissions (colored balls) to the box, each at his own rate, without coordination (asynchronously) with other subscribers until the box reaches a steady-state condition of being full.

The transmitting party may know if the party being called is busy in a number of ways. One method samples the box to see if there are any balls in it of the called party's color. If the box is overloaded, the processes of recognizing colors are gradually degraded by cochannel interference until the system reaches a point at which recognition is almost impossible. The box is completely overloaded and the balls "roll out"; thus, communication ceases. At this point, some of the subscribers must stop transmitting. It is also possible to have color differences so small that distinguishability is difficult; this is analogous to orthogonality between addresses. To be realistic, we shall assume that the more balls in the box the more difficult it is for a receiver to recognize its own color, analogous to self-interference.

In considering SOMADA systems, the number of colors will be limited to an amount equal to the capacity of the system (or box). The box can hold N balls, where N is still much less than Z but is now nearly equal to the expected number of simultaneous transmissions during certain busy-hour conditions. Each transmitter and receiver is thereby restricted to coloring and recognizing N different hues, which are selected for maximum contrast (orthogonality) with each other. To transmit, a subscriber must monitor the colors of the balls in the box at all times, selecting from N colors any color for transmission that is not in use. Because all receivers are constantly monitoring the box, all subscribers know what channels are available (what colors are not in use). A color in this case does not represent an individual's discrete address, but a channel, circuit, or net, and we are now using channel addressing rather than message addressing.

A subscriber knows a transmission is intended for him through a signaling scheme. The first part of a transmission uses a header to indicate who the addressee is, and all other subscribers ignore the rest of that transmission (particular colored balls) until a ring-off signal is sent, at which time the channel is available for use by other subscribers. When all channels are busy, other subscribers cannot gain access to the system until a channel is free. Unlike random-access systems, the system cannot be degraded by overloading and interference generated by other subscribers. The penalties paid for this advantage are the imposition of a finite limit to system use and the need for additional signaling and logic. The probability of encountering delay is defined as the *grade of service*. Acceptable grades of service usually range from 0.1 to 0.06 (10 percent to 6 percent) or better. This value depends on the traffic characteristics of the family of subscribers as does the duration of delay, which is often just a matter of seconds.

As a communications system philosophy, the SOMADA form of MADA is a compromise between the flexibility, freedom of operation, and the limitations exhibited by RADA systems and the restrictions, inhibitions, control, and efficiency advantages characteristic of highly organized conventional systems.

Comparison with conventional techniques

Conventional systems provide communications capability by subdividing either the time, frequency, or wire medium that is allocated and fixed over long periods of time. For example, two parties (A and B) may be connected by a wire, a common radio frequency, or a common time slot in a frequency band shared by others. Groups of subscribers may communicate by sharing a common wire, by being directly connected to each other by wire, or connected to each other through a switching system. In radio systems, communication can be effected by placing all parties on a common frequency (channel) called a net or each party can be given his own frequency (address).

MADA systems, although having certain characteristics in common with conventional systems, differ primarily in three areas: how a channel is defined, how capacity is allocated, and if synchronization is required. All communications systems provide a channel or circuit upon which to transport information. MADA systems differ in the way a carrier is used and in what constitutes

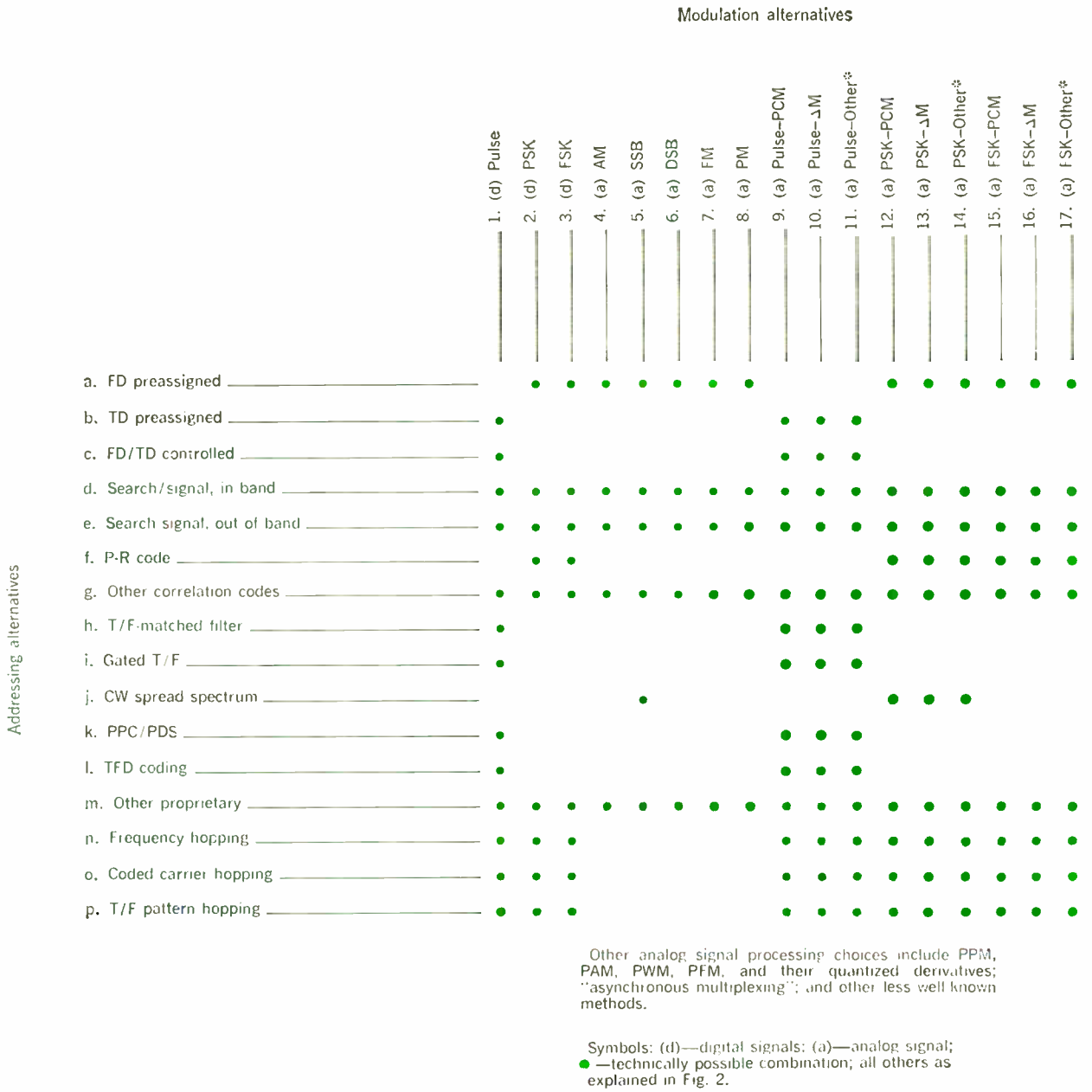


FIGURE 1. Possible MADA addressing and modulation combinations.

a channel; a MADA channel may be a code, either a time or frequency pattern of energy, a time slot, or a comparatively narrow frequency band. The most significant characteristics of MADA systems are:

1. No fixed channel assignments, advanced agreements, organized central control, or intermediate handling is required to connect a transmitter to the desired receiver, other than a signaling scheme.
2. The system is adaptive in its ability to accommodate a wide variety of traffic conditions.
3. It somehow assigns available system capacity to those transmitters that are active at any instant.
4. It can survive destruction down to the last two subscribers or units.

A MADA system can then be viewed as a radio or wire dial telephone system without conventional switchboards. Routing and addressing information is contained in either the modulation or coding used as a discrete address, or in the search and signal scheme used to select a channel. The capabilities that have caused recent active interest in these systems are primarily the previously described characteristics plus a number of special by-products that result from the unique coding of transmissions.

MADA signal transmission techniques

Part of understanding MADA is an awareness and appreciation of the coding and modulation methods used to achieve discrete addressing and the related independence from manual switching and inflexible assignments.[6] It is through the unique addressing used in these systems that multiple access to either a contiguous broad frequency spectrum or to narrow frequency channels is accom-

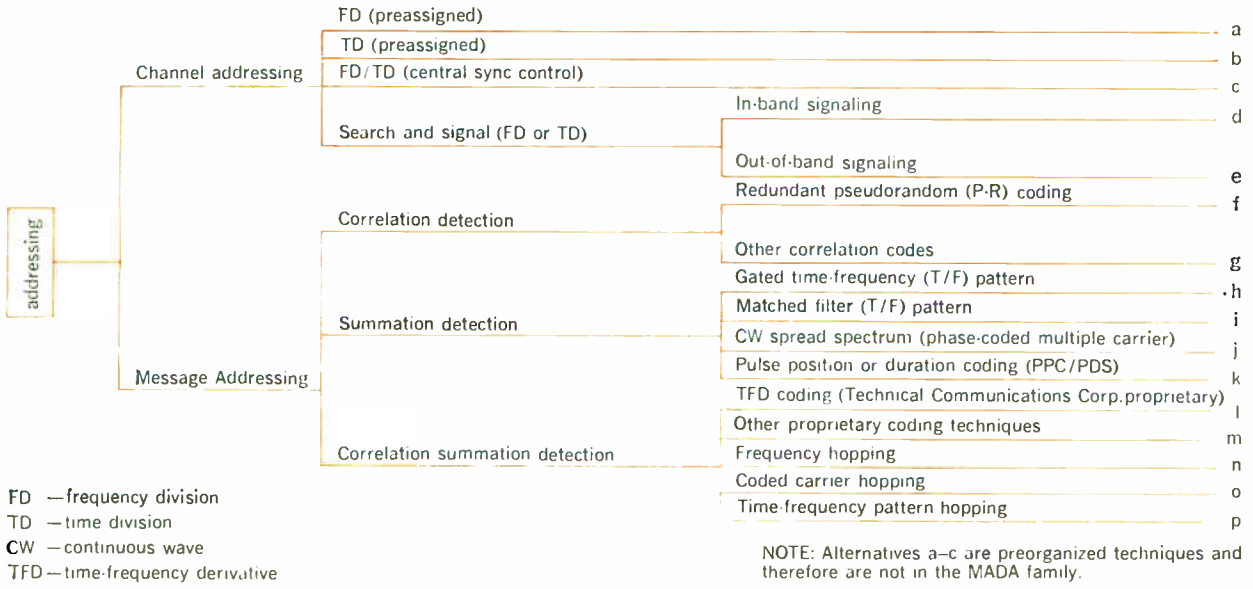


FIGURE 2. A tree of addressing relationships.

plished. The same unique addressing also provides the ability to be self-organizing (adaptive) with respect to traffic conditions. Figure 1 identifies most of these techniques as reasonable combinations of addressing and modulation alternatives in a matrix. The colored dots indicate technically possible combinations that can be used to define a channel and to address or code a message so as to direct the information to the recipient.

Figure 2 organizes the addressing schemes in a tree of relationships. Channel addressing is most often associated with SOMADA systems and message addressing with RADA systems; there are also combinations of the two. For example, a correlation detection code (item g in Fig. 2) can be used to delineate a channel as well as to address a message; the channel is then used in a SOMADA system. Addressing technique f (pseudorandom code) in this example can be combined with any one of the modulation schemes 2, 3, or 12–17 of Fig. 1 to describe a channel in a channel-addressing scheme (SOMADA) or a message in a message-addressing scheme (RADA).

Although there are many combinations of addressing and modulation techniques (over 150 are indicated in Fig. 1), the subject can be adequately described by using *broadband* and *narrow-band* versions as examples. The many competing MADA techniques were organized to aid both the conception and understanding of new designs. The first step is to realize that all possible techniques are represented by fewer than MA combinations, where M is the number of practical ways to transmit intelligence (modulation methods) and A is the number of feasible addressing methods. The addressing alternatives are where the challenge lies.

As previously indicated, addressing of transmissions in a MADA system can be accomplished either on a channel or on a message basis. In the former, the system is preorganized by physical connections, allocated frequency, time slots, etc., such that messages are constrained to move along directed paths. Establishing a call is usually done by searching and signaling. In the latter case, the message itself is organized to be received by the desired addressee (who has prior knowledge of the organization) and by no one else. Channel-addressing systems are much more efficient in terms of utilization of the basic time–bandwidth envelope. The maximum system capacity in terms of simultaneous transmissions possible is theoretically $2TW$; using practical circuitry it is TW, where T is the inverse of the information rate and W the system bandwidth. This is superior to the capacity available from practical message-addressed alternatives because of the zero self-interference characteristics of channeled systems.

There are, however, several important reasons for going to broadband RADA (message addressing) in special cases. For one, the number of addressees is far greater than the number of simultaneous transmissions, and this situation is accommodated better by message-addressed techniques. Second, the infrequent but immediate access requirements, mobility, and variable equipment characteristics of the various small terminals do not permit the kind of system organization and control required for channel addressing. Finally, the practicality, cost, reliability, and related factors of channel-addressed systems are questionable in some situations; synchronization, frequency stability, linearity, and other close requirements cannot always be met easily.

RADA techniques require an "advance agreement" between transmitter and receiver, with the burden of signal extraction placed on the receiver. The alternatives can be considered to fall into three subcategories: correlation detection, summation detection, or a combination called correlation summation detection (see Fig. 2). The first category depends on cross-correlation of the incoming signal with a stored replica of it, properly synchronized. Its principal problems are the close synchronization required between transmitter and receiver and the relatively high bit rate needed to achieve sufficient addresses and good correlation properties. The second category, summation detection, requires simply the detection of the presence or absence of energy at particular times at spe-

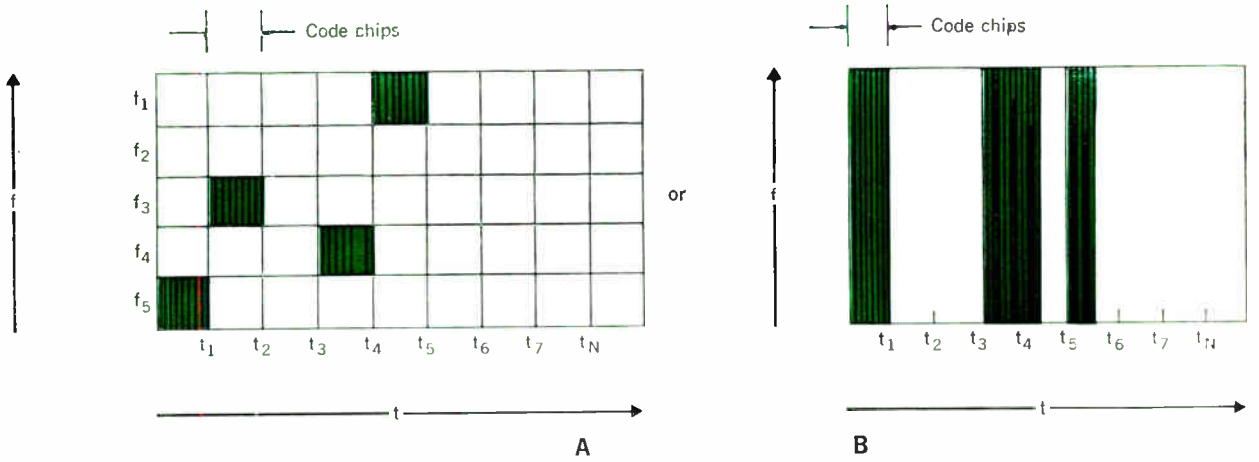
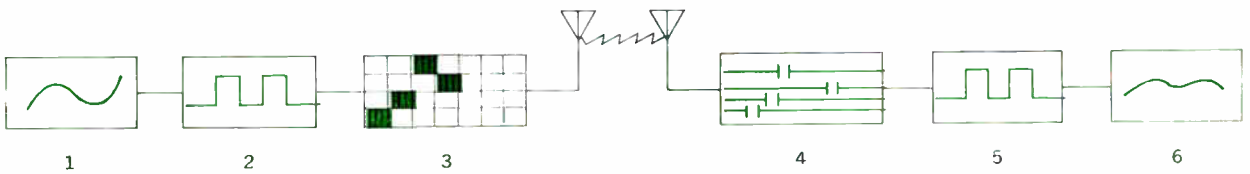


FIGURE 3. Examples of broadband RADA. (A) An address is an individual time-frequency slot. (B) An address is a PN code occupying total bandwidth.

FIGURE 4. Block diagram of a simplified broadband RADA system.



cific frequencies, followed by an addition of these energy contributions. The addition may be coherent, by envelope summing or simply by counting. The major disadvantages of these systems are the problems encountered in locking on and holding the desired transmitted signal in the presence of interference, and the relatively limited system capacity per unit of bandwidth.

For broadband RADA applications, the most promising techniques for the future seem to be those that combine the advantages of correlation and summation detection. Examples are systems employing linear or stepped pulse compression and matched filters, pseudorandom hopping of time-frequency matrix addresses, and other complex variations in the transmitted signal that allow enhanced discrimination at the receiver without requiring very precise standards of time or frequency. Many of these techniques are proprietary, most are as yet inchoate, and much work remains to be done in design and performance prediction.

The trick is to predict the nature of the interference, which is uncontrollable, as well as of the designed signal, which is controllable after a fashion. There are some peculiarities in mobile, digitized-voice MADA systems that require special attention in predicting receiver inputs. In general, we are forced to deal with nonlinear, non-Gaussian, time-variant processes and devices.

Representative designs. Broadband RADA involves a broad contiguous band of RF spectrum (perhaps 3 to 30 MHz), usually divided into time slots of millisecond or microsecond durations. In Fig. 3(A) the frequency band is divided into narrow frequency slots and an address may be an individual time-frequency slot in the matrix of slots; in Fig. 3(B), there is no subdivision of frequency and an address could be a pseudonoise (PN) code occupying the total available bandwidth. Here, each bit of information must be successively addressed. Access to the allocated RF spectrum is on a random basis, in terms of when the various transmitters come on the air. In each case the burden is on the receiver to recognize its address, thereby extracting its message from the many on the air. There are, of course, many other ways of broadband addressing, PN phase coding being one that is receiving serious consideration.

A hypothetical broadband system is shown in Fig. 4. An analog voice signal (1) is converted to a digital signal (2), and addressed and transmitted (3). The receiver (4) recognizes its address and the signal is converted to a stream of bits (5) and then to an audio output (6).

In SOMADA, channels are used wherever available in the RF spectrum, as in normal circuits. However, available channels are automatically assigned by the signaling scheme to those who wish to transmit. The assignment lasts as long as one complete conversation (ten seconds to about two minutes); afterwards the channel is released and immediately becomes available to other subscribers. Addressing is accomplished by digital signaling in any free channel that is mutually accessible to both parties.

Partly, SOMADA is an attempt to combine some of the flexibility of RADA concepts with the more rigid control and efficiency of conventional schemes. In this case the flexibility related to the uncontrolled use of capacity and gradual degradation with overload is used to offset the inflexibility of fixed assignments, scheduling, or central control. Using a signaling scheme, assignment of available capacity as needed is in part a broad definition of the SOMADA concept.

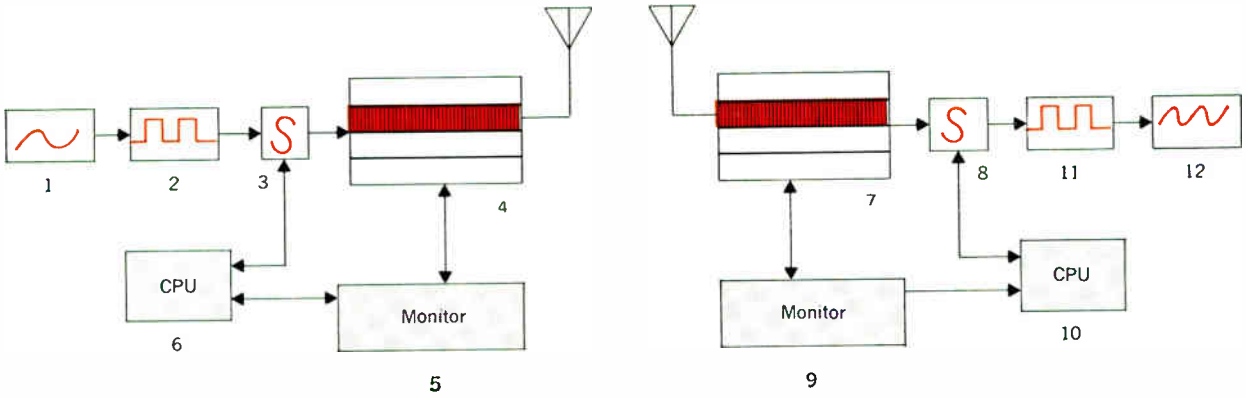
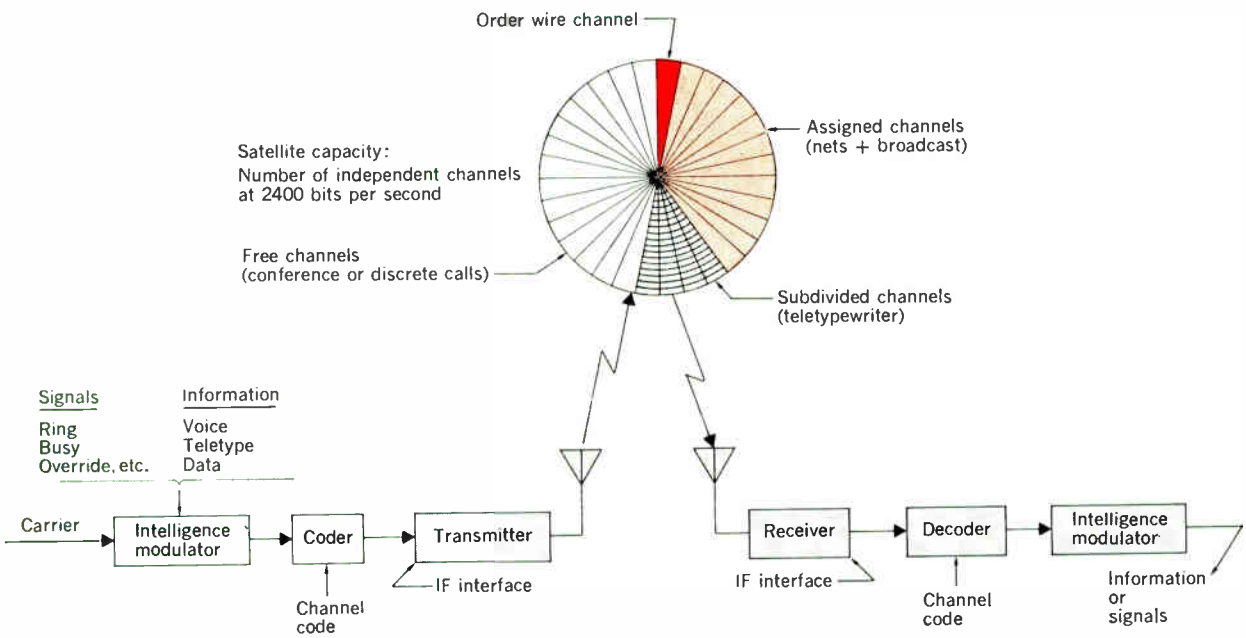


FIGURE 5. Block diagram of a hypothetical SOMADA system.

FIGURE 6. Code-division multiple-access operation.



A conceptual SOMADA system is shown in Fig. 5. The analog signal (1) is changed to digital (it can also be transmitted in analog form) (2) and applied by a switch (3) to a free channel for transmission (4). The free channel was selected by the monitor (5) and the central processor unit, or CPU (6). Establishing the circuit is achieved by a digital signal recognized by the receiving station's CPU (10). The station receives the transmission on the free frequency (7) and the message is routed to the recipient by switch (8) and monitor (9), and is controlled by the CPU. The stream of bits (11) is changed to an audio signal (12) and the circuit is completed.

The ability to satisfy the communication traffic requirements of a fairly large number of subscribers with comparatively few narrow-band channels is based on the concept of accepting a grade of service greater than zero; specifically, a grade of service of 0.01 is often used. This can be realized with a number of channels far fewer than the total number of subscribers if individual subscriber duty cycles are low. In short, the total spectrum occupation of the system is kept at a high load factor by time and frequency sharing of the system by all subscribers. A critical factor in achieving this high a quality of service relative to the few number of circuits used and the rather large number of subscribers is the utilization of markedly improved signaling and audio quality.

It is possible to combine both the operational and signal transmission techniques of RADA and SOMADA approaches (Fig. 6). In this case a RADA discrete address is used as a channel rather than as a message address, whereas the access and use of each channel are controlled by a SOMADA approach; the system is thereby optimized against stringent interference and control factors.

Implementation factors

The difficulties in coping with adequate measures of effective spectrum utilization are well known. The parameters for MADA systems not only are variable, but to some extent are shared on a random basis. Consequently, the expression, talkers per megahertz (T/MHz), has gained

acceptance. By definition T/MHz is the number of simultaneous transmissions that can take place among subscribers within radio range (interference distance of one another) per unit spectrum.

In general, narrow-band SOMADA is more efficient with respect to spectrum utilization than conventional net operation and appears about equal to a good trunking approach for relatively small systems (about 100 to 150 simultaneous transmissions). As the systems become larger and assume low individual duty cycles, broadband RADA systems exhibit increasingly better spectrum utilization.

Unfortunately, the performance of most MADA techniques investigated to date is extremely dependent on the operational and traffic environment. It is virtually impossible to provide meaningful quantitative answers with respect to spectrum utilization except for those specific cases in which both the technique and the environment are stipulated. In fact, it is likely that a system designed for one set of traffic and operational conditions would, when applied to another set of conditions, perform poorly.

Cost considerations. It is difficult to estimate the cost of a commercial discrete-address communications system, primarily because most current hardware experience has been in military applications. In general, the estimated cost for a military transceiver package has been about $6000 to $10 000 per unit in mass-produced quantities. The cost of a discrete-address base station would be about the same, depending chiefly upon the antenna height and RF output. Assuming that the price of integrated circuitry continues to decrease and that this technology is applied to MADA equipment, one would estimate a cost over the next five years of about $4000 to $5000 per transceiver for a broadband RADA system.

There are also discrete-address techniques that permit adding a coding and decoding unit to existing equipment. The cost for any of these might vary between $500 and $2000. Again, it is difficult to generalize; however, narrow-band SOMADA would be less expensive than broadband but more expensive than conventional equipment used in net operation.

Compatibility. One of the major restraints in acceptance of broadband RADA systems is the lack of compatibility with conventional equipment and the difficulty in interfacing. With few exceptions, difficulties in interfacing except at audio levels will result in additional system costs. Compatibility is also related to system expansion, particularly if subscribers have an investment in existing plant and equipment. Implementation is one of the major factors restricting the application of these techniques to military communication, even though it is easier for the military to control implementation and to phase in new systems.

A few techniques presently under development hold promise for circumventing this restriction. One method permits existing equipment to have a coder–decoder package attached to it, and the equipment can then be operated either in a conventional mode or in a discrete-address mode at a restricted bit rate.

Narrow-band SOMADA attempts to cope with the compatibility and implementation problem as a facet of, rather than as an adjunct to, the system's basic design. In the final analysis, the acceptance of MADA by the commercial market will depend on whether the market feels that the benefits of MADA are sufficient to warrant the price one has to pay in terms of cost, compatibility, implementation, and other factors. The price to be paid in spectrum utilization is probably a factor that is more in the purview of the FCC than of the users themselves.

Reliability and complexity. Assuming that integrated circuitry is used, reliability by present standards should be excellent. Although digital equipment appears to be quite complex, it is more a matter of complexity of logic than of the electromechanical interactions of larger components. Equipment that appears to have highly complex logic often evokes the response that reliability will be degraded. Fortunately, this is not the case; one expects MADA equipment to be adequately reliable. It is also anticipated that the useful life span of the equipment will be longer that that of present equipment, which, to a certain extent, may offset the higher initial cost.

System selection

Because of MADA's break with conventional communication techniques and processes, it has been difficult to identify parameters for optimizing these systems and relating a system's design to a specific application. Traffic analysis is used to identify representative requirements, including the grade of service desired and the general characteristics of the system. Another important factor is the role of supervisory traffic, which refers to signaling, ring-up, ring-back, etc. Repeat traffic is also a major contributor to total traffic on the air. Nevertheless, in most communication systems, supervisory and repeat traffic constitute a surprisingly large portion of the total traffic load; if these can be reduced there should be a distinct improvement in overall communications.

From a design viewpoint, the question of which communication technique is most applicable is difficult to answer in the abstract. The choice is between conventional communications, narrow-band SOMADA, and broadband RADA. In many cases a study may indicate that if the signaling and audio characteristics of a conventional system are improved, or if a conventional system is modified by the application of vocoders and digital transmission, most of the more pressing requirements can be satisfied without recourse to MADA.

When "cleaned-up" conventional communications cannot satisfy the requirements, it seems best to explore the application of SOMADA, as compared with RADA, primarily because of the simplified implementation and compatibility problems. Unfortunately, SOMADA in any form may be difficult to utilize in small units, such as vehicular sets, within the next few years because of the need to employ data processing for implementing signaling logic and the need to monitor a number of channels. However, limited MADA is feasible; in this case, a subscriber has multiple access to only a few of the narrow channels, and thus it might best be described as a selective SOMADA system.

The other alternative is RADA, which (with a few significant exceptions) theoretically offers the most for the classical communications problem. Unfortunately, there are three major negative factors. One is the requirement for a large spectrum allocation, which is very difficult to satisfy in many applications. Another is the severe compatibility and associated implementation problems and the need for interface equipment. The third is the complexity and consequent cost of handling messages that must be relayed beyond the normal line-of-sight transmission range.

To make the analysis and design manageable, it is usu-

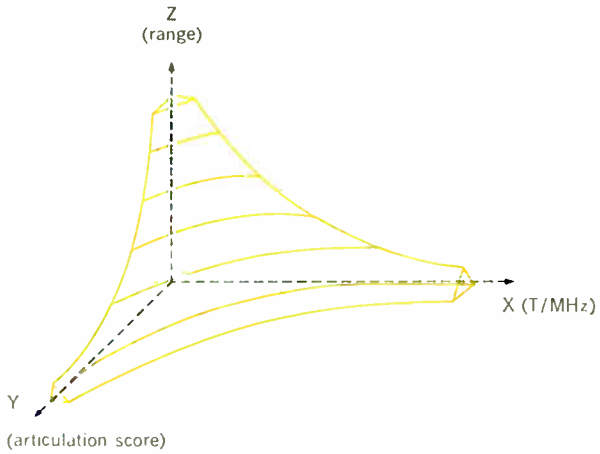
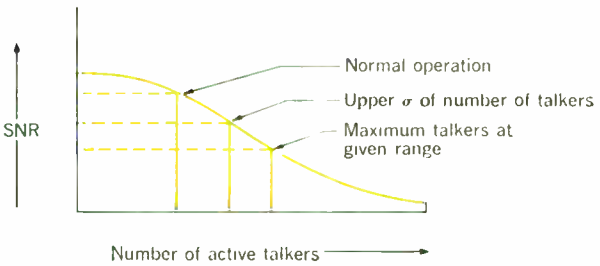


FIGURE 7. Three-dimensional matrix showing the significant factors found in a communications system.

FIGURE 8. Degradation of audio signal-to-noise ratio with increasing system loading.



ally best to reduce the trade-off and optimization to three parameters. Three that can be used, depending on the specific application, are range, articulation score, and talkers per megahertz. By constructing a three-dimensional matrix, one can work with the problem in a convenient manner. Figure 7 shows the general relationships normally found in many communication systems. Notice that when the range of a user's set is increased, many of the techniques require either increased spectrum utilization or degradation of intelligibility. Figure 8 represents the anticipated degradation of audio signal-to-noise ratio as a RADA system is loaded to the design maximum. Broadband techniques permit the utilization of this concept to provide a "soft" overload (graceful degradation) characteristic, with respect to the capacity, which is not available in most other techniques. Audio signal-to-noise ratio and related error rate are useful as measures of system degradation and overload. The correlation between the standard deviation of either duty cycle, range, or the number of active talkers with other design parameters, such as audio signal-to-noise ratio, is also a measure of the system's flexibility and capability to accommodate wide operational environments.

Conclusions

Most of the broadband techniques examined by the writer appear to be severely limited with respect to their potential application to a general communications service. The major reasons for this are the significant increase in cost per user set, the lack of compatibility and interface problems between broadband systems and conventional systems, problems in implementation, the difficulty in acquiring fairly large contiguous bands of spectrum for these systems, and traffic problems. This statement is not intended to imply that RADA should be ruled out; as a technique it holds considerable long-term promise for special applications.

Narrow-band SOMADA techniques appear more attractive than broadband RADA for most applications. One obvious difference between SOMADA and conventional systems is the direct communication between subscribers without going through a base station. If the traffic pattern is from a base station to subscribers and return rather than from subscriber to subscriber, it is doubtful that MADA in any of its forms can offer much improvement over conventional systems, with the exception of some computer applications.

It is quite possible that there are a variety of special applications that seem attractive for the implementation of SOMADA techniques. Data transmission from subscribers to time-sharing computer systems may be one of them. In this case, most of the transmissions are very short and it is imperative that the transmission be interpreted only by the proper receiver—that is, the one associated with a certain computer. Other potential applications include civil defense, telemetry for use in data systems, and satellite and tactical military communications.

In spite of the problems associated with the practical implementation of RADA and (to a lesser extent) SOMADA, there may well be a place for them in the future. As is often the case with advanced technology, its usefulness and application must be nurtured and explored, at least on a limited scale.

The techniques, criteria, and methodology discussed in this article represent the efforts of a number of Technical Communications Corporation staff members. The author is indebted to these people for their contributions.

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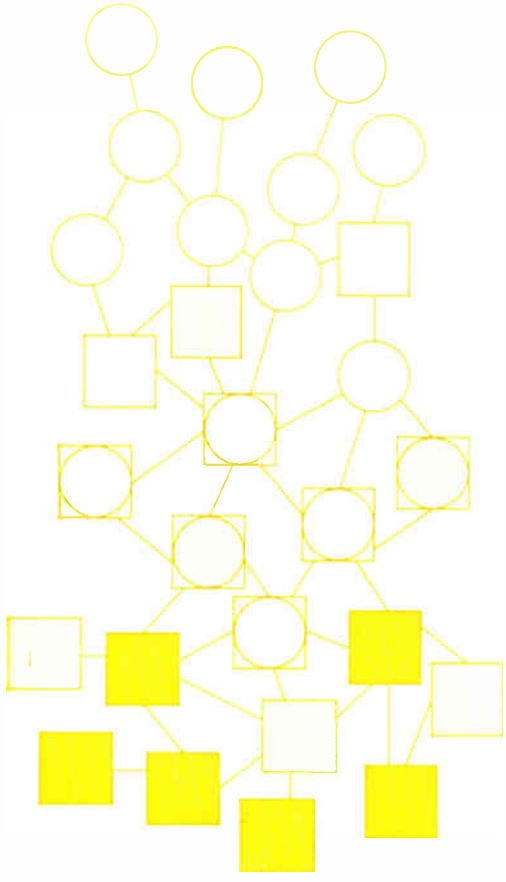
Educating for the new technology

The modern engineer must broaden his spectrum of knowledge rather than confine it to a narrow specialty; he must possess both a decision-making capability within his field and a responsibility toward society

Howard W. Johnson
Massachusetts Institute of Technology



It is the responsibility of the colleges and universities to provide the engineering student of today with a competent technical background without overemphasizing specialization. The education of the engineer should be founded on a broad-based program designed to equip the graduate with sociological insight and capability, thus providing society with a useful and cognizant citizen as well as a competent engineer.

If it is difficult to characterize the whole scope of modern electrical and electronics engineering, how much more difficult it is to characterize in a few words the whole range of activity, the potential, and the hopes of this remarkable and complex society of ours in which engineering functions. Intellectual observers from de Tocqueville to Galbraith have tried to do so, and so have the political activists from the Federalist presidents and near-presidents to the incumbent President. As a result, we have all kinds of adjectives modifying the noun *society*, from "democratic" and "just" to "affluent" and "great." Shorthand such as this can be reasonably useful, however; and I want to add a few adjectives myself for consideration, especially in the light of society's need of both engineering and education.

The first of my three adjectives is *technological*. Technology concerns itself with the means used in providing "objects for human sustenance and comfort." The base on which technology is built in our time is the pursuit of scientific truth and discovery. This pursuit must be, in a real sense, independent of the applications that proceed from it; and I believe that our concern today should be to strengthen substantially this scientific underpinning. Sometimes I hear argument that makes it sound as though emphasis on science on the one hand and application on the other are by nature competitive. I don't believe that. They both need massive independent support, and to shortchange first-class basic science is the surest way to long-term technological failure. Let us not be caught in the trap of arguing for one over the other.

Rising from the scientific base, the superstructure of technology relates to the imaginative and economic application of ideas to human needs. We have seen the amazing combination of enterprise, intelligence, and growing expectations that comprise our technological economy. But there is a problem that puts this normal process of technological realization in a different light. We must find ways to place new emphasis and attention on the systemic nature of large-scale human uses of technology. I mean by this that in this next period of history we must make a special effort to meet the massive needs of our society. This human focus of technology should be a primary concern for today and for the future. To achieve these goals—to harness technological means for large-scale human problem-solving—will require a new order of thinking, creativity, and decision making on the part of our citizens, our companies, our government, and especially our schools and universities. It is this task of educating for what I call the "new technology" that I wish to discuss.

The new technology

I think we would all agree that technology has been successful in serving a wide variety of our individual needs; but quite often, in so doing, it has operated without the long-range vision necessary to provide a total atmosphere conducive to man's development. In addition to being concerned with every man, technology must also be concerned with the whole man. It must seek to create the large-scale environment in which man can realize his full potential as a human being. It must

be as sensitive to aesthetics as to efficiency, to human growth as to economic and industrial expansion. Today, we have come to realize that the environment is not merely a conditioner of man's "physical" existence, but penetrates and influences all aspects of our life.

We are discovering that the right of free citizens to move freely without hindrance can be made meaningless by the breakdown of mass transportation, and the right of free assembly can be negated by impassable city traffic, or, for that matter, by uncontrolled crime in the city streets. We are beginning to suspect that free speech and a free press might become irrelevant if we were slowly strangled by the air we breathe, or slowly poisoned by our drinking water. We are beginning to see that equal rights and equal job opportunity, when finally obtained by citizens long denied them, can be made meaningless by intolerable housing conditions or by ineffective education systems. We are beginning to realize that if exploding populations create a world of starving humans practically standing on each other's shoulders, all concepts of freedom can become irrelevant, and U.S. prosperity could be infuriating and incendiary to billions deprived of either hope or future.

Problems of progress

All these are truly massive problems, and they are the products, in a very literal sense, of a technology that has been successful beyond the dreams of its early practitioners. It is the advance of medicine that has created the explosion of the world's population through lowered death rates. It is the creation of thousands of new products, new services, and new jobs that has transformed American society from a predominantly rural to a predominantly urban one, and at the same time so multiplied the output of each farmer as to send millions of marginal farmers to the cities. It is the increased effectiveness of new forms of transportation—air and auto—that has weakened the railroads. It is the enormous increase in automobile ownership that jams our streets and highways. It is technology's increase of income and expectations that crowds our colleges. The history of technology may be summarized as having continuously created more and cheaper energy, more effective forms of human organization, more and faster transportation and communications. Each increase in one factor has increased the effectiveness of the other two, and all three factors have increased the speed of performing large-scale operations.

It is no exaggeration to say that just as technology made Big Business possible, through increasingly larger aggregations of people, capital, and equipment, so it also made Big Government inevitable. But Big Business and Big Government both must be as responsive as ever, in fact more so, to the needs of individuals and also to the complex groups of individuals that form the modern metropolis. A concomitant of great organizational size has been the frequent depersonalization of administrative, political, and management controls and methods that sometimes deprives the individual of a sense of participation in meaningful decisions regarding his own life and work. This in turn has contributed to a sense of frustration and bafflement often expressed by young people today. In all these outpourings of uneasiness about the dual result of technology, both positive and distressing, it does no good to long for the old days, because we cannot go back.

I summarize then by adding the second of my adjectives to the lexicon of society descriptives. We live in an *interdependent* society that is irreversible in its dynamics. The very fabric of the city creates interactions that make the quality of transportation, education, politics, economics, and citizenship all closely interconnected. In this setting, the task of the modern engineer assumes a higher order intellectually than that which is associated with understanding basic science. And this applies to engineers who must now concern themselves with old problems in new forms, such as communication, power, and transportation. Just as the so-called "new economics" seeks to affect the macroeconomic system, so must the "new engineering" seek to affect the macrotechnical system.

A broader technology

I hold that the solutions to these problems are implicit in the problems themselves. Just as technology has created massive problems, so their solutions can only be found in great new discoveries and advances of technology—a new and broader technology that encompasses not only science, but all the activities and concerns of man (including the humanities, art, social sciences, and government).

I have used the mosaic of the city as a background for the statement of urgency of the new technology and the new engineering, but there are many other examples. One can scarcely imagine a major societal problem in the world today—whether it be arms reduction and control, reduction of the world food shortage, exploration of extraterrestrial opportunities, or the great gulf between the haves and the have-nots—which does not require a technological and management approach that combines engineering, the social sciences, and, most of all, a philosophy for understanding our goals. By the same token, tomorrow's challenges are so huge that the men capable of dealing with them will need to be technological generalists rather than technical specialists.

Today, the specialist whose interests are limited to the narrow definition of his field is not the best person to guide the progress of our society. We need people who, in Norbert Wiener's words, have the one quality more important than "know-how." This quality he calls "know-what, by which we determine not only how to accomplish our purposes, but what our purposes are to be." We need men and women whose awareness includes the broader human implications of their studies and actions.

Responsibilities of education

The universities today have both the resources and the responsibility to respond to the challenge of educating for this new technology, and of tempering progress with perspective. Yet we must be careful not to respond haphazardly to the needs that confront us; we must not try to be too many things to too many people. The fundamental purpose of the university is to provide for learning, and it is only within this educational context that we must seek to develop the means whereby we can serve society effectively.

Unchanged throughout the years, a fundamental objective of the university today is to provide talented young people with a liberal education—with the opportunity to learn to think, to develop a sense of balance and perspective, and, I would add, to develop a taste for

quality. I believe we will come to see that the undergraduate curriculum must be built both on science, for science is the essential determinant of our lives, and on the humanities, because they provide the essential meaning of our lives. In my opinion this combination is vitally important to produce a truly liberal education for the world of the new technology.

Let me hasten to clarify here that when I speak of a liberal education, I mean to distinguish it from the concept of a "liberal arts" education, as it is sometimes interpreted to mean a concentration on humanistic subjects to the virtual exclusion of the physical sciences. I would say that such an education today may fall short of its "liberal" objective. In fact, it may be confining, as it would offer the student a limited perspective. It would tend to shield him from exposure and understanding of the forces of scientific discovery that shape our civilization; and it would deprive him from participating in the problem-solving activities of the technological revolution. I believe that effective education of men and women to understand and to master today's problems requires a basic comprehension of science and technology in balance with the appreciation for the valuable insight gained by the study of literature, history, and the arts. Without this balance, educated people run the risk of serving the technology that was meant to serve their human needs. This raises the third of my adjectives: we must seek a *diverse* society, one that utilizes the rich contributions of all fields of knowledge. How can we do this without preparing our leadership groups broadly in both science and the arts?

The liberal education

This liberal education I speak of is the philosophical framework within which the learning process must go on in today's world. At the heart of the learning process the exchange between teacher and student takes place at three distinct levels, which are parallel and, for the most part, inseparable from each other.

The first level is that of *technical competence*. Whatever the subject may be, science, engineering, economics, or literature, the student learns to master new knowledge and ideas in depth. There is a sense of conquest in this aspect of learning: to understand and become conversant with, to be able to use as your own, facts and concepts that were not yours before. This is the stretching of the mind, the intellectual scholarship that I define as technical competence.

The second level is that of integrating diversity for the purpose of *decision making*. The training of the mind to analyze and to ask the right question, to choose, to judge and discriminate, to consider the human factors, to order chaotic situations, and to deal with ambiguity (the standard condition of our modern world of change), these are also some of the cardinal elements of learning that add character to depth and technical competence. They make possible the effective application and extension of knowledge; they allow for the mark of individuality in scholarship.

Finally, I believe that our students should be educated at the level of *personal responsibility and contribution to society*. I mean by this that they must learn not only how to get but how to give. Whether one relates this to a family, a university, a company, or a country, the young men and women of today must know that they have a contribution to make if the society is to improve. We find over and over again that the greatest source of pride of our alumni is the knowledge that they accomplish something. I am convinced that it is through this level of personal contribution that our students will satisfy themselves that they can reach as far as their potential allows, that their education can be a real and effective learning experience.

An example to others

If we can succeed in these forms of liberal education, if we can develop diversity within an interdependent technological society, we will have succeeded in making the United States a more interesting model for other countries to examine. It seems to me that we always run the risk of assuming that other countries will look to the United States only in terms of its great and growing gross national product. True enough, our economic system is a remarkable development and its emulation in even the most unexpected quarters is now evident. But that model is incomplete. We must be prepared to demonstrate that we can produce a new and fulfilling pattern of city life that goes beyond the growing shambles of the present. A new and higher quality of daily living will serve to give meaning to the greater personal incomes our system can produce. And beyond the scope of these comments, I hope we can keep in the United States a genuine idealism that in its freshness and worth serves to light the path of progress for a cynical world. If we lose that unabashed idealism, and we could, we will lose the chance to serve as a model for others despite a high gross national product.

The needs of the new technology

This then is my message:

First, that the world today is a technological one, but it demands a new technology that must be redefined to contain the imperative of our times: to understand science and to harness its applications for the satisfaction of our large-scale human needs.

Second, that with this new technology goes a new concept of liberal education, one that rests on science as well as the humanities and the arts, one that aims at producing in one person the rare blend of the "poet and the useful man." The society will be most satisfying if it safely becomes a diverse one.

Third, that in the atmosphere of a world characterized by ambiguity and change, the universities in the world are called upon to provide leadership in this liberal education, not only to those who are preparing for a professional career, but also to those who are midstream and wish to restructure their lives and recharge their intellectual batteries. To make an effective contribution consistent with their basic educational objectives, universities must stress the development of technical competence, an integrated and broad judgment, and a sense of personal contribution.

I salute you for the efforts that your Institute has made in seeking to define the goals for a technological, interdependent, and, I hope, diverse society; and I wish you continued success in providing the leadership to reach these goals.

Essentially full text of an address presented at the 1967 IEEE International Convention, New York, N.Y., March 20–23.

Thyristors and rectifier diodes—the semiconductor workhorses

Keys to the substantial growth predicted for power semiconductor devices are the increasing diversity of available types, improvements in their characteristics and ratings, and their downward cost trend

F. W. Gutzwiller *General Electric Company*

Power semiconductor devices have become one of the main bridges between the electrical and electronic equipment technologies. They are being used increasingly in every phase of generation, distribution, and consumption of electric power. This article surveys the various types of components, their applications, and the outlook for the future. The stress is on thyristors and silicon rectifier diodes, which exhibit electrical characteristics that are uniquely tailored to ac utility power systems.

Today it is difficult to imagine the difficulties and limitations under which power conversion and control design engineers worked before the silicon-semiconductor era of 10 to 15 years ago. Before then the selenium rectifier stack was the only power semiconductor element available. Yet with this rather bulky device, combined with large quantities of copper and iron, the design engineer could achieve the latest word in control then—the power magnetic amplifier, a sluggish and costly array by any of today's standards. The more electronics-oriented designer used the thyratron tube, or for higher power levels he turned to the ignitron tank, with its requirement for 40-ampere trigger pulses and cooling-water plumbing. For even the simplest job of power conversion, such as for converting the 24-volt dc supply of an aircraft to a few watts of B-plus for a radio receiver, he required a miniature motor–generator set in the form of a dynamotor. For his automobile radio he used a mechanical vibrator to step up the dc supply. Power electronics technology was essentially restricted to a few industrial motor drive and electrochemical applications, to X-ray equipment, to radio transmitters, and to induction and dielectric heaters.

The swift and successive development of the silicon rectifier diode, the power transistor, and the thyristor in the ensuing years has added a new dimension and degree of freedom to the science of electric power conversion and control. Only in the past few years have the engineers in the electrical and electronics industries, not to mention their colleagues in less directly involved technologies, begun to realize what tremendously powerful tools they now have at their disposal for fundamentally reshaping the way in which electric energy is handled from generation to ultimate use. Power semiconductors have removed the very basic constraints that had previously limited circuit and systems designers to the classical power control techniques, which had gone virtually unchanged for 50 years. Limited speed of operation, massive size and weight, high maintenance costs, and substantial first costs were the most prominent obstacles. Just as the modern computer would not be possible without discrete and integrated transistors to overcome the limitations of vacuum tubes, the typical new power conversion and control system would also be out of the question if the power semiconductor had not overcome many of the limitations of the power tube. Imagine the frustrations of an engineer assigned to design the variable-speed hand drill, the automotive alternator/rectifier system, the wall-switch lamp dimmer, or the static variable-frequency drive system in the era preceding power semiconductor devices.

Today the impact of power semiconductors is being felt by all branches of the electrical industry and by many fields where electronics was never before considered. Notable examples of fields into which the power semiconduc-

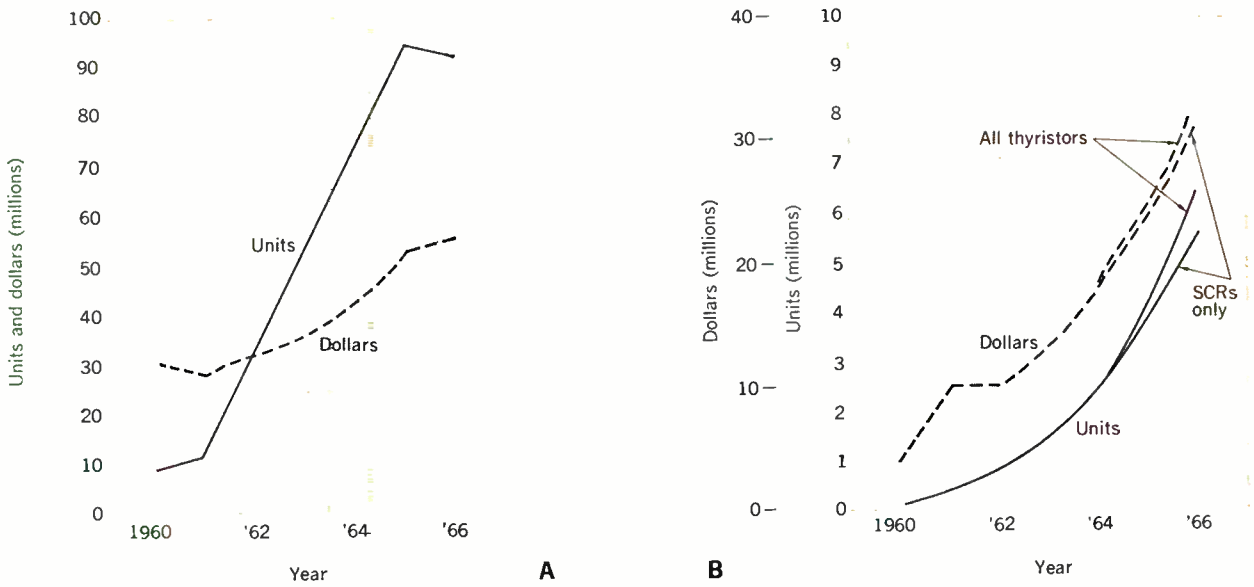


FIGURE 1. Shipments of chassis-mounted silicon rectifier diodes (A) and thyristors (B) from manufacturers in the United States. (Source: Electronic Industries Association)

tor introduced electronics technology are lighting, heating and ventilating, home appliances, automotive controls, and power tools. As this new technology is digested and optimized in the next few years, we can anticipate substantial changes in our everyday environment.

No longer is any job too big for power semiconductors. They are finding their way into every phase of generation, distribution, and consumption of electric power. For instance, five megawatts of power semiconductor capacity are required just to excite and control the larger steam turbine generators now being ordered by electric utilities.[1] At the other end of the power system, dc drives for steel mills are operating with semiconductor controlled rectifiers controlling motors rated as high as 12 000 hp (9 MW). New mills currently being designed will push the SCR capacity in one installation to 55 MW, and an induction heating system requiring 200 MW of SCR control in a single installation will be announced shortly.[2] Even these bulk power handlers are dwarfed in sheer kilowatt ratings by the total semiconductor capacity being installed in such consumer applications as the automotive alternator. Here many thousands of megawatts of silicon rectifier capacity are being manufactured each year, a power-handling capability of roughly the same magnitude as the total new utility generating capacity coming on line each year in the United States.

The total power-handling capacity of potential power semiconductor applications is greater than that of all the installations now in place. Uses for electric heating equipment in the home, including space heating, ranges, and other heating appliances, alone add approximately 80 000 MW of new installed load each year in the United States.[3] A significant share of these new heating loads can be ultimately expected to use solid-state controls. Equally impressive figures apply for other commercial and consumer applications, such as motor controls. For instance, if the much-discussed electric automobile[4] becomes a reality to the extent of 10 percent of the total automobiles now being manufactured, current industrial electric motor production will be dwarfed by the new requirements, and so will present power semiconductor component production by the control demands for this application.

Thyristors and silicon rectifier diodes are the workhorses of this power semiconductor revolution. Because of their ability to handle large blocks of power at minimum cost per kilowatt among static components, these devices have no serious challengers. Their significance is further assured by the fact that the energy source and muscles of our society today lie in the ac utility power system, for which the electrical characteristics exhibited by thyristors and power diodes are uniquely tailored.

Figure 1 shows the growth of silicon rectifier diode and thyristor component shipments in the United States during the past seven years, according to data from the Electronic Industries Association. These figures apply only to non-lead-mounted types. Addition of lead-mounted types would roughly double both the unit and dollar quantities. Estimates indicate that these growth curves will continue at roughly the same rate.

Major power conversion and control methods

An interface that requires rectification exists between the typical ac utility power system and the type of load that requires a dc source. Typical dc loads for which sili-

con rectifiers provide the rectification function include dc motors, generator and magnet excitation, electrochemical processes, battery charging, welding, dust precipitators, and electronic power supplies for systems ranging from computers to table-top radios. In the past few years, other applications independent of the utility grid have been attracted by the economies of ac generation and silicon rectification, namely, the automotive electric systems already mentioned, and diesel-electric locomotives. In the latter application, alternators are replacing the previously used dc generators.[5] High-voltage silicon diodes now convert several thousand kilowatts of alternator output to direct current for the traction motors on the trucks of each of this new type of road locomotive.

Power semiconductors are having their greatest impact on power control and amplification. Some applications, notably audio- and higher-frequency signal amplification and active power supply filters, require a linear power amplifier. For this function, the power transistor, acting as a variable resistance, stands virtually unchallenged among static components. However, even the most effective type of linear resistive control scheme usually must be abandoned when the load power exceeds a few hundred watts. The limitation arises from the fact that a resistive element capable of controlling a fixed load over any significant range must itself be capable of dissipating one quarter of the maximum load energy. This necessitates a large control element and limits the overall efficiency.

Switching techniques, on the other hand, overcome these limitations. Although a switch is fundamentally an on/off device, it can perform linear functions if one introduces the concept of *average* voltage or power over a finite period of *time*. Figure 2 illustrates ways in which fast switching devices can be used in the efficient modulation of voltage and power in dc and ac systems. In addition, this figure indicates some of the many other functions of switching devices as well as a number of prime power-conversion applications. Note that switches can be used between any combination of ac or dc supplies or loads. Although the output voltage waveforms in switching circuits are characterized by abrupt changes in amplitude, which result in high harmonic content, these waves can be shaped to desired forms when required by reactive elements or by synthesizing the required waveshape from combinations and phase interplay of more than one square wave.[6,7] Frequency and voltage level also can be adjusted in some of these systems.

The ideal switch (no leakage current when open, no voltage drop when closed, and no power losses during the switching transition) would apply and remove power to a load with no internal power loss. Hence, a lossless switch could handle an infinite load. In more practical terms, a small semiconductor with characteristics approaching those of the ideal switch can control power to a large load while incurring only very low power losses.

The versatility and efficiency of switching devices for controlling and converting power are sparking intriguing new applications. Significant developments include electric drives for industrial and highway vehicles[8,9]; high-frequency fluorescent lighting[10]; ultrasonic power generation[11] for welding, cleaning, and underwater detection; variable-frequency ac drive systems for industrial processes[12]; arc-furnace controls; ultrahigh-speed circuit breakers; and dc power transmission.[13]

FIGURE 2. Major types of electric power conversion and control using fast-switching components

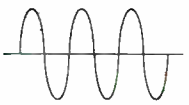
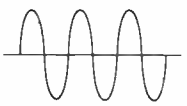
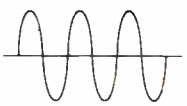
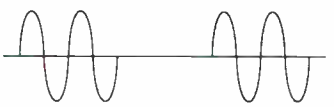
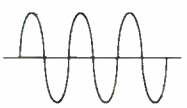
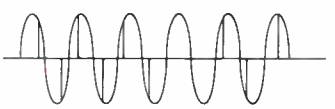
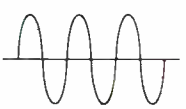
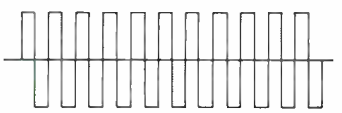
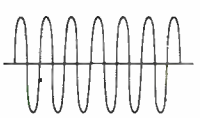
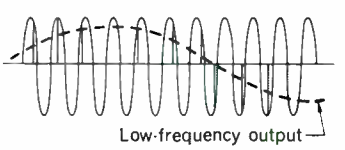
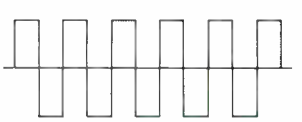
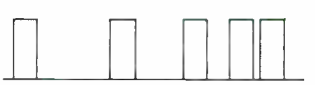
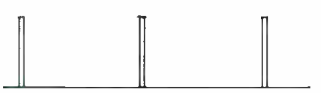
Power transistors vs. thyristors

In addition to its linear amplification capability, the power transistor is ideal for power switching duty within its ratings. When driven sufficiently into saturation, the transistor has a very low conduction loss and hence is particularly attractive in comparison to thyristors (like the SCR) in low-voltage circuits, such as inverters operating from 12 or 24 volts dc. As the supply voltage increases, the power transistor rapidly loses its efficiency advantage. Its few tenths of a volt conduction-drop superiority over the SCR becomes negligible from an efficiency standpoint when employed in supplies of several hundred volts. Furthermore, transistors that are designed for higher voltage have lower current gain. Also, at high continuous-current levels, the transistor does not make as efficient use of silicon as a comparable SCR; hence the transistor tends to cost more per voltampere of power-handling capability. In fact, at the two extremes of dc switching duty the SCR has very natural advantages over the power transistor in current-handling as well as average current gain capability. Under continuous direct-current conditions, the current density in an SCR is uniform over the entire emitter area; in a transistor, the current density is much greater at the emitter periphery. Here the SCR requires only a pulse to initiate conduction, whereas the transistor requires continuous base drive to stay in conduction. Adequate base drive becomes particularly critical in a transistor under overload conditions so that the transistor will be kept in saturation.

At the other extreme from continuous duty is the kind of application typified by a pulse modulator. Here a very high peak current is conducting, generally for a few microseconds, followed by an off period of a few hundred microseconds. In this application a typical SCR does not get fully into conduction,[14] yet its regenerative action keeps its collector junction in saturation without external drive, even at several hundred amperes. A properly designed SCR with 10 amperes continuous-current rating can be adequate for several hundred amperes peak current under these conditions. On the other hand, this type of duty would require a power transistor of 100 or more amperes continuous rating and a base drive of many amperes in order to keep the transistor in saturation throughout the high-collector-current pulse.

The silicon power transistor has an advantage over the SCR because of its higher allowable operating temperature and because of its ability to interrupt unidirectional load current simply by removing base drive. In contrast, the SCR requires momentary reversal of anode voltage by external means to regain its blocking ability. The external means usually consist of energy-storage elements in conjunction with suitable switching circuitry. At first glance this may appear to be an insurmountable handicap for the SCR. Actually, circuitry developed in the past few years can provide "commutation" of SCRs at no great penalty in many applications.[15]

It is interesting to observe how the rivalry between SCRs and power transistors is causing each device and its circuits to become more like the other. For instance,

General Category	Specific Type	Input Voltage Waveshape	Output Voltage Waveshape (resistive load)	Typical Applications
AC to DC	Rectifier switch			Battery charging, electroplating, welding, flashers
	Phase-controlled rectifier			Regulated dc supplies, dc motor drives, field excitation, battery charging
AC to AC	Switch (random and zero-voltage switching)			Temperature controls, contactor replacement, ac flashers, static circuit breakers
	Variable-voltage phase control			Lamp dimming, ac regulation, ac motor control, welding
	Frequency changer with dc link			High-voltage power supplies, high-frequency fluorescent lighting, ultrasonic cleaning, ground power for aircraft
	Cycloconverter		 Low-frequency output	Vehicle propulsion, portable power plants, variable-speed constant-frequency systems for aircraft
DC to AC	Inverter			Variable-speed ac drives, emergency power, ac power on vehicles, sonar systems
DC to DC	Chopper — Pulse-width control			Battery-operated vehicles, dc motor drives, flashers, exciters, regulated power supplies
	Chopper — Time-ratio control			
	Pulse modulator			Radar modulators, laser supplies, nuclear accelerators

power transistor switching circuits now often require reactive circuit elements similar to those in SCR commutation circuits to assist them in interrupting the stored energy in inductive power circuits and to avoid operation in the destructive second-breakdown region.[16] On the other hand, SCRs suitable for inverter applications now require heavier gate drive to improve their switching characteristics and, like a transistor, often need square-wave gate drive rather than pulsing for proper circuit operation. Moreover, to achieve improved switching characteristics, state-of-the-art SCR designs are employing interdigitated emitter–base structures similar to those in power transistors.[17]

Although the availability of steadily increasing power transistor ratings is continually threatening the lower level of SCRs in chopper and inverter applications, thyristors are almost certain to continue to be the mainstay for higher-power applications. This is particularly likely as new thyristor types are introduced with significantly improved turnoff characteristics. As switches, it is expected that power transistors will consolidate their hold on low-voltage applications, on very-high-speed switching circuits, and in those applications in which temperatures above 150° C must be tolerated.

The thyristor family

The term *thyristor* applies to any semiconductor device that operates on the p-n-p-n regenerative principle.[14] Figure 3 lists the major members of the thyristor family in groups, according to their unidirectional or bidirectional conduction characteristics and number of terminals. Although the listing shows only those major components that are commercially available at this time, it is apparent that several other variations are not only possible but probable in the future as the functional need arises.

Among the dozen types listed, the SCR is by far the most widely used variation of the thyristor. Its popularity stems from its early introduction (first commercially available in 1958),[18,19] its direct analogy to earlier components such as the thyratron and ignitron, and its high degree of versatility in both dc and ac circuits. In comparison with the SCR, other members of the thyristor family are for the most part quite specialized in their area of application due to the specific advantages and limitations of their characteristics.

The *light-activated thyristors* (the LAS, LASCR, LASCS) offer unique advantages where electrical isolation between trigger signal and load circuit is required or where the trigger information is provided in the form of optical radiation.[20] However, the irradiance required to trigger a thyristor has considerable temperature dependence as well as a variation with anode voltage from unit to unit. These properties preclude the use of light-activated thyristors in the many applications for light level sensors or threshold detectors. Precisely timed triggering with these devices requires a significant change in light level applied with a fast rise time, as typified by the signals that can be obtained from lasers, light-emitting diodes, or mechanical shutters. An intriguing application is the triggering of long high-voltage strings of high-power thyristors by optical pulses, either directly from a single common light source or through smaller pilot optical thyristors connected to the respective gates of higher-power switches.[21,22]

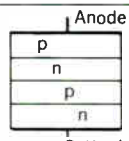
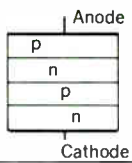
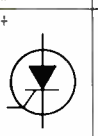
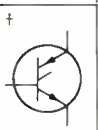
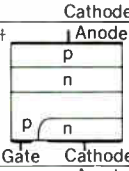
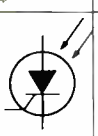
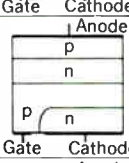
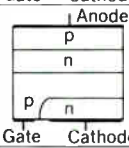
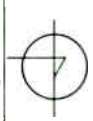
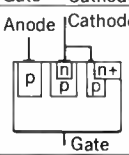
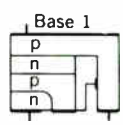
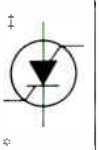
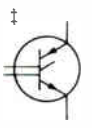
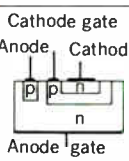
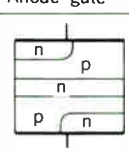
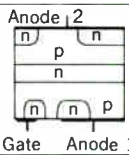
FIGURE 3. Characteristics of the major types of commercially available monolithic thyristors.

The *turnoff thyristor* (GTO or GCS) has stimulated considerable interest and activity because of its ability to interrrupt load current by suitable control signals on its gate.[23] Although it has thereby promised to combine the advantages of both the SCR and the power transistor, it has not yet been accepted for any applications of practical significance. Up to now GTO devices have been handicapped by the combined disadvantages of both the SCR and transistor. One of the more serious disadvantages is the fact that turnoff thyristors with reasonable turnoff current gains (i.e., > 5) have so far had considerably higher forward voltage drop than conventional SCRs. Moreover, current crowding occurs during turnoff at points farthest from the gate or base rather than near the control base, as is the case with a transistor. The result is a loss of turnoff control above a given anode-current level, and sudden destructive failure in a manner similar to second breakdown in a reverse-biased transistor when turnoff is attempted above a critical anode-current level. To minimize these objectionable effects, gate turnoff thyristor designs require transistor-like interdigitated gates and continuous gate drive to broaden the range of current operation. Barring significant improvements in characteristics, one finds no really adequate answer to the question, "Why use the turnoff thyristor rather than the power transistor except for very specialized applications?"

The *triac*, which is one possible form of bidirectional triode thyristor, has recently earned widespread acceptance in moderate-performance lower-power full-wave ac applications.[24] It accounts for most of the deviation between SCR and thyristor production that appears in the data for 1965 and 1966 in Fig. 1. This device has introduced economic benefits over the alternative of two inverse-parallel-connected SCRs with their attendant triggering complications and transient-overvoltage protection requirements. To date, triacs have been limited to use in lower-voltage commercial-frequency applications because their switching and dynamic characteristics have not been as good as those of SCRs. These limitations are inherent in the currently used dual-conducting structure of the triac, which does not provide complete isolation between the two halves of the pellet. As triac designs become more sophisticated to minimize these effects, we may expect to see their use at higher current, frequency, and voltage levels, although the top performance requirements for bidirectional devices will continue to be relegated to pairs of SCRs.

With the exception of the tetrode thyristor (SCS),[25] all of the remaining thyristor types listed have some type of voltage-threshold triggering mechanism in common, and this in turn is a clue to their application.[26] In general, this type of characteristic dictates their use in low-level control circuitry, where matching of the specific device's trigger-voltage level to the application need can be accomplished by potentiometer means. Ideal applications have included their use for triggering higher-power thyristors, in timing circuits, and for logic functions.

Use of these voltage-triggered components directly in

Type	Number of Leads	IEC Official Name	Common Name	Schematic Symbol: Usage	Schematic Symbol: USASI	Equivalent Cross Section	Main Trigger Means	Maximum Ratings Available	Major Applications
Unidirectional (reverse blocking)	2 (diode)	Reverse blocking diode thyristor	Four-layer (Shockley) diode				Exceeding anode breakover voltage	1200 V 300 A peak pulse	Triggers for SCRs, overvoltage protection, timing circuits, pulse generators
		Reverse blocking diode thyristor	Light-activated switch (LAS)				Infrared and visible radiation	200 V 0.5 A	Static switches, triggers for high-voltage SCR applications, photoelectric controls
	3 (triode)	Reverse blocking triode thyristor	Silicon controlled rectifier (SCR)				Gate signal	1800 V 550 A avg.	Phase controls, inverters, choppers, pulse modulators, static switches
		Reverse blocking triode thyristor	Light-activated SCR (LASCR)				Gate signal or radiation	200 V 1 A avg.	Position monitors, static switches, limit switches, trigger circuits, photoelectric controls
		Turnoff thyristor	Gate-controlled switch (GCS, GTO)				Gate signal turns GCS off as well as on	500 V 10 A	Inverters, pulse generators, choppers, dc switches
		—	Silicon unilateral switch (SUS)		—		Exceeding breakover voltage or gate signal	10 V 0.2 A	Timer circuits, trigger circuits, threshold detector
		—	Complementary unijunction transistor (CUJT)		—		When B1-emitter voltage reaches predetermined fraction of B1-B2 voltage	30 V 2 A peak pulse	Interval timing, trigger circuits, level detector, oscillator
	4 (tetrode)	Reverse blocking tetrode thyristor	‡ Silicon controlled switch (SCS)				‡ Gate signal on either gate lead	200 V 1 A avg.	Lamp drivers, logic circuits, counters, alarm and control circuits
Bidirectional	2 (diode)	Bidirectional diode thyristor	Biswitch, diac, SSS		—		Exceeding breakover voltage in either direction	400 V 60 A rms	Overvoltage protection, ac phase control, triac trigger
	3 (triode)	Bidirectional triode thyristor	Triac		—		Gate signal or exceeding breakover voltage	500 V 20 A rms	Switching and phase control of ac power
		—	Silicon bilateral switch (SBS)		—	Two SUS structures inverse-parallel on same chip	Exceeding breakover voltage in either direction or gate signal	10 V 0.2 A	Threshold detector, trigger circuits, overvoltage protection

* Also U.S.A. Standards Institute alternate symbol.
† Complementary equivalent also available in some ratings.
‡ Also available in light-activated version (LASCS).

high-power applications, such as overvoltage suppression, usually requires well-defined breakover-voltage characteristics, much like those of high-power regulator (Zener) diodes. This lack of versatility dictates against general-purpose usage. Normally, it is more economical and versatile to perform voltage-level sensing with a selectable voltage and at a low power level, and then to trigger a power thyristor by gate means when the preset adjustable voltage level is exceeded.

Voltage

The most direct way of increasing the power-handling capability of a given size of semiconductor pellet, whether it be a thyristor or rectifier diode, is to raise its blocking voltage ability. From an application standpoint, higher voltage requirements often go hand in hand with higher current ratings because of the desirability of operating more substantial power loads on high-voltage supplies such as commercial 480-volt ac systems. Thus, power diodes with 2600 volts peak reverse rating are in service in electrochemical applications, and 1800-volt SCRs are commercially available today. Current ratings in these single-pellet devices are 800 amperes average for the diode and 840 amperes rms for the SCR. In Japan, 3000-volt 300-ampere diodes are in railroad service. However, only in few, if any, practical applications can these ratings be employed on a continuous basis, because substantial transient overvoltages and overcurrents are inevitable in power control systems, either from unexpected and undesirable sources or as part of the normal operating function. Typical examples occur during fuse blowing and reversing of motor loads. As voltage ratings are pushed higher, an area of diminishing returns is approached. Even though single-junction capability as high as 10 000 volts is possible and has been demonstrated,[27,28] such a component has a higher conduction-voltage drop than the total drop of a series-connected string of lower-voltage devices. To achieve equivalent efficiency such an ultrahigh-voltage device would have to be operated at lower current density than its more conventional counterparts. Also, because of rapidly escalating electrical losses in the blocking state, such a device would be much more prone to thermal runaway and would have to be thermally derated to reduce this probability.[29] Recovery characteristics too would be objectionable in many applications.

Instead of dramatic increases in the working-voltage ratings of single junctions well beyond the 3000-volt level, it is more reasonable to expect further refinement in the techniques of series-connecting power semiconductors to achieve desirable levels. The necessary voltage sharing and switching precautions will become considerably simplified and more reliable as improved junction-forming processes produce components with more nearly identical and optimized electrical characteristics—for example, switching speed, leakage currents, avalanche voltage, and stored charge.[30,31] As mentioned earlier, light triggering has promising implications where unusually high voltage requirements otherwise pose difficult insulating problems. The quickening interest in high-voltage dc power transmission at voltages of approximately 500 kV provides great incentive for high-power thyristor strings capable of blocking and switching hundreds of thousands of volts with extremely high reliability and competitive cost and efficiency.[13]

Cost of individual junctions in the 1000-volt-plus region depends greatly on the success of techniques used to stabilize blocking junctions around their periphery. Carefully contoured surfaces that are currently used add substantial cost in themselves and dispossess valuable current-conducting area of the silicon.[32] Nonmechanical means of uniformly distributing the high dielectric fields may help to reduce costs here.[33,34]

Current

The junctions in silicon diodes and thyristors can operate at continuous current densities as high as 150 amperes per square centimeter. Many hundreds of low-power devices (rated less than 1 ampere) can therefore be fabricated from a single wafer sliced from a typical 3-cm-diameter silicon rod. At the other extreme, a single component capable of continuously handling 500 amperes or more can be fabricated from the same wafer. As we look to the still higher current ratings required for some applications, where is the upper limit? The answer lies in both technology and economics.

Every silicon wafer has a probability of small localized flaws or nonuniformities.[35] When the wafer is diced into many small pellets, testing can remove those pellets containing substandard characteristics. Since the single large device can be no better than its weakest point, however, the achievement of superior electrical characteristics in devices with very large junction diameters is possible only with the probability of a higher proportion of scrap units and therefore relatively higher cost per ampere. Conceivably, this limitation may someday be lifted by development of effective means of selectively isolating inferior sections of a wafer without dicing and repackaging only the good units. This would strike a parallel to the technique currently being considered for large-scale integration of signal circuits—that is, the interconnection and use of only the "good" circuits on a wafer. Process refinements of the future undoubtedly will make for greater uniformity across large-diameter wafers and will develop means for reducing kerf losses during sawing and breakage in the handling of fragile slices with greater than a 100-to-1 diameter-to-thickness ratio. These technical and economic improvements will result in gradual increases in single-wafer diameters above the present maximum of 3 to 4 cm. An influence that tends to accelerate this upward trend is the cost-reduction pressure on signal planar components and integrated circuits. In this field particularly, larger-diameter wafers permit processing of additional components at the same basic labor cost, thus reducing per-unit cost.

Counteracting this trend toward larger-diameter pellets for power devices is the successful experience with paralleled components to achieve the same end. The same process refinements that make for greater uniformity in a single wafer decrease the problems associated with matching the electrical characteristics of individual pellets for parallel operation. This can be accomplished either by mounting and interconnecting several pellets in a single housing or by paralleling individual devices that are already housed into a larger subassembly or equipment. Clusters of this type are commercially available as diodes rated to 1000 amperes[36] and as high-frequency SCRs.[11] In the case of thyristors, paralleling of suitably selected smaller devices constitutes a form of interdigitation. Improvements in switching characteristics result from trig-

gering at several gates rather than one. Since the total junction perimeter of paralleled small devices is greater than that of a single large device there is a greater likelihood of potential surface degradation and failure.

Thermal considerations

Closely associated with power-handling capability are thermal and packaging factors. Efficient as they are, silicon power semiconductor components still generate a considerable amount of heat for their size. For instance, an SCR operating at 300 amperes develops in the silicon almost 400 watts of heat losses, which must be dissipated. For satisfactory operation, the temperature of the junctions must not rise more than 70 to 80°C above the ambient. Therefore, an efficient cooling system between the junctions and ambient temperature is required. In low- and medium-power devices the silicon wafer is usually soldered or brazed to a copper base, which is in turn mounted on a heat sink for cooling. Larger-diameter pellets may require use of a molybdenum or tungsten layer to protect the silicon from stresses due to the high-temperature coefficient of expansion of copper, especially if a device is expected to resist wide temperature excursions in service. Since the shear stresses on a restrained piece of silicon increase with junction diameter, additional precautions become necessary on larger devices.[37] Recently the thermal and electrical contacts to the basic junction sandwich of large power semiconductors have been successfully accomplished by pressure contacts in which sliding action between surfaces relieves shear stresses as temperature varies. A side benefit of one type of pressure-contact device results from the introduction of double-sided cooling for large semiconductors (Fig. 4).[22,38] With heat sinks on each side of the wafer, temperature rise is nearly halved. Conversely, continuous-current-handling ability is increased. The effectiveness of double-sided cooling permits the use of forced air cooling in applications that require 300 to 400 amperes continuous per device.

Despite its inconveniences, liquid cooling can significantly enhance current-handling capability beyond that possible with air convection. As the concentration of heat in a small area is pushed still further in high-power-density applications, vapor cooling can possibly be used to advantage. This technique has been used for cooling high-power transmitter tubes. It must be recognized that, although the improved cooling techniques mentioned here increase steady-state current-handling capability, the effect on single-cycle and shorter-interval surge ratings is negligible.

The packaging and mounting of a power semiconductor component have significant effects on its cost as well as its current rating. Although power devices have established their enviable performance and reliability records largely with hermetic glass and ceramic seals, the established success of plastics for housing low-power consumer-type semiconductors is symptomatic of what will happen to reduce costs on higher-power devices as well. Acceptance of plastic encapsulation at voltages higher than about 400 volts depends largely on development of stable, passivated junction surfaces. Such programs are among the most active ones currently engaging the industry. Of course, pellets with stabilized surfaces at high voltage offer other potential opportunities as well. We can expect chip-and-wire and thick-film assembly of such passivated components to flourish in power applications as well as in the signal-level circuits in which these techniques are currently being used. Electrically insulating substrates of thermally conductive materials, such as beryllium oxide, make assemblies of power-device pellets particularly feasible and attractive.

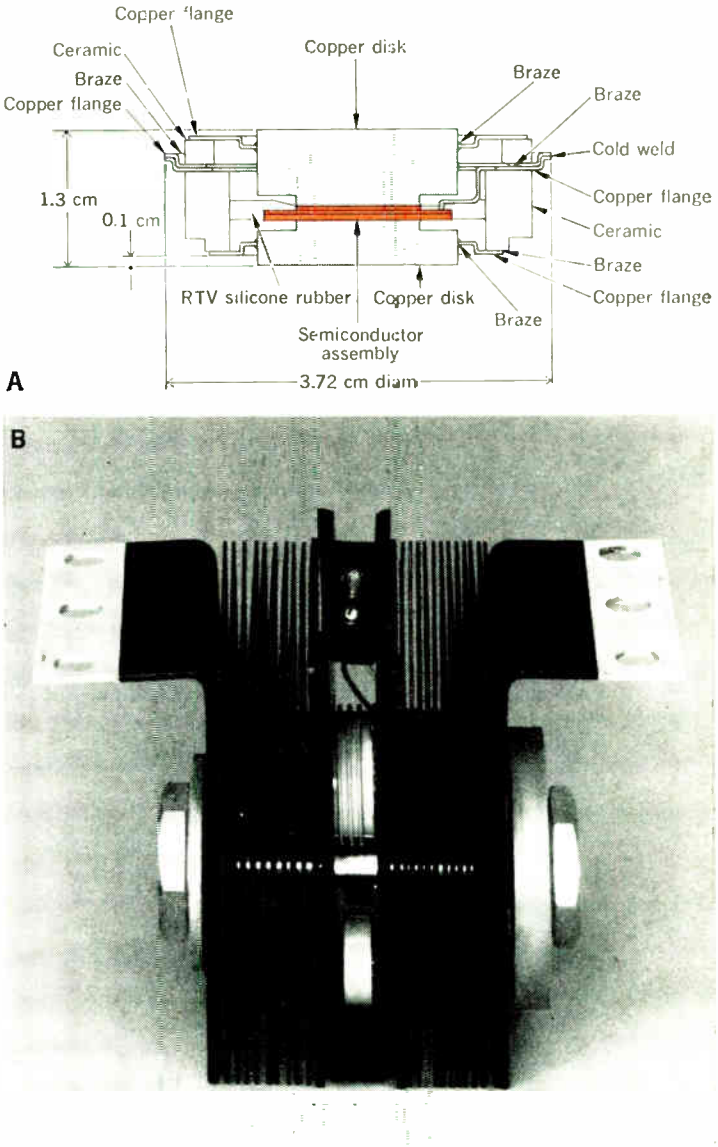


FIGURE 4. Two types of pressure-contact SCR designed for double-sided cooling. A—Cross section of GE C380, rated 150 amperes in typical applications. B—GE C500X3 forced-air-cooled SCR, rated 320 amperes in typical applications.

Dynamic properties

Static voltage- and current-handling capability in a power semiconductor is much like the physique and brawn of a fighter. They are necessary and fundamental attributes, but for optimum effectiveness these characteristics must be capable of being put to work swiftly and judiciously. Even the voltage-current characteristics of the power rectifier diode are being examined today in the light of behavior under dynamic conditions. Of particular interest are the speed and nature of the reverse recovery process immediately following conduction. In many power switching circuits, even at 60 Hz, conventional

rectifier diodes may cause severe transient disturbances and failure to themselves because of the length of time they require to recover their reverse blocking ability as well as the abruptness with which the recovery occurs.[39,40] These needs are resulting in a new breed of fast-recovery rectifier diodes which typically display on the order of one per cent of the recovery charge of their predecessors (Fig. 5). To achieve these characteristics, compromises are made in conduction voltage drop and peak-voltage rating.

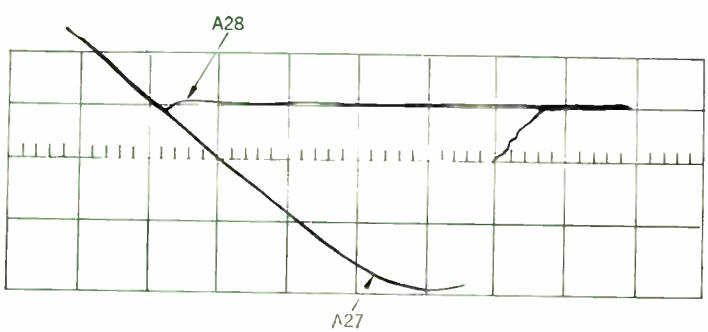
Dynamic properties are an even more vital concern in thyristors. As quickly as superior characteristics are developed, astute circuit and equipment designers seem to make good use of them and to demand even greater device performance.

The major dynamic properties of concern are di/dt, dv/dt, and turnoff time. Each of these characteristics is a subject in itself.[14,15] The di/dt value, which defines the ability of a thyristor to switch on into a fast rising current repetitively, generally becomes critical as frequencies rise above 400 Hz. Pulse modulators for radar systems and for energizing lasers are particularly demanding of high values of di/dt. The better SCRs today employ specially optimized gate structures to develop di/dt capability of hundreds of amperes per microsecond. For comparison, this rate of change is of the same order of magnitude as that which would occur in a hypothetical 10-GHz signal transistor!

The dv/dt property measures the ability of a thyristor to remain blocking while a swiftly rising voltage is applied to its anode. This ability is particularly important immediately following commutation. Many modern SCRs use localized short circuits across the emitter to shunt capacitive currents and thus prevent regenerative action under high dv/dt conditions.[24-26] Such devices continue to block as voltage is applied at 200 V/μs or more under rated temperature conditions.

Turnoff time is of vital interest where energy storage means are used to commutate or turn off an SCR. A turnoff time specification defines how long the anode of an SCR must be reverse-biased for it to regain its forward blocking ability immediately following conduction. As turnoff time requirements become lower, less energy must be stored for the commutation process, and hence lower-cost reactive storage elements are required. The fastest SCRs today exhibit turnoff time between 5 and 10 μs. Unfortunately, short turnoff time is inconsistent with high voltage-handling ability in an SCR.[41] For example, commercial 1000-volt SCRs at this writing exhibit turnoff times an order of magnitude greater than this range.

FIGURE 5. Comparison of reverse recovery characteristics of a fast-recovery silicon rectifier diode (A28) and a conventional silicon diode (A27) of equivalent current rating in a sinusoidal circuit. (Vertical scale = 8 A/sq; horizontal scale = 0.5 μs/sq)



The ultimate objective for any sophisticated power control equipment is a minimum-size box containing the "ideal switches" described earlier. In order for such a control to have negligible losses and a minimum cost, it should require no reactive elements, such as di/dt-limiting inductors, dv/dt-limiting capacitors, and oscillation-quenching resistors. Today's thyristor technology is rapidly approaching the ideal wherein most applications need not consider the addition of these auxiliary crutches for the SCR. To push dynamic limitations beyond the range of concern, SCR designs are taking on some of the constructional features of the power transistor discussed earlier. Interdigitated gate structures overcome di/dt limits by initiating turn-on action over an extended front. Such structures also permit more effective electrical control of the thyristor cross-sectional area by external gate circuitry during blocking and turnoff as well.[17] Such approaches may provide the keys to solve the high-voltage/fast-turnoff-time conflict. It is no longer unreasonable to speculate on the development of high-current SCRs able to block 1500 to 2000 volts and with turnoff time requirements of a few microseconds or less.

Other trends for the future

Thus far we have discussed the direction in and the degree to which improvements in existing characteristics can and will likely take place. As specialized needs arise, or as a commonality of function combinations becomes evident among a number of applications, unique new types of thyristors can be expected. Clues to some of the possibilities are suggested by the gaps or missing combinations in Fig. 3 as well as by the entire field of reverse-conducting types, which have not been exploited until now.

Other innovations will result from integrating accessory functions into the basic thyristor pellet or package to simplify circuitry and reduce overall system cost. Examples already exist in a number of areas. The triac integrates the function of two inverse-parallel SCRs, though thus far only at relatively low power and frequency levels. The so-called quadrac incorporates a trigger device with a triac in the same package. Controlled avalanche reverse characteristics protect against transient voltage failure in the reverse direction of some types of SCRs; anode self-triggering can protect against transient voltage damage in the forward direction. Both mechanisms can be used to eliminate the need for external surge suppressors, thus effectively integrating these functions. Improvements in di/dt and dv/dt, if sufficient to eliminate the need for R-C networks and inductors, also constitute functional integration. One inverter designer estimates that superior dv/dt characteristics on present-day SCRs save him $5.00 for each filter he formerly required.

Other possibilities include integration of more elaborate triggering schemes with such features as stable voltage or current threshold sensing or logic functions. These functions may be incorporated as outboard elements, as separate chips in the same housing, or monolithic integration on the same chip if the materials are compatible. Sophisticated trigger functions are already being performed by outboard monolithic circuits, such as in a zero-voltage switching temperature control module recently an-

nounced.[42] Other integration opportunities for thyristors are phase-control triggers, RFI filtering, overload self-protection, overtemperature and undertemperature tripping, and MOS-type input triggering sensitivity. The basic motivation for such developments is primarily the economics of the overall system, although size and reliability factors are also considerations. Monolithic integration of power semiconductors on the same scale as with signal devices is unlikely because of the limitations in single-wafer silicon technology and because of the problems of cooling and connecting such concentrated power circuitry. As previously mentioned, manipulation of the current gains of the respective transistor structures in a thyristor, as well as the interplay between these gains, can be expected to produce interesting and useful characteristics. With adequate gate control over the emitter area, one can envision wider application of thyristors that are naturally in the "on" state unless held off by a suitable gate signal. Other thyristor designs may require positive and negative gate drives similar to those used in some transistor circuits.

As one might expect, the additional layer in a thyristor leads to many more possibilities and variations than in a transistor. For the same reason, optimized thyristor designs with predictable and consistent characteristics require very close process control in production. Here lies the major challenge in this field today. Thyristors with highly desirable electrical characteristics have been demonstrated on a laboratory feasibility basis. Putting these sophisticated devices into large-scale and economical production can be quite another story, as testified by the typical passage of several years between demonstration of feasibility and practical commercial availability.

Neither technology nor power semiconductor circuit development needs are approaching saturation. Moreover, no serious alternative exists today to challenge the silicon power semiconductor in its functions of static power control and conversion.

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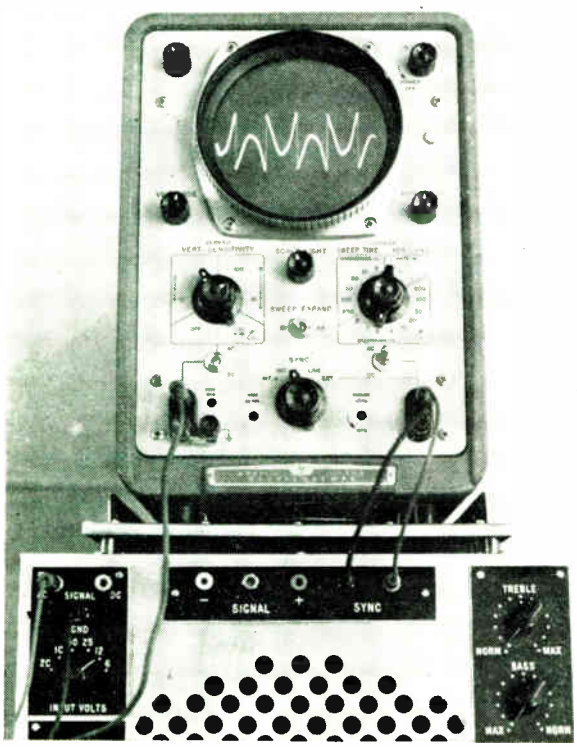
"Mathematics 10"

An affectionate reminiscence of the pre-World War I era, when B. O. Peirce and W. E. Byerly (highly respected to this day for the accuracy and completeness of their table of integrals) conducted Harvard's famous "Math 10" course

E. S. Purington

Gloucester, Mass.

FIGURE 1. Aural and visual indication of the residue of a square wave after aural indication that the fundamental has been subtracted out.



When a researcher is troubled by a problem in his own real domain of time, he sometimes takes a round trip to the mythical land of the complex frequency. To assure any possible success, and to provide for re-entry back home, he takes a table of integrals as his passport. Perhaps more often than not, this is the collection of B. O. Peirce from his own records and those of W. E. Byerly. Those who stake their own reputations upon the intellectual integrity of these two may wish to know of their standings and contributions in the field of education.

In late May of 1912, David Sarnoff by his reporting of the loss of the *Titanic* had created immense popular interest in radiotelegraphy; Alfred Goldsmith as one of a team of three had helped create the Institute of Radio Engineers; John Hays Hammond, Jr., was studying how best to serve the United States and the Institute as a delegate to the upcoming International Conference of London. These events mark the date when a student, in consulting with an overseer of his college, said, "I am in a dilemma. Our college has provided for a year of postgraduate work in a school of my choice. I would very much like to apply at the Massachusetts Institute of Technology, but I think our faculty would prefer that I go to Harvard. If you will tell me what is best for me to do, I will do it." And Alfred Burton, the first dean of M.I.T., unhesitatingly advised, "Go to Harvard, by all means, and be sure to take Math 10."

Now Math 10 was a hybrid sort of course. Peirce taught something of the methods of setting up the differential equations of mathematical physics, and Byerly taught something of how to use them in solving specific problems. But to many, the most important things they learned were not to be found in the textbooks.

One bright winter day, the sunlight scattered from the newly fallen snow over toward the Law Library filled the classroom on the second floor rear of Jefferson Physical Laboratory. Peirce entered from the corridor on the right—sturdy, jovial, urbane—with a "Good afternoon, gentlemen." Walking to the blackboard at the rear of his desk, he drew the outlines of three cumulus clouds with arrows here and there pointing perpendicularly away from their surfaces. Turning to his class, he said, "Today we are to study about Green's theorem. But first, I think you should know a little about Green himself. George Green was the son of a greengrocer, so now you know he was British. His folks were too poor to give him much of an education, but he got hold of books and became very proficient in mathematical physics. Finding something he thought to be of importance, he sent a paper up to the Royal Society at London. At first the bigwigs said, 'What can this George Green, the son of a greengrocer, know of importance that we do not already know? Why, he never went to Eton or Harrow, let alone Oxford or Cambridge.' But as often happens, a Britisher came

along with some sense, and so today we are privileged to know what of importance he had found out." And the student thought, "Harvard professors too, as boys, threw their firecrackers at the heels of an imaginary George the Third."

At Sever Hall in the Yard, Byerly—frail, somber, rural—greeted his class, "We have finished what is in the book about Fourier and his series and integrals. Before going ahead with other kinds of harmonics, I think I should devote this hour to the ideas of another Frenchman who provided a more physical approach to trigonometric harmonics." Then he proceeded along the lines of what is now a usually uncredited "least-squares approximation property of Fourier series." He stated that if the first m components of a repetitive wave already had been found, what was definable as the mth residue was to be found by subtracting the sum of the m components from the original wave. The nth component could be then chosen of such amplitude and phase that the nth residue would represent less power than for any other choices. The nth component thus found would be precisely the same as though it had been obtained in the classical Fourier manner.

Thus Byerly was not at all humiliated when the needs of his students caused him to set forth a point of view that was not included in his textbook. He would have been now among those who approve and encourage the use of electronic aids for increasing the understanding of mathematical ideas. In the "post-Sputnik" era such an aid was designed to use aural as well as visual means for studying electronic circuits. Thus the setup of Fig. 1 provided speaker indication of the audio waveform shown by the scope. Here, an input was provided by which a student could subtract out a controllable amount of fundamental from a square wave. The speaker and scope both indicated the residue of the square wave when the adjustment was so made that the student knew aurally that the fundamental no longer existed in the speaker and scope input. Math 10 thus provided a background for an experiment by which elementary students can now get some qualitative and quantitative information about the Fourier principle.

In a Peirce examination, the student surveyed the ten questions to decide whether to try for an A or to play it safe and try for a B. One question read, "I have a pyramid made of metal with a specific gravity of five. The sides of its square base are four centimeters in length and the apex is three centimeters perpendicularly above the center of the base. What, in CGS gravitational units, is the surface integral of the outwardly normal component of the gravitational force due to the material within this pyramid?"

The student was amazed. "Why does Professor Peirce ask for the integration of forces when he couldn't himself do it in the three hours allowed for ten questions? But, hold everything. He has not specifically asked us to set up equations and integrate them. What he is up to is finding whether his students have sense enough to get answers to problems in the simplest legitimate way. All I'll have to do is multiply four by four by one third of three, then by five, then by four times 3.1416, and not forget to put a minus sign before the result." Thus it was that Peirce taught that theorems were made to be used and not merely to be discussed and admired, and that woe would be unto him who knew them but didn't know enough to use them.

In the final session of the course, Byerly announced, "You probably all know this is the last year that Professor Peirce and I will give Math 10. All that is left is the final exam. It don't make sense to have you bone up on questions that won't be asked. Here are ten problems. Take them with you to your rooms or homes, consult any books or printed matter you may wish, but of course consult with no one personally. So that you may not be under pressure and will have plenty of time to check and recheck your answers, it will be all right if you mail your bluebooks back to me postmarked not later than a week from today. So goodbye and good luck to you, gentlemen."

One problem postulated that the earth behaved as though it were mathematically describable by stated values of thermal conductivity and specific heat capacitance; and that its surface temperature varied throughout the year in a periodic manner, with stated equal values at the March 21 and September 20 equinoxes and stated maximum variation from mean in summer and winter. The problem was, "When will the frost come out of the ground in the spring, and how far below the surface will the temperature vary throughout the year by one degree?" When the bluebook was in the mail, the student pondered. "That exam took 20 hours to work out, but never before was I so relaxed and sure of the correctness of the results. Others before have called us gentlemen, but Byerly more positively accepted us as such. I wonder if he gave us a hidden message. Is he retiring to his farm and doesn't expect to plant his Fourth of July peas until after April 17, 1914? Is he looking forward to the time when his bodily remains will be comfortably six feet under the earth's surface?"

There are many today and there will be many in the future who express their respect for B. O. Peirce and W. E. Byerly by using their formulas in a table of integrals. And there are still a few who remember the devotion of these men to the idea that, in educational matters, the needs of the students are of prime importance. At least one knows why it was that a dean of the Massachusetts Institute of Technology once said, "Go to Harvard, by all means, and be sure to take Math 10."

Dibner—Michael Faraday

Michael Faraday—a centennial

On this hundredth anniversary of the death of Michael Faraday, we are again reminded of our debt to the genius whose discovery of electromagnetic induction in 1831 was the beginning of a new era in mankind's development—the Electrical Age

Bern Dibner *Burndy Corporation*

Beyond his own material contributions to the electrical art, Faraday's experimental approach and intuitive resolutions opened channels of inquiry into which his successors moved. Thus his bequest to society has increased in value far beyond that which he himself could have envisioned. In this article commemorating the centennial of Faraday's death, we follow him from his humble beginnings as a simple bookbinder's apprentice until he quietly passes into history at the age of 76—the leading scientist of his generation.

A hundred years ago, on August 25, 1867, the weary heart of Michael Faraday stopped beating. At the end, he just sat quietly in his chair, his faculties spent, his awareness of his surroundings gradually reduced to zero. Thus the leading scientist of the first half of the 1800s passed into history. He had found the peace that he was awaiting when he wrote to his friend Auguste de la Rive, in 1861, "and there is the rest for those who like you and me are drawing near the latter end of our terms here below." He died, as he had lived, with absolute modesty, avoiding every ostentation and denying all pomp and honors. His funeral was of the simplest, held in privacy. His grave in Highgate Cemetery bears simply his name and date of birth and death. He had rejected titles, pension, and burial in Westminster Abbey.

The same intelligence that had revealed to this blacksmith's son the important laws of nature that he and his successors wove into the great electrical networks of today had also taught him that his heritage did not lay in impressive monuments. Instead, he left a series of observations in physics and chemistry that were to guide research for most of the coming century. He had won a following among the scientists and scholars of the great universities, in the research laboratories, and in the shops and industries created from his discoveries. He had founded the electrochemical industry, had established an important branch of metallurgy, and had provided guidance in the ways of research by an extraordinary series of published experiments. His lectures at the Royal Institution in London set a pattern for disseminating the progress in the physical sciences, thereby attracting the support of the flourishing industries of Victorian England. Only half a century spanned the announcement of Faraday's most important discovery—electromagnetic induction—and its application as a central station generating and distributing network.

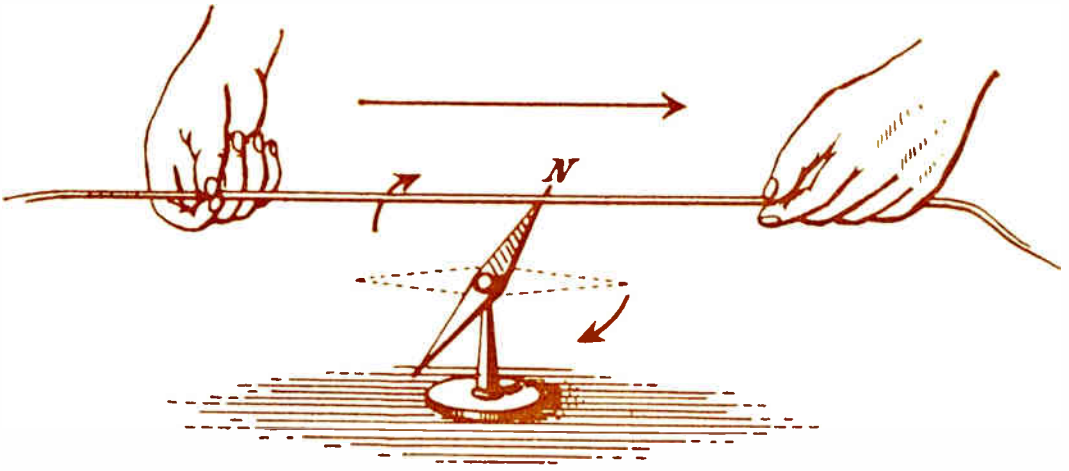
THE AGING Faraday is shown in an exceedingly rare photograph found recently in Paris. Having risen from bookbinder's apprentice to the foremost scientist of his time, he shows here the stresses of his dedicated life.

Three important steps

Three discernible steps have elevated the electrical science from the oblivion of the past to its present position of primacy of man's energy forms. The first of these was the formation in 1600 by Dr. William Gilbert of London of the known electrical behavior of his time. His important book, *De Magnete*, summed up the magnetic knowledge so urgently needed by the explorers and navigators of the early 1600s. The book also contained a chapter on electricity, a science which evolved through the electric machines of Otto von Guericke and Francis Hauksbee that made electrical experimentation dramatic and popular. It was Franklin and van Marum who pushed elementary electrostatics to the limits of its development.

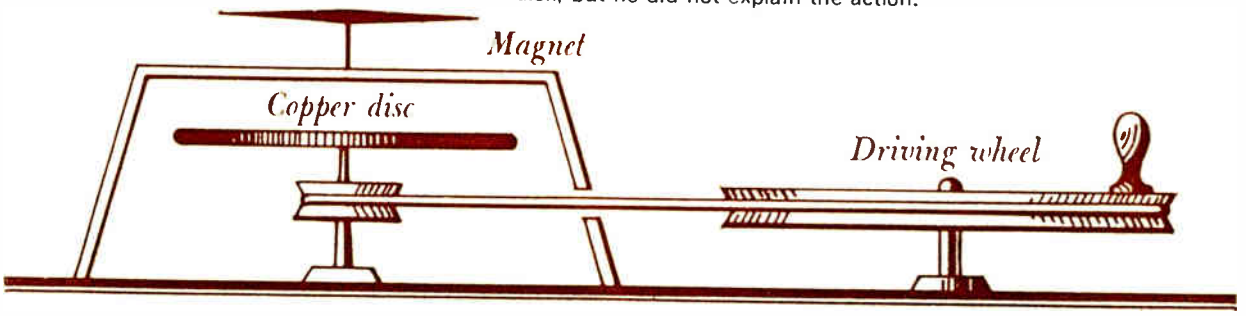
It remained for Alessandro Volta to introduce a second form of electric generation (by chemical means) with the discovery of his voltaic pile. His primitive electric battery provided a continuous source of electrical flow that opened ways to illumination by the electric arc, electroplating, and the dissociation of water into oxygen and hydrogen. But most important, Sturgeon's construction of an electromagnet, in 1825, provided the lead for the electric telegraph. This was the first wide application of electricity, but the energy for it came from voltaic batteries. Broad electrical development depended on a different energy source—the electric generator, and later, the transformer. These developments stem from the genius of Faraday.

The era that was opened with the introduction of Volta's battery in 1800 remained comparatively quiescent during its first two decades. In 1820 H. C. Oersted in Copenhagen announced a singular discovery; he had observed that

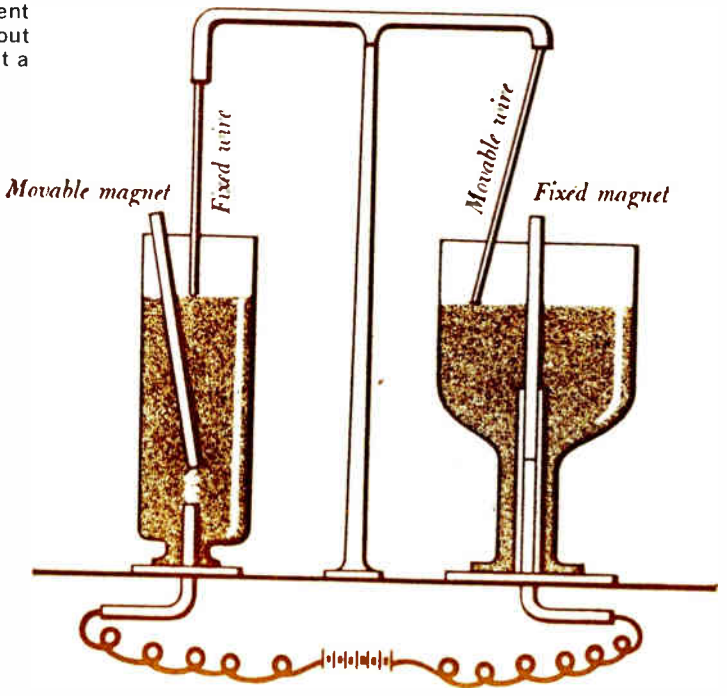


WHEN Oersted passed a voltaic current through a wire he noticed that a magnetic needle set itself transverse to the wire.

ARAGO caused a magnetic needle to drag after a revolving copper disk, but he did not explain the action.



IN FARADAY'S first famous experiment a magnet was made to revolve about a conductor and a conductor about a magnet.



a wire carrying an electric current had a magnetic field generated around its length. This startling announcement set off investigations in many laboratories and especially stimulated Ampère in analyzing the electromagnetic forces in adjacent conductors. The great holding power of an electromagnet turned the keenest minds of Europe and America toward further experimenting and calculation. They faced the obvious challenge: if such intense magnetic fields could be developed from an electric solenoid, why could not the process be reversed? Why could not electricity be generated from magnetism? Between 1820 and 1831 Faraday alone had made four extended efforts to convert magnetic energy into some electrical form, but without success. His triumph in 1831 was the commencement of the Electrical Age.

The early years

In an England that accepted strata in society, Faraday never forgot his humble beginnings. Born on the outskirts of London on September 22, 1791, his father was a working blacksmith, a trade which was also followed by his brother. Michael's early schooling was very elementary and at the age of 13 he became apprenticed to a bookbinder and bookseller in London. This choice of occupation was fortunate for Michael because he not only learned to bind books, but made the time to read them during the eight years of apprenticeship. He learned of the marvels of electricity from the *Encyclopedia Britannica* and about chemistry from Mrs. Marcet's *Conversations on Chemistry*. Both disciplines led to experiments with such apparatus as he could acquire with his very slender wage. He constructed an electrostatic machine and in 1812 he built a voltaic pile. It was then that Faraday learned of lectures being given in chemistry in London and he borrowed funds from his brother in order to attend them. While carefully listening and observing the experiments, he made many notes and illustrations. These he transcribed and assembled into four volumes, which he bound and presented to his sympathetic and intelligent employer, George Riebau. A visiting patron of the bookshop was so impressed by the notebooks that he invited young Faraday to accompany him to a Friday evening lecture at the Royal Institution on Albemarle Street in London. The speaker was the director of the laboratory of the Institution, Humphry Davy, and the occasion left a profound impression on the lad. During the day of the third of the four lectures attended by Faraday, the excitement was heightened by the conferring of knighthood on the lecturer, thereafter known as Sir Humphry Davy.

When his term of apprenticeship was over, young Faraday applied to Sir Humphry for employment at the Institution and, in December 1812, as a measure of his interest, he sent bound copies of the notes he had made during Davy's four lectures. In the following March, Faraday was hired for 25 shillings a week as a laboratory assistant—and thus commenced the fruitful association of the two great minds that were to fashion so much that was new in the sciences. In October 1813 they embarked on an 18-month journey to the Continent, returning home in April 1815. In spite of the disturbances of the Napoleonic wars, Davy's international reputation made it possible to cross frontiers without difficulty. He and Faraday, his general assistant, visited the laboratories and talked to the savants of Europe. Calls were made on such famous scientists as Ampère, Chevreul, Humboldt, and Gay-Lussac. Prior to this visit, Faraday, now 22 years old, had never been farther than 12 miles outside of London; he now faced and talked with the men whose books and papers he had so avidly read. A high point of their visit to Italy was a meeting with Count Alessandro Volta, who was dressed in the formal uniform of the Court. The contrast between this eminent figure and the erstwhile bookbinder's apprentice was not lost on the sensitive young man.

Another impressive visit was to Count Rumford, with whom Faraday dined at his home near Paris. The Count's interest also spanned physics and chemistry but he had acquired yet another distinction. A colorful American (born Benjamin Thompson at Woburn, Mass., in 1753), Rumford had founded the Royal Institution in 1799. As a veteran of the American Revolution (on the Tory side), he had seen all of Europe in revolutionary turmoil, and he had observed, as had others, that science was to be an offspring of that revolutionary age. To promote the interests of science, Rumford had established the Royal Institution as essentially a "learned society" whose purpose was "diffusing the knowledge and facilitating the general introduction of useful, mechanical inventions and improvements, and for teaching, by courses of philosophic lectures and experiments, the application of science to the common purposes of life." At that time, "philosophical" meant broadly "scientific" and Faraday always preferred to be called a philosopher rather than a physicist. The Institution differed from the Royal Society in that it was mainly concerned with organized experimental research rather than with acting as a clearinghouse for the reports of its members and affiliates as did the Royal Society.

At the lectures held at the Royal Institution a platform was provided for the man of science and engineering—the chemist, electrician, physiologist, geologist, or mineralogist—to present a new approach, a novel theory, or a promising experiment. In addition to the thrice-a-week afternoon courses, there were the six lectures for juveniles at Christmas time and the more formal Friday night discourses. By explanation, illustration, and demonstration, the world of science came to witness the work of Davy, Faraday, Brande, and later Tyndall and Dewar. The Christmas series was especially prepared by Faraday for boys and girls and was given for 19 Christmas seasons. Having had no children of his own, this provided a special outlet for his generous personality.

Faraday remained at the Royal Institution for 54 years and in his time published 158 papers. His greatest monument, *Experimental Researches in Electricity*, appeared in 29 series of papers gathered and published in three volumes after their appearance over a span of 27 years. For his work he was awarded more than 100 academic and scientific honors, including degrees, medals, orders, and other marks of distinction. He actively sought only Fellowship in the Royal Society but he declined its presidency, as well as a knighthood and a pension. He never applied for a patent and preferred to "remain plain Michael Faraday to the last." Although he had no training or ability as a mathematician, he was a founder of one of the most exacting of sciences—electricity—but channeled his research through experiment. His interest in the sciences was very broad, involving him in chemistry, geology, metallurgy, mechanics, optics, acoustics, heat,

magnetism, and electricity. It was this breadth of interest that made him intuitively recognize the conservation of energy and its transformation into various forms. It was this drive that stimulated him to hunt for, and finally find, a means of transforming magnetism into electricity.

His greatest discovery

The events that led to Faraday's most important discovery—magnetoelectricity—stemmed from a chain of earlier observations and theories by contemporary electricians. Davy, primarily a chemist, opposed Volta's theory of electric generation in the pile as merely the contact of dissimilar metals by proving that a chemical change took place in the battery elements of copper and zinc or of silver and zinc, and the electrolyte between them. Oersted's simple but critical link of magnetism to electricity has already been mentioned. On learning of Oersted's discovery, Davy and Faraday repeated the experiment and verified the results. A magnetic needle now became an indicator of the direction of flow of a current in a wire. Ampère's experiments with the dynamics of current-carrying wires became the quantitative basis of investigation. Arago, in France, magnetized iron bars by inserting them into energized solenoids and thereby produced "artificial" magnets. He also caused a copper disk to spin on its center and noticed that a magnetic needle positioned over the disk tended to be dragged by the disk, but for unexplained reasons. Joseph Henry, in the United States, improved electromagnets to the point where one could support a weight of nearly a ton. These novel results of research into electromagnetic relationships stimulated Faraday to shift his major interest from chemistry to electricity. Henry had independently discovered the principle of induced current (hence the *henry*, unit of inductance), but he credited Faraday with priority for the discovery because the latter had published earlier. Henry visited Faraday during his stay in England in 1837.

The first fruit of his intense investigation appeared in 1821 when Faraday demonstrated electromagnetic rotation. In a brilliantly devised setup he showed how the same electric current could cause a magnet to move about a fixed conductor and a conductor to move about a fixed magnet. His apparatus consisted of two glass vessels partially filled with mercury, with a fixed wire in the first and a magnet in the second vessel. About the fixed wire there was pivoted a movable magnet and about the fixed magnet in the second vessel was suspended a movable wire, its lower end dipping into mercury. When current was fed to the fixed wire, the movable magnet began to rotate, and concurrently in the second vessel the movable wire rotated; both motions continued as long as current flowed. This impressive experiment greatly expanded Faraday's reputation and in 1824 he was nominated by his friend Richard Phillips for membership in the Royal Society.

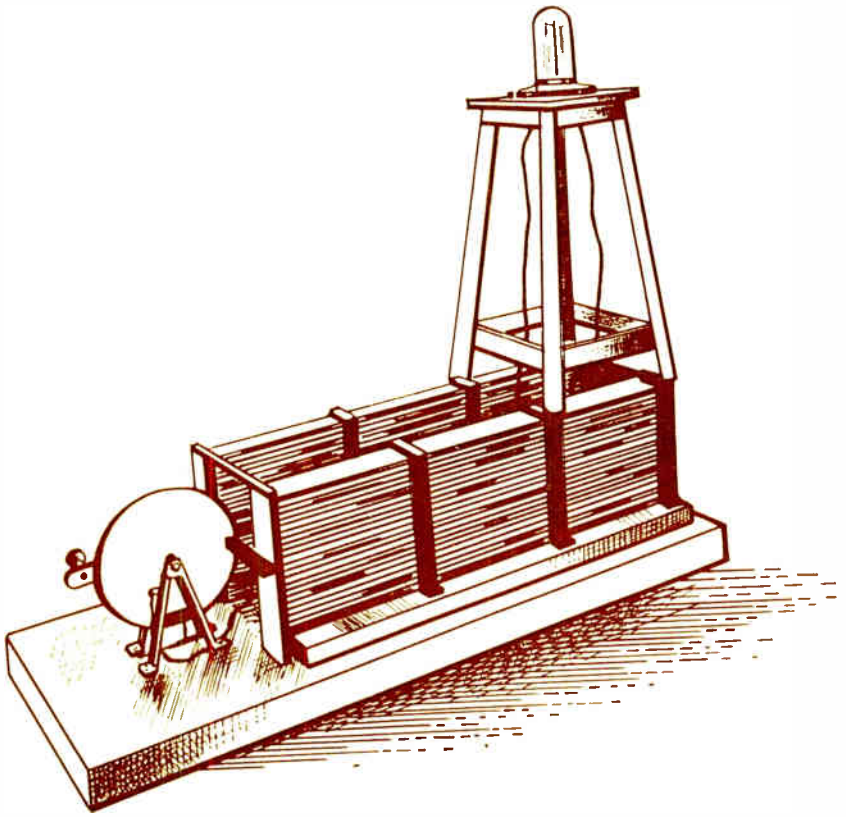
During the ten years from 1821 to 1831, the desire to demonstrate the successful generation of electricity from a magnetic source remained constantly with Faraday. He was now in full manhood, 40 years of age, and a correspondent with the foremost experimenters in England and on the Continent. He read and followed promising leads toward his goal, but nothing came of them. He was aware that electro*static* induction had been investigated and described during the previous century, but the constant-flow voltaic current could not be made to induce a similar current in a nearby wire. In an 1824 experiment Faraday had placed a bar magnet into a round copper wire coil but noticed that no electricity was produced. Other experiments proved equally fruitless, yet he was convinced that by the interplay of forces some process converse to that discovered by Oersted must be possible, and he was determined to find it. Other experimenters—Ampère, Arago, de la Rive, Herschel—tried disks, coils, and wires, but none struck the conclusive note.

In the summer of 1831 Faraday began his fifth series of investigations by making a soft iron ring some 15.2 cm in diameter. He then wound a coil of insulated copper wire on half of the ring's circumference and on the other half he wound a second coil. Upon connecting the first coil to a battery and the second coil to a galvanometer, he noticed a swing of the galvanometer needle, but it immediately returned to the zero position. However, when the connection was opened, a similar swing in the opposite direction was noted. Faraday linked the behavior of the galvanometer in his ring and coil experiment with the drag of the magnetic needle in Arago's experiment. He repeated the Arago experiment, observing the interaction of the needle's magnetism with the disk's magnetism created by the induced current. This resolved the problem in his mind.

From August to November 1831 Faraday carried on an intensive investigation of electromagnetic effects involving a series of simple but telling experiments in which he proceeded step by step toward the tantalizing problem. On September 23 he wrote to his friend Phillips: "I am busy just now again on Electro-Magnetism, and think I have got hold of a good thing, but can't say; it may be a weed instead of a fish that after all my labour I may at last pull up. I think I know why metals are magnetic when in motion though not (generally) when at rest."

Faraday's clinching experiment was performed on October 28, 1831, in which he reversed the relative motion of conductor and magnet. He did this by placing a 30.5-cm copper disk between the pole pieces of the great permanent magnet belonging to the Royal Society. The disk was provided with a crank and bearings so as to rotate easily. A metal collector rode on the periphery of the disk and another collector rode on its axle. Wires from the collector strips were led to a galvanometer. When the disk was revolved the galvanometer needle was deflected; when it was revolved in the opposite direction, the indicator needle was reversed. Faraday visualized the disk in motion "cutting" the magnetic lines of force across the magnet's poles. In ten days of intensive work all the questions arising in his mind were resolved. On November 24 Faraday read a memoir before the Royal Society. This was supplemented by a detailed letter to Phillips sent from Brighton on November 29 in which the exhausted Faraday gleefully reviewed his success and projected further exploitation of his discovery. The substance, he wrote, was that "currents of electricity are formed in the direction of the radii; continuing, for every simple reason, as long as the motion continues, but ceasing when that ceases."

Faraday modified the essential elements, substituting wire loops for the disk, electromagnets with and without cores, disks of different metals, etc. The revolving loop showed an alternating current, whereupon Faraday rectified the current by a true commutator. He now had all the essential elements of a practical dc generator. The Jan-



USING the great horseshoe magnet of the Royal Society, Faraday revolved a copper disk at the poles and first generated a continuous electric current.

uary 1832 issue of the *Philosophical Transactions of the Royal Society* carried the first of Faraday's 29 papers on his electrical research.

The discovery of electromagnetic induction led to other important electrical developments, including recognition of self-induced current, polarity in diamagnetic bodies, lines and fields of magnetic force, and the use of induced current as a measure of field intensity. Advances in the field of electrochemistry followed, including the annunciation of Faraday's law of electrochemical decomposition, analysis of electric generation in the voltaic pile, and the general theory of electrolysis. He introduced new terms such as electrode, electrolyte, electrolysis, anode, cathode, ion, anion, and cation; the new vocabulary indicated Faraday's expansion into other fields of science.

Faraday established "specific inductive capacity" by comparing the dielectric properties of oil, sulfur, shellac, and glass with those of air. As a result of this contribution, the International Electrical Commission, at its meeting in Paris in 1891, termed the electrical unit of capacitance the *farad*. A second unit, honoring Faraday's contributions to electrochemistry, is the *faraday*; it represents the amount of electric charge carried by one gram-molecule of an ionized substance. Thus, Faraday has the rare distinction of having two units named for him.

Faraday's Bakerian lecture at the Royal Society in 1856 was his last contribution to that body. He held his final Friday night discourse at the Royal Institution in June 1862 and the final entry in his experimental notebook concerned the effects of magnetism upon a beam of light, although the instruments were too crude to be effective. (Zeeman was successful 35 years later and was awarded the Nobel Prize for this observation.) In 1865 Faraday transferred the directorship of research at the Royal Institution to his friend, Dr. John Tyndall. For his final years Queen Victoria offered a house at Hampton Court to be used by the Faradays as long as they lived; to this, after 1862, they retired. His eyes were finally closed there on August 25, 1867.

The heritage

Beyond the limitations of mathematical analysis of which he was capable, Faraday's experimental approach and intuitive resolutions opened channels of inquiry into which the Thomsons and Maxwells moved. He had written: "Nothing is so good as an experiment which, whilst it sets error right, gives an absolute advancement in knowledge." His concern, in his more mature years, with the universal forces of attraction were well analyzed in a recent biography by L. Pearce Williams. Faraday's concept of the line of force was "the physical line across the gulf that separated action-at-a-distance physics from field physics." Few of his contemporaries shared Faraday's notions of the line of force but staunch support was accorded it by Maxwell, whose paper, given before the Cambridge Philosophical Society in 1855, bore the title "On Faraday's Lines of Force," and in which he acknowledged his debt to Faraday. Two years later, in a long letter to Faraday, Maxwell wrote: "Now as far as I know you are the first person in whom the idea of bodies acting at a distance by throwing the surrounding medium into a state of constraint has risen, as a principle to be actually believed in." In the following two decades Maxwell developed the concept of field theory as the proper representation of electromagnetism.

Little could Faraday have dreamed, during his lifetime, of the vast and beneficent forces that his work was to bequeath to man.

Economics of indoor climate control

Modern heating and air conditioning systems should be able to provide complete temperature control throughout the entire year. There are many misconceptions, however, as to which systems are best

H. L. Laube *The Singer Company*

Of the many combinations of heating and air conditioning systems available, only a very few are capable of providing both heating and cooling throughout the year, at the tenant's discretion. The tenant of an office building, to be comfortably satisfied, must have a pleasant environmental temperature in which to work, provided by a system that is versatile and easy to control. One of the most promising of these is all-electric, completely decentralized, and economical.

Air conditioning for human comfort is a field of infinite variety. Spaces to be air-conditioned vary in size from a telephone booth to the Astrodome in Houston; and a vast assortment of available components comprise the building blocks for systems of countless variation. Any brief discussion pertaining to the economics of indoor comfort control cannot possibly cover all possible combinations of available equipment, structure size and usage, and climatic environment. Thus we will limit our consideration to privately owned buildings, since it is necessary for the private sector of our economy to be cost-conscious.

These buildings, from the standpoint of the air conditioning industry, include primarily apartment houses, dormitories, hospitals, hotels, motels, nursing homes, and office buildings.

As we approach our subject we will consider the usual factors pertaining to total owning and operating cost. But before proceeding with the matter of economics, two points should be made:

1. When the comfort air conditioning industry came into being 45 years ago, buildings were heated with combustible fuels exclusively. Heating systems had been centralized because, 40 or 50 years earlier, it had been learned that this was the only satisfactory method of heating buildings with combustible fuel. Hence, when cooling came along, it was natural to combine it with the central heating plant—and thus was born the central air conditioning system.

2. Anything concerning environmental control that can be done with a combustible fuel can also be accomplished with electricity. However, electricity can do what combustible fuels cannot do. And this uniqueness makes possible what, without electricity, was impossible: the fully decentralized comfort system for multiroom buildings.

First costs

The cost factor that most builders of privately owned multiroom buildings consider initially is first cost. Central air conditioning systems installed in multiroomed buildings generally range in first cost from 26¢ to 43¢ per watt* of refrigeration. The floor area that corresponds to 1000 watts of refrigeration is usually from 6.6 to 8.6 m^2 in an office building, to 10.6 to 11.9 m^2 in an apartment

* *Watt*, in the context of this article, applies to the thermal capacity of a heating or cooling system, as opposed to a unit of electrical consumption. One watt = 3.41 Btu/h.

house. The installed cost per square meter may be anywhere from $21.60 to $64.70—with some ill-conceived heat-of-light "energy conservation" systems running over $108.00 per square meter.

In contrast, the first cost of a fully decentralized all-electric system of the very highest quality may be $13.50 to $27.00 per square meter. A major developer of new downtown buildings has made the flat statement that the decentralized all-electric concept reduces the first cost of an office building by $21.60 per square meter, as against the use of a central system.

How, in addition to making financing easier, does this influence the profit and loss statement of a building? Today, 6 percent is a favorable rate for mortgage money. A $2.00 saving in first cost, amortized over 20 years, will add $1.87 per square meter per year to operating profits. Add 1 percent for insurance and 2 percent for taxes and this addition to profit is increased to $2.52 per square meter—or an increase in profit of $23 400 per year, for a moderately sized office building of only 9290 m² of rentable floor area. And let it be emphasized that this saving is in fixed charges only.

Operating costs

"Everybody knows that a multitude of small machines costs more to operate than one large central cooling plant." This was the general belief of the air conditioning industry until a few years ago, and is still widely believed today. In 1961, however, some surprising facts came to light concerning two semicentral comfort systems installed in office buildings in Philadelphia and Pittsburgh. The cooling function of these installations was accomplished with decentralized air-cooled refrigeration equipment, exactly the same as in fully decentralized all-electric installations. Instead of a radiator for heating, the equipment contained a heating coil supplied with steam or hot water from a central plant, thus making the system semicentral. Since these were existing buildings, they had to be rewired to supply energy to the cooling equipment. It was feasible to meter this energy separately, and this was done. The results showed that the 24-story Philadelphia building, with 11 140 m² of rentable floor space, had a total cooling cost, including maintenance and filter cleaning, of less than 97¢ per square meter per year.

In Pittsburgh the electric rate was a little less. The 26-story building there had a total area of 31 400 square meters. Of, this 25 600 m² was supplied by the semicentral system, and the corresponding total cooling cost was 86¢ per square meter per year. Neither figure means anything, however, unless it is compared with the corresponding cost for cooling in comparable office buildings in the same cities. Fortunately, such information is readily available.[1] In terms of average cost per square meter per year for cooling, 19 buildings in Philadelphia reported $2.45; in Pittsburgh, seven buildings reported $2.55. An analysis of these savings published more than three years ago still appears to be sound.[2] The savings were accomplished by overall seasonal energy utilization efficiency.

The general belief with respect to relative cooling costs of decentralized electric versus central fuel-fired systems applies even more strongly in the field of heating. In fact, the biggest obstacle to the sale of electricity for heating is the widespread conviction that operating costs will be excessive. Here again, facts are becoming available that indicate the need for a change of attitude. Consider, for example, a study of campus buildings made on behalf of the State of Pennsylvania a few years ago.[3] This study showed that the amount of heating energy being purchased for groups of buildings heated with fossil fuel from a central plant was four or five times as great as the energy required to heat similar buildings with fully decentralized electric heat. Gas at 6¢ per therm costs 57¢ per gigajoule; electricity at 1½¢ per kWh costs $4.17 per gigajoule. Thus, even if five times as much gas energy is needed for a specific load, it may be argued that at these rates it would still take $4.17 worth of electricity to do the work of $3.00 worth of gas. But this is not the whole story. It ignores the fact that on large fuel-fired systems the auxiliaries are normally operated by electricity, and it is necessary to add the cost of the electricity required to the cost of the gas.

Actually, a careful analysis of the energy cost to heat a 20-story 8350-m² office building in a 5000-degree-day* location indicates something of a standoff when using gas at 57¢ per gigajoule and electricity at $4.17 per gigajoule. Unfortunately, however, it is impracticable to confirm comparative feasibility studies. To do so would require two identical buildings in adjacent locations with identical occupancy and usage. Thus, the best we can do is to "look at the record." A case in point is the all-electric Nassif Building in Washington, D.C., which is occupied by the Defense Department and has a gross floor area of 25 300 and a net floor area of 21 300 m². Total energy cost for this building, including cost of equipment maintenance from May 1, 1964, through April 30, 1965, was $4.58 per square meter per year. The corresponding 1965 average cost for a group of Washington office buildings was $5.65 or 23.3 percent greater.[4] To the annual saving of $1.07 per square meter in operating cost must be added the significant savings in fixed charges made possible by the decentralized all-electric system plus the further saving resulting from its automation, making one or more operating technicians unnecessary.

The matter of occupancy

The key to the financial success of any privately owned multiroom building can be described by one word: occupancy. The higher the financial break-even point, the greater is the financial incentive to promote high occupancy. If the break-even point is 70 percent, then a reduction from 100 percent to 90 percent reduces profit by one third. If the break-even point is at 80 percent, then the same reduction cuts the profit in half. For 1965 the average break-even point reported by 598 office buildings in 94 cities was 75.7 percent.[4]

* A degree-day is a unit used to estimate fuel consumption and to determine the heating load of a building during the winter months. For a given day, the degree-days are computed by subtracting the mean outside temperature, in degrees F, from 65°F. Cumulative degree-day records are kept by the Weather Bureau during the heating season.

Present indications are that in some parts of the United States there has been overbuilding in the field of apartment houses, motels, and office buildings. After reaching an all-time peak of about 99 percent in 1946, the trend in occupancy of office buildings has been constantly declining. As of October 1, 1966, occupancy averaged 93.7 percent for 2297 buildings reporting.[5] The natural result is increased competition to hold present tenants and to get new ones.

Occupancy is influenced by location, cost, and prestige. But, other things being equal, one of the strongest influences is the tendency of the occupant to remain in or return to the place that has given him a completely satisfying indoor environment. Satisfied present occupants also give favorable referrals to potential new occupants; dissatisfied occupants give poor recommendations.

Forty years ago the availability of indoor cooling through the hottest summer weather was greeted with astonishment, as a modern miracle. Since then, although the available standard of indoor comfort has been creeping upward, the expectancy of occupants has been running ahead of what is available.

Part-time versus full-time comfort

The purpose of air conditioning is to assure the well-being of the occupants of the air-conditioned space, in terms of thermal, acoustic, and olfactory environment.

For our present purpose let us assume that all central, semicentral, and decentralized systems have an equally low and acceptable noise level. Let us also assume that they all do an equally good ventilating job. Although neither of these assumptions is true, they do enable us to compare systems on the basis of their relative abilities to supply individual building occupants with the thermal environment each desires.

Not all contemporary systems have an equal ability to provide individual occupants with a favorable thermal environment, but several systems of year-round air conditioning possess ability to provide full-time comfort, provided they are operated to the full extent of their capabilities. Other systems are lacking, irrespective of how they are operated. The minimum conditions necessary to achieve full-time comfort for the occupants of a multiroom building appear to be three:

1. The desired environmental conditions must already exist when the individual occupant enters the conditioned space.
2. The individual occupant must be in complete control of his environment while he is occupying the conditioned space.
3. A source of heating in winter and cooling in summer is not enough. Both heating and cooling must be immediately available, preferably at all times, but definitely during the changeable weather of spring and fall.

System capabilities

Generally speaking, systems of complete multiroom air conditioning belong in either of two groups: (1) those that cannot supply cooling while supplying heat, or vice versa; and (2) those that, by offering both, are capable of giving each occupant a choice of heating or cooling.

The most popular system in the first group is the so-called two-pipe fan-coil system. In winter it heats by circulating hot water through room cabinets. In summer it cools by circulating chilled water through the same pipes. Thus, the choice of the occupant is limited to heating or nothing, when the water is hot; cooling or nothing, when it is chilled. Full-time comfort is impossible with any system that gives all tenants heating when some want cooling, and vice versa.

To illustrate why some people need cooling while others require heat, consider this simple example: John Doe has his office on the south side of a building; Richard Roe has his on the north side. The offices are alike as to internal heat and ventilating loads, and we will assume that both men desire the same inside temperature. Each office has 9.29 m^2 of window area. It is a sunny October 21, at 40° north latitude in, say, Philadelphia. With drapes drawn, the sun nevertheless delivers an extra 3220 watts (11 000 Btu/h) to John Doe's office that is not received by the office of Richard Roe. Without detailed calculations it is thus obvious that:

1. On a certain sunny *mild* day John Doe's office requires 3220 watts of cooling, while Richard Roe's requires neither heating nor cooling.
2. On a certain sunny *cold* day John Doe's office requires no heating or cooling but Richard Roe's requires 3220 watts of heating.
3. On certain sunny *intermediate* days John Doe requires 1610 watts of cooling while Richard Roe requires 1610 watts of heat.

If then, on the intermediate day, hot water is being circulated, Richard Roe will be content but John Doe will not. And, if chilled water is being circulated, John Doe will be content and Richard Roe will ask the manager to "turn on the heat." In short, he will not be enjoying full-time comfort.

Let us now revert to the second group of systems—those capable of giving each occupant a choice of heating or cooling. The most popular of such systems are:

1. *Dual-supply fan-coil systems.* In these systems both centrally heated and chilled water may be available at the terminal element, and under the control of the occupant.
2. *Dual-supply induction systems.* Except for better ventilation, these systems differ significantly from the first group only in the manner in which room air is recirculated through the terminal element.
3. *Dual-duct systems.* In such systems one set of ducts offers warm air and the other cool air. A thermostat operates mixing dampers to provide the room temperature desired by the occupant.
4. *The semicentral system.* This system combines central heating and decentralized cooling, both (when central heat is available) being under the control of the occupant.
5. *The all-electric decentralized system.* This system is the same as (4) except that the heating is accomplished locally, by means of resistance elements, assuring full-time availability of both heating and cooling.

All of these systems have the capability of providing full-time comfort, depending, however, on how they are operated.

Operating practices

System capability is one thing, operating practice is quite another; and operating cost is an important factor in the case of privately owned buildings. Central boiler plants are not operated for heating in July nor are water-chilling plants used for cooling in January.

In the case of systems 1, 2, 3, and 4, the usual practice

is to operate by the calendar. Using Philadelphia as our example, heat may be turned off on May 15 and not turned on again until October 1. Water chillers may be started April 15 and turned off by November 1. Subsequently, a choice of both heating and cooling is available for only two months in the year.

Insofar as systems 1, 2, and 3, in particular, are concerned, there is another operating practice that prevents office building occupants from enjoying full-time comfort, illustrated by a sentence from the standard form used in New York City for office building leases: "Air conditioning shall be furnished by the landlord on business days from 8 A.M. to 6 P.M. except Saturdays when the hours shall be from 8 A.M. to 1 P.M." From this quotation it is obvious that building occupants who find it necessary to work evenings, holidays, or weekends, other than Saturday mornings, may have to do so in discomfort.

The problem is mitigated, in the case of semicentral system 4, since cooling is available at all times on an office-by-office basis. The decentralized all-electric system (5) eliminates it entirely; both heating and cooling are constantly and immediately available at full-rated capacity of the equipment.

An invention called a triple overriding dual control (TODC) contributes greatly to assure full-time comfort for all office building occupants in the case of the decentralized system. Impulses are sent from a central point to the individual air conditioners over the power wires to start all equipment in random sequence before offices open on business days, then shut it off at normal quitting time. Any occupant working late or on weekends simply touches a button to restart his local equipment, thus avoiding wasteful operation of unneeded equipment.

The central TODC control may be set for any schedule. Typically, it stops all restarted equipment at 9:00 P.M. and midnight every day, and equipment restarted on weekends or holidays at 5:30 P.M. After each shutdown any remaining occupant may again restart his equipment at the touch of a button.

Another factor interfering with the full-time comfort of occupants is equipment failure. If one component of a central system fails, occupants of the entire building are deprived of comfort until the component is repaired or replaced. In contrast, failure of one component of a decentralized all-electric system affects only one small space. Normal practice is to carry a small number of replacement components in stock. Thus, in a few minutes, the inoperative component may be replaced and service restored.

Why air conditioning?

When the owner of an office building or other multiroom structure invests in air conditioning, his action is predicated on the belief that doing so will assure the comfort of his building's occupants. It is obvious that if this comfort is provided on a full-time basis, the reaction of his occupants—the rent-paying tenants—will be more favorable than if only part-time comfort is offered.

This reaction is a powerful influence, an influence that many building owners, and most members of the air conditioning industry, have so far neglected. Unfortunately for building owners and agents, tenants do not neglect this factor. Occupants of multiroom buildings are demanding more comfortable working conditions.

The need for a method of rating air conditioning systems relatively, in terms of the comfort they actually supply, is becoming increasingly apparent. It is believed that a new concept, possibly called the "comfort factor," could be established for each type of system, based on its design and on the normally prevailing operating practices for each major application. Some five years ago the writer canvassed industry editors to ask if such a concept had, to their knowledge, been previously proposed. They answered in the negative, as did the then manager of research of the American Society of Heating, Refrigeration and Air Conditioning Engineers.

The expression "comfort factor" may be defined as the number of hours during which the occupant of a conditioned space has within that space those conditions that fully satisfy his desire for personal comfort, divided by the total hours of occupancy, and expressed as a percentage.

Multiroom buildings represent the field of application for which the comfort factor is the most readily adaptable. Unlike theaters, restaurants, or department stores, multiroom buildings provide an opportunity to treat the occupants as individuals. In this connection it should be emphasized that comfort is a completely personal sensation. Because people differ, clothes differ, health and metabolism differ, as do activities, such buildings provide the closest approach to a situation in which the full-time comfort of each occupant is possible.

In conclusion

Someone has said that when something has been done in a particular way for 15 or 20 years it is a pretty sure sign that there is a better way to do it.

The present central systems of air conditioning are basically dual-fuel systems. They use gas, oil, coal, or street steam in combination with electricity, and they have been on the market for over 20 years. During this time the people have demanded and achieved a constantly higher standard of living. In the light of this progress and these changes, let us now summarize:

1. The first cost of the decentralized all-electric comfort system—using the best available components—is significantly less than that of any central system capable of giving even approximately comparable results.

2. The operating cost of the decentralized system is no greater, and often less, than that of central systems.

3. The higher comfort factor offered by the decentralized system has a favorable influence on building occupancy and, thus, on the profit potential of the building in which it is installed.

Here, then, are the significant economic reasons that favor the all-electric decentralized comfort system. They are the reasons why builders of privately owned multiroom buildings should investigate the subject for themselves before deciding which comfort system and energy source to use.

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IEEE publications

scanning the issues
advance abstracts
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special publications

Scanning the issues

The National Academy. To those who are not organizationally minded or who by temperament are not "joiners," there may be something both depressing and bewildering in the vision of our society's tendency to proliferate ever more organizations. One may, of course, ignore the existence and role of these new social units but suffer from the decreased likelihood of making a decent livelihood; or one may try to "keep up" and suffer the exasperation and boredom of trying to penetrate the obscure generalities that organizational people usually perpetrate when they try to explain their missions in life. Then, of course, there are those types of people who have a passion for exploring the intricacies and minutiae of organizational lore. Were it not for the exceptional numbers of organizations, one might think such people to be in a minority. Perhaps not. In any case, whichever group you belong to—either those who couldn't care less or those who do—there is recommended for your attention a short ($2^1/_2$-page) and clear statement about the origin and role of the National Academy of Engineering by its president, Eric A. Walker. Inasmuch as all IEEE members have already demonstrated at least a minimal interest in organizations developed to the promotion of the engineering profession, it would seem a natural extension of this interest to become concerned with the functions of the NAE.

President Walker argues coherently the need for a distinctive academy of engineering at the national level. He makes the point that despite many efforts to build a truly representative voice of the entire engineering profession, none has entirely succeeded, and there has never existed a viable organization through which engineering advice and counsel could be made available to the government and brought to bear on large national problems—nothing, that is, comparable to the National Academy of Sciences (NAS), which for over a century has served this purpose for the scientific community. In fact, the founding of the independent National Academy of Engineering in December 1964 was expedited by the discovery that it could be formed under the NAS charter.

The NAE, which now has 95 members and is in the process of electing 100 more, is not merely an honorary society. When a man is elected to membership, he is expected to contribute by serving on a working committee and by participating in the Academy's activities.

The need for the Academy's existence, Walker says, is illustrated by the fact that its services have already been requested by a number of government agencies and bureaus. In fact, he says, it would be fair to say that the major characteristic of the operations to date has been that the Academy has been asked to undertake more projects than it can handle.

What kinds of projects is the NAE becoming involved in? A Committee of Public Engineering Policy has been set up, the counterpart of a similar NAS committee, but with the emphasis on the engineering aspects of large national problems rather than the scientific. A Projects Committee has been set up to screen the numerous proposals being made to the Academy. For instance, should NAE concern itself with engineering education? Walker says, obviously this is an area of importance to the profession and to the nation, but it is also an area in which many groups are already very active. What part, if any, then should the Academy play?

Another typical kind of problem on which the Academy should be able to offer good advice is on whether or not the government should become involved in the engineering and development of commercial aircraft. To answer this, NAE has set up a Space Engineering Board at the request of NASA.

What about bioengineering? The Academy has been asked by the National Institutes of Health to provide advice and direction on potential engineering developments in medicine and biology. Another committee has been formed to study the problems of the control of wastes in air, water, and on the land. As Walker points out, there is certainly no lack of work to be done.

All engineers should be awake to the growth and evolution of the National Academy. Those who thus far have been ignorant of its existence might begin by reading Eric Walker's account. (*IEEE Trans. on Industry and General Applications*, May/June 1967.)

Fast Fourier Transform. A technique that substantially reduces the time required to perform Fourier analysis on a computer, called the fast Fourier transform, is the subject of a special issue of the IEEE TRANSACTIONS ON AUDIO AND ELECTROACOUSTICS. The significance of the technique is brought out in a Guest Editorial by Bruce P. Bogert. He notes that although the application of the digital computer to audio signal processing (particularly speech processing) has followed the explosive growth of application in other fields, it has not found its fullest utilization in the audio field. This is because digital technology has been restrained by the complexity associated with the transformation between time and frequency. Many signal processing operations involving manipulation in the time domain are easy to carry out accurately and flexibly in digital terms, but only recently did the translation from time into frequency, or vice versa, become an operation of equal ease.

In 1965, a paper by J. W. Cooley and J. W. Tukey described a recipe for computing Fourier coefficients of a time series that used many fewer machine operations than did the straightforward procedure. This saving in computation, Bogert points out, can amount to a factor of as much as several hundred for usefully long stretches of data. About the same time, in 1965, G. Sande at Princeton University developed another algorithm of the same class. He used it to calculate covariances with equally im-

pressive savings, although not of the same magnitude. Procedures that provide reductions in complexity of this order, Bogert asserts, may rightfully be called breakthroughs.

After the publication of Cooley and Tukey's paper a number of earlier papers were discovered describing the essentials of the fast Fourier transform. In fact, it turns out that the fast Fourier transform algorithm has a long and interesting history behind it that was appreciated only after the Cooley and Tukey work. This history is recounted in this special issue in "Historical Notes on the Fast Fourier Transform" by J. W. Cooley, P. A. W. Lewis, and P. D. Welch. As Bogert puts it, what had happened had happened often in other fields. The early papers appeared too early. They solved a problem whose importance had not, up till that point, been adequately recognized.

Besides making digital spectrum analysis more attractive from an economic standpoint, the fast Fourier transform has changed the concepts of digital filtering, in that the intellectually appealing approach of filtering in the frequency domain is now very often simpler and quicker than by convolution, even though two transforms between time and frequency are employed.

In the use of digital systems, Bogert says, the important barrier between the time and frequency domains has been significantly lowered. Given the on-going intensive and widespread development in digital circuit technology, this means that many new applications for digital processing will be opened up. The audio engineer, Bogert goes on, who naturally thinks only in terms of analog processing might well become familiar with what the digital approach is now able to offer. He may be surprised. (*IEEE Trans. on Audio and Electroacoustics*, June 1967.)

VSCF Systems. An advance in the field of power generation is evidenced in a conference panel discussion reported in the current issue of the IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS. The session deals with high-speed (20 000-r/min) solid-state rectification. A number of speakers at the panel discussion gave status reports on various aspects of VSCF (variable-speed constant-frequency) systems. W. T. Beatson of Naval Air Systems Command, moderator of the session, said that circuitry presented in AIEE meetings in the mid-50s had indicated the possibility of a static regulation system for ac aircraft power. By 1959, semiconductors were big enough to make engineers think in terms of power. In the past seven years, Beatson went on, much has been done in Defense Department-sponsored research and development and in development programs by private companies.

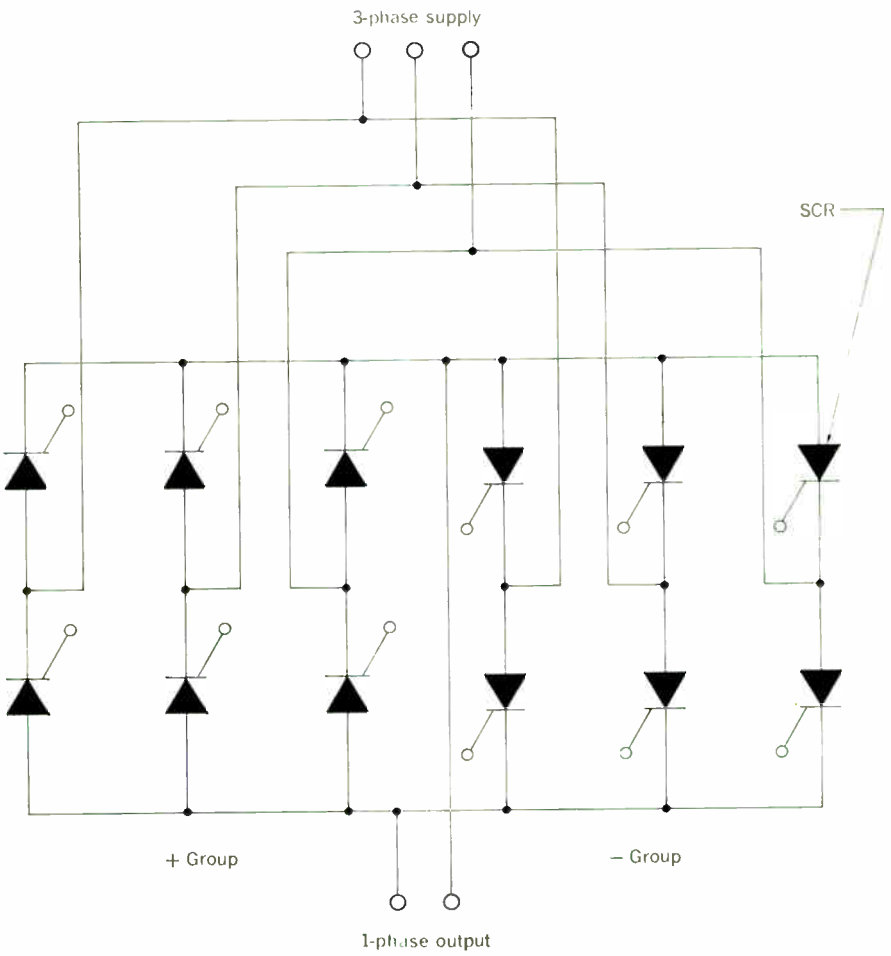
Among the speakers reporting on the advances of these years was S. Gail of Lear-Siegler, who talked on the "Design Approach to VSCF Generators." He described the problems of high-speed systems, up to 20 000 r/min, and predicted a good production system in the near future.

L. J. Lawson of Lear-Siegler talked about "A Practical Cycloconverter for Aerospace Power Systems." The key component of an aircraft VSCF system, he pointed out, is the static frequency converter. He asserted that extensive studies have shown that a modern implementation of the classic cycloconverter is the most suitable circuit configuration capable of producing the desired 400-Hz power. A practical cycloconverter-type frequency changer has been completed and tested, and has gone into limited production. The cycloconverter circuit consists of two three-phase full-wave rectifier bridges, one for the positive current flow into the load and the other for the negative current flow. It takes three of these circuits, using 36 thyristors, for a three-phase cycloconverter. The circuit of a single-phase full-wave cycloconverter appears in Fig. 1.

Other speakers and their subjects were as follows: D. Plette of GE on "Advances in VSCF System Technology"; B. West of GE on "Generators for VSCF Systems"; K. Chirgwin of AiResearch on "Hybrid VSCF Systems"; and M. Wall of The Boeing Company on "VSCF Aircraft Generating System Performance."

Evidently, future progress on bringing out potential advantages of VSCF systems depends, according to D. Plette, on the imagination and the desire for progress of the entire aerospace electrical industry, including government agencies, aircraft users, airframe manufacturers, utilization-system builders, and generating-system suppliers. K. Chirgwin also stresses cooperation. Let's get together, he says, and figure out a way to take advantage of this new type of technology. (*IEEE Trans. on Aerospace and Electronic Systems*, July 1967.)

FIGURE 1. Single-phase full-wave cycloconverter.



Advance abstracts

The IEEE publications listed below are abstracted in this issue. The publications will be available in the near future. Information on prices may be obtained from IEEE, 345 East 47 Street, New York, N.Y. 10017. Please do not request copies of individual articles, as they are not available.

Proceedings of the IEEE	Vol. 55, no. 7
IEEE Transactions on	
Aerospace and Electronic Systems	Vol. AES-3, no. 5
Automatic Control	Vol. AC-12, no. 4
Education	Vol. E-10, no. 3
Electron Devices	Vol. ED-14, no. 7 & 8
Electronic Computers	Vol. EC-16, no. 4
Geoscience Electronics	Vol. GE-5, no. 2
Industry and General Applications	Vol. IGA-3, no. 3
Information Theory	Vol. IT-13, no. 3 & 4
Magnetics	Vol. MAG-3, no. 3
Microwave Theory and Techniques	Vol MTT-15, no. 8 & 9
Power Apparatus and Systems	Vol. PAS-86, no. 7
Solid-State Circuits	Vol. SC-2, no. 2
IEEE Journal of Quantum Electronics	Vol. QE-3, no. 8

Proceedings of the IEEE

Vol. 55, no. 7, August 1967

(Special Issue on High-Power Semiconductor Devices)

Silicon Power Device Material Problems, *H. F. John*—The limitations imposed on the performance of large-area p-n junction devices by the size and quality of the silicon material are reviewed. It is shown that material quality problems—such as nonuniform resistivity, foreign particulate matter, microdefects, dissolved oxygen, and various crystallographic defects—represent real limitations on device performance and yields; however, the effects of process-induced defects—such as diffusion or stress-induced dislocations, diffusant precipitation, heavy metal precipitation, and interface degradation—often obscure, or even overwhelm, the effects of the grown-in defects. The importance of the interaction of process-induced defects with grown-in defects, and particularly the interaction of heavy metals with defects, foreign particulate matter, and dissolved oxygen, has been emphasized by the results of recent investigations. The need for defect-free processing techniques in obtaining information on the effects of grown-in defects is discussed. Representative studies of the effects of defects on device performance are listed. New techniques for studying defects are reviewed with reference to results of interest to silicon device technology. Some growth techniques that may be helpful in eliminating certain material quality problems are discussed briefly.

Second Breakdown—A Comprehensive Review, *H. A. Schafft*—A comprehensive review is presented of the published literature dealing with the phenomenon of second breakdown in semiconductor devices and the problems it creates in the design, fabrication, testing, and application of transistors.

Power Thyristor Rating Practices, *J. S. Read, R. F. Dyer*—The power thyristor is the most important semiconductor device used in the control of electric power. An explanation of thyristor ratings and rating presentation is required for the complete understanding and successful application of these devices. The meaning of thyristor temperature, voltage, current, and gate ratings is explained, and insights are presented into how these ratings are developed. Both the semiconductor controlled rectifier (SCR), which is properly called a reverse blocking triode thyristor, and the bidirectional thyristor rating methods are discussed. The SCR rating methods are further divided into those applying to phase control applications at power frequencies and those applying to high repetition rate inverter and pulse current applications.

The di/dt Capability of Thyristors, *S. Ikeda, T. Araki*—An experimental investigation of the *di/dt* failure mechanism of thyristors is described. The location of the initial turn-on region and the spread of the "on" region were observed on a specially designed thyristor having many monitoring electrodes. The turn-on process was studied for triggering by gate, by break-over, and by *dv/dt*. In many cases it was found that turn-on occurred at almost the same region, whether it was triggered by break-over or by *dv/dt*. This area coincided with the final holding position in the turn-off process. The *di/dt* capability of the thyristor was measured. It was found that the capabilities were almost the same for the three triggering methods. The destruction temperature in the *di/dt* test was estimated from the area of the burn-out spots and the energy dissipation.

Behavior of Thyristors Under Transient Conditions, *I. Somos, D. E. Piccone*—The capability of gate-triggered thyristors to withstand steep-wavefront, high-current pulses (i.e., *di/dt* capability) is a function of both junction temperature and frequency of operation. Localized internal heating occurs during turn-on and may lead to thermal runaway. The conditions required for this to occur have been determined by destructively testing many devices. The initial conducting area of a thyristor largely determines *di/dt* capability, which is not necessarily related to the size of the device but is a function of the design of the gate region. Two devices that have been designed to increase the initial conducting area are described. However, gate drive is very important in determining the *di/dt* capability of a thyristor and in some cases too much gate drive may actually reduce the device's capability. This characteristic can be studied by observing the reverse recovery current immediately following short forward current pulses.

Bidirectional Triode Thyristor Applied Voltage Rate Effect Following Conduction, *J. F. Essom*—The bidirectional thyristor commutation effect, which involves the rate at which off-state voltage can be applied following current flow, is described. This effect is contrasted to the circuit commutated turn-off time effect associated with semiconductor controlled rectifiers. To help describe the commutation effect in bidirectional devices, two common circuit applications are discussed. A test method is introduced for characterizing the commutation behavior as a function of all operating conditions. A great deal of quantitative information about the commutation effect is presented for a typical medium-current bidirectional triode thyristor.

p-n-p-n Charge Dynamics, *R. L. Davies, J. Petruzella*—A simple unified charge model applicable for both unsaturated and saturated p-n-p-n dynamic behavior is analyzed. Expressions are obtained for three important dynamic conditions, *di/dt* prior to saturation, voltage drop during turn-on, and reverse current during recovery. Comparison with measurement shows that interdigitated gate p-n-p-n devices match one-dimensional turn-on theory and closely approximate the behavior of p-i-n rectifiers under similar pulsed conditions. The major analytical simplifications of the one-dimensional theory are examined. The limitations imposed by these simplifications can be avoided by use of numerical integration techniques.

Reverse Recovery Processes in Silicon Power Rectifiers, *H. Benda, E. Spenke*—A number of investigations recently carried out in the Semiconductor Laboratory, Siemens AG, Pretzfeld, Germany, are described. The switching processes in power rectifiers from the forward into the reverse state differ greatly from the corresponding processes predicted by low-level theory. This result is caused not only by the fact that the conditions are different for high injection, but also because the sweeping out of the charge carriers takes place from two sides, owing to the nearly uniform concentration distribution in the forward state. Because of the unequal electron and hole mobilities, the impurity distribution on the side of the p contact is of much greater importance than at the n contact; if there is no p-n junction on this more important side, then the stored charge can be swept out without much voltage buildup (for example, rectifiers from uniformly doped p material). If, on the other hand, a p-n junction lies before the p contact (for example, rectifiers from uniformly doped n material), then the reverse recovery current decays soon but slowly, and the switching process takes a longer time. This fact also contributes to the relatively long turn-off time of the thyristors.

Protection of Semiconductor Devices, Circuits, and Equipment from Voltage Transients, *B. Reich*—A survey is presented on the means that can be applied to the suppression of voltage transients that can affect the reliability of equipment and systems employing semiconductor devices. Consideration is given to some of the ways transients are generated, their duration and magnitudes, and the approach taken in MIL-STD-704 in confining the power supply characteristics within definite limits which must

be tolerated by the utilization equipment. Emphasis has been placed on the various techniques that can be applied in suppressing transients generated from 28-volt dc power supplies and their advantages and limitations. In addition, various device approaches used to limit voltage transients to rectifier diodes are presented.

Power Absorption Capability of Punch-Through Devices, *J. H. King, J. Philips*—The power-absorption capability and high-current characteristics of silicon high-voltage punch-through structures are investigated. Impact ionization is observed in the devices using 100- and 75-ohm-cm base material. The transient power absorption capability of these structures is found to be less temperature-dependent than that of avalanche devices. With proper surface contouring, a power absorption capability of 48 kW/cm^2 at 10 μs is achieved at a junction temperature of 26°C and 38 kW at 200°C for devices made of 350-ohm-cm base material.

Graphical Analysis of the I-V Characteristics of Generalized p-n-p-n Devices, *J. F. Gibbons*—A new form of the basic equation for the *I-V* characteristics of a generalized p-n-p-n device is derived. Approximations are then introduced to obtain a simplified basic equation in which all current-dependent terms appear on one side of the equation and all voltage-dependent terms on the other. A graphical technique for solving the simplified device equation is then described and used to develop and illuminate the family resemblance among a large number of related p-n junction devices; viz., the p-n junction diode, the p-n-p diode, the p-n-p transistor, the p-n-p-n diode, and the p-n-p-n triode.

A Theory and Some Characteristics of Power Transistors at High-Level Conditions, *O. Jäntsch, I. Feigt*—The concentration of injected carriers is large compared with the impurity doping concentration in the base region of a power transistor operating at a high level. Carrier concentration and characteristics of a two-dimensional transistorized model are calculated for this case. Emitter and base contacts are in the form of strips. Most of the injected emitter current reaches the collector while the remainder recombines in the slightly doped base region under the emitter, resulting in a current in the highly doped base contact. In addition, a recombination current generated in the base region under the base contact is added to this base current and results in a decrease of current gain. In order to analyze the base recombination current, a special transistor with divided collector contacts was prepared. In this way the collector current due to the region under the emitter contact can be separated from the collector current due to the region under the base contact. The theory presented could be verified. Additional corrections are necessary, however, in the direction of the current in the slightly doped base region.

The Saturation Characteristics of High-Voltage Transistors, *L. A. Hahn*—It is shown that the saturation characteristic of high-voltage n-p-ν-n transistors can only be explained by a lowering of the ν-layer resistance due to conductivity modulation. A semiquantitative model is developed that explains this modified saturation region. An experimental method of isolating the resistive portion of the external collector-base voltage is presented. The results verify that the CB junction may be forward-biased even when the characteristic seemingly indicates that the transistor is unsaturated. Data are also presented showing how variations in collector resistivity and thickness alter the saturation region.

The Potential and Carrier Distributions of a p-n-p-n Device in the ON State, *R. A. Kokosa*—The potential and carrier distributions of a p-n-p-n device in the ON state are measured by electrical and optical probing techniques. The measurements are compared with numerical calculations of the potential and carrier distributions and the current–voltage characteristic as a function of device temperature. The calculations are based upon an analysis of the p-n-p-n device at high current densities using an abrupt junction model and including the effects of carrier-carrier scattering, conductivity modulation, and the dependence of emitter efficiency upon current density. The conditions under which the p-n-p-n device may be approximated by a p-n-n$^+$ device are also considered. The range of applicability of the results includes all ON currents of practical interest in a p-n-p-n device.

The Forward Characteristics of Thyristors, *M. Otsuka*—A theory on the forward *I-I* characteristics of p$^+$-p-n-p-n$^+$ thyristors is proposed. Taking account of the minority carrier lifetime in the base region, the effects of the device structures on the forward characteristics are discussed in the following three cases: (1) low-level operation, (2) middle-level operation, and (3) high-level operation. At the middle-level operation, the term that is independent of current, and at the high-level operation the $\sqrt{I}$ dependency appear in the forward characteristics of the thyristors. The general theory is illustrated by reference to experimental results on silicon-controlled rectifiers.

High-Voltage Planar p-n Junctions, *Y. C. Kao, E. D. Wolley*—A concentric ring junction has been devised to prevent surface breakdown of a planar junction. By properly choosing the spacing between the main junction and the ring, the ring junction acts like a voltage divider at the surface. In addition, the ring junction minimizes the effect of the junction curvature at the periphery of a planar junction. Devices fabricated with three such rings showed breakdown voltages of 2000 and 3200 volts on n-type silicon with impurity concentrations of 6.5×10^{13} and 2.5×10^{13} cm^{-3}, respectively. That the structure operated as proposed was corroborated by comparison of the reverse leakage current with a one-parameter fit to a theoretically calculated current obtained from the approximated volume of the space-charge regions. These results together with the photoresponse measurements indicate that the field-limiting ring junction can be used successfully to obtain high-voltage planar p-n junctions.

High-Power Pulsed GaAs Laser Diodes Operating at Room Temperature, *H. Nelson*—The fabrication and characteristics of a high-power GaAs injection laser for room-temperature operation are described. A single laser emits 100 watts peak power from one facet at four times the threshold current. The diodes are fabricated from epitaxial wafers prepared by the solution-growth process. Scaling from work on low-power (7 watts) units to this high power has been accomplished by increasing the junction width, which requires general improvement in the crystalline quality and in the control of the doping. Data are given on the effect of doping density crystal quality, and imperfections near the junction, as well as junction width. The reduced yield in high-power diodes, of which only one third from a single batch give the desired output, is associated with filamentary lasing and with superradiant walk-off modes, neither of which is under full control. Preliminary data on life tests show that long-lived units can be made, but that apparently identical units from the same batch show wide variations in the rate of degradation.

Coherent Amplification Characteristics of a GaAs Phased Array, *R. Vuilleumier, N. L. Collins, J. M. Smith, C. S. Kim, H. Raillard*—The coherent amplification properties of anti-reflective coated GaAs diodes are considered for application to a phased array amplification scheme. The development and design characteristics of a ten-element array system are discussed. An experimental diode array possessing good electrical and spectral match among diodes and excellent thermal dissipation is shown to provide optical gains, for main master laser modes, of at least 13 dB per array diode after coating. Temporal and spatial coherence within a GaAs laser spot, approximately 35 μm wide, is found to be adequate for array amplification purposes. The effects of array amplification on an incident coherent beam are evaluated by comparing predicted fringe patterns with observed interference patterns. The coherence of the incident beam is shown to be preserved during amplification.

Consumer Applications of Power Semiconductors, *R. Greenburg*—Power semiconductors—transistors, thyristors, and rectifiers—all have found widespread application in the three major consumer markets—automotive, entertainment, appliance. These devices have been developed to provide low-cost solutions to existing needs. In the mid-1950s, the germanium power transistor, as used in hybrid auto radio sets, was the sole power semiconductor represented in a consumer application. It was soon joined by rectifiers designed for power supply use in line-operated television sets. Near the turn of the decade, the development of press-fit alternator rectifiers created a completely new consumer use. Today these devices in only slightly modified form are used for the original application as well as a host of allied uses. Recently power thyristors expressly designed for appliance controls have opened up entirely new concepts in this market area. Upwards of 200 million power semiconductors are used in consumer applications each year. As technology progresses, indications are that this market will more than double in the next few years as triaes and quadraes open new appliance markets, as high-voltage power transistors phase into television, and as alternator regulators switch to large-area integrated circuitry. Whether the market is automotive, appliance, or entertainment, and whether the application is audio, phase control, or switching, the penetration of power semiconductors into consumer use has followed a history of applying advanced device technology directly to a market opportunity. The successes have always been the result of providing lower costs, a better way, or in adding value to the consumer product. The features of consumer power devices and their applications that make them different from their predecessors are discussed.

Flat Packaged Thyristor Assembly for High-Voltage Application, *T. P. Nowalk, H. E. Ferree, T. C. New*—Applications for high-power thyristors continue to increase at an accelerated pace. The circuit designer (user) and device designer (producer) have attained a high degree of maturity in their respective areas of interest and in the joint effort of mating the device to this application for optimum performance. Recent developments in the device encapsulation design area that are directed to tailoring thyristors for high-power, multikilovolt service are described and analyzed. The use of conventional thyristors in an application requiring, for example, 100 kV of holdoff capability, presents a number of problems. The physical layout alone is quite extensive, considering perhaps 100 devices plus balancing networks, anode reactors, firing circuitry, etc. Also, one must properly cool the aggregate of units which may be dissipating on the order of 25 kW. A thyristor encapsulation and stack module specifically designed to fulfill the requirements of high-power multikilovolt applications are described. Compression bonded encapsulation and integral heat sink design principles are employed. Stack modules for forced air cooling and oil cooling applications are reviewed. Particular note is made of a radar modulator application and, more recently, the projected use in high-voltage dc transmission-line converter stations. Mechanical and thermal design features are emphasized. Potential application

of the devices in conventional bridge-type arrays is explored.

Use of Power Semiconductors to Control Locomotive Traction Motors on the French National Railways, *F. Nouvion*—The application of semiconductor rectifiers and thyristors in the control of power to ac, dc, and diesel-powered locomotives on the French National Railways is presented. Since 1959, 260 locomotives have been equipped with 60 000 semiconductor rectifiers. The failure rate of these rectifiers has been 0.12 percent or 1.35 percent for every million kilometers traveled. Four locomotives have been equipped with thyristor control circuits and it is anticipated that all future single-phase ac powered locomotives will use thyristors.

Oscillator-Circuit Thyristor Converters for Induction Heating, *E. Golde, G. Lehmann*—For the induction heating of metals it is advisable in many cases to use higher frequencies. So far, the input required has been supplied by rotary converters or high-vacuum valves. Recently, static converters with thyristors have also been employed. A plant already installed is described, and details are given on the considerations leading to the solution adopted.

High-Power Thyristor-Battery Drive for High Peak, Low Average Power Pulse, *V. Wouk*—High-power thyristors are employed with a battery to provide constant voltage to a one-quarter-megawatt dc load for one-half second, in order to opefate a sonar transducer at a pulse repetition period of ten seconds. Despite the heavy pulse power and the low duty cycle, the power drawn from the mains is maintained almost constant at approximately 12.5 kW, with less than 5 percent variation over a power pulse cycle. The system utilizes a battery for energy storage, in conjunction with a phase-controlled ac line to charge the battery at essentially constant current. The availability of high-power thyristors for a high-frequency inverter-type dc-to-dc converter makes the entire concept feasible, as the battery voltage drops substantially during the pulse. The inverter is pulse-width-controlled during the output power pulse, to maintain the dc output voltage constant within 3 percent during the power pulse. Basic circuits are described for providing the high peak power to the load and maintaining virtually constant average power drain from the source over the entire cycle.

Stability Problems in Transistor Power Amplifiers, *O. Muller, W. Figel*—For devices to be useful, they must be applied in circuits. Expensive power transistors can be destroyed by undesired oscillations and instabilities. Furthermore, troublesome unwanted spurious frequencies must be avoided. The problem of stability is complicated by the fact that a class C amplifier represents the superposition of a linear class A amplifier and a nonlinear circuit as soon as a direct current is flowing. Therefore, linear and nonlinear instabilities can occur. Different physical transistor effects that could be responsible for such instabilities are discussed. An attempt is made to clarify several aspects of the stability problem in RF power amplifiers. It is shown that this problem can be solved, at least to a certain extent, if one increases the stability of a hypothetical superimposed class A amplifier in the critical frequency range $F_1 < F < F_2$. In this region the transistor is potentially unstable due to internal feedback. The upper limit F_2 of the critical frequency range is given approximately by one half the transconductance cutoff frequency. F_2 may be much lower than the operating carrier frequency. Rules for the design of stable RF power amplifiers are given.

Power Regulation and Control Using Multifunctional Integrated Circuits, *M. L. Embree, P. D. Fisher, B. H. Hamilton*—The rapidly advancing integrated circuit technology is making practical the inclusion of increasing numbers of circuit functions in small individual packages. In power applications, the most significant effect will be the reduced cost of regulating small amounts of power. The magnitude of cost reduction for high-performance regulators at fractional-watt power levels is great enough to open new possibilities for decentralizing the power regulation function. A versatile, high-performance, integrated voltage regulator circuit is described. This integrated circuit features excellent decoupling from the power source, insensitivity to load and temperature variations, and provision for switching off power to the load. Particular aspects of the integrated circuit development discussed include temperature compensation, stability, noise, and close tolerance on output voltage. By adding external components, the integrated circuit can be used to perform a number of operational functions. Examples are given of possible applications of the integrated circuit to the control of larger devices for regulating power at high levels and as a voltage sensor for actuating various alarm and protection functions.

Proceedings Letters

Because letters are published in PROCEEDINGS as soon as possible after receipt, necessitating a late closing data, we are unable to include a list here of the letters in the August issue of PROCEEDINGS. The list will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 55, no. 7, July 1967.

Electromagnetics and Plasmas

Comments on "Optimization of Beam Efficiency and Synthesis of Nonuniformly Spaced Arrays," *H. A. Shubert, J. K. Butler, H. Unz*

Dominant Mode Reflection at Circular Horn Junctions, *E. Gillitzer*

On the Radiation Fields of Rhombic Antennas Buried in Snow, *C. M. Knop, T. Charlton*

Comments on "Guided Waves in a Simple Moving Medium," *H. Berger, J. W. E. Griemsmann, T. Shiozawa*

Surface Current of a Locally Flat Conductor and Depolarized Backscatter, *P. Beckmann, A. K. Fung*

A Theorem in the Field of Steady Current Flow, *M. Tsukada*

Total Reflection at the Interface Between Relatively Moving Media, *T. Shiozawa, N. Kumagai*

Circuit and System Theory

The Relationship Between Noise and Impedance Matching in a Negative-Resistance Amplifier, *M. L. Attanasio-D'Atri, G. Martinelli*

Parallel Connection of *n*-Port Networks, *V. G. K. Murti, K. Thulasiraman*

A General Invariance of the Ratio of Open- and Short-Circuit Impedances for Liner *n*-Port Networks, *J. Andersen, W. H. Ku*

Analysis of the *n*-Wire Exponential Line, *E. C. Bertnolli*

A Note on Equicofactor Matrices, *G. E. Sharpe, G. P. H. Styan*

On the Stability of Ideal Transformer Realizations with Active Elements, *V. Cimagalli*

Closed-Form Solutions of Linear Stationary State Equations, *M. L. Liou, W. R. Broyles*

Electronic Circuits and Design

A Self-Compensating Lumped Element Broadband HF Directional Coupler, *R. D. Wanselow, D. W. Milligan*

An Analog Multiplier, *G. W. Beene*

Comment on "A Bistable Flip-Flop Circuit Using Tunnel Diode," *Z. C. Tan, P. C. Maxwell, V. Uzunoglu*

Nanosecond Word Generator Using Boff Diodes, *T. V. Attwood*

Frequency Multiplier Using a Charge-Storage Diode in an Inductive Circuit, *D. J. Roulston*

Comment on "Dual-Input *RC* Null Networks," *U. S. Ganguly*

Electronic Devices

Anomalies in Transistor Low-Frequency Noise, *T. C. Verster*

A Dual Offset Gate Thin-Film Transistor, *R. G. Wagner, G. C. Breitweiser*

Experimental Results with a New Lower-Frequency Pumped Parametric Amplifier, *M. Pommereit*

Capacitive Feed-Through Calculations in MOSFETICs, *R. H. Crawford*

High-Power Pulsed Avalanche Diode Oscillators for Microwave Frequencies, *M. Gilden, W. Moroney*

Multimode Operation in Gunn Oscillators Induced by Cooling and Illumination, *K. G. Sewell, L. A. Boatner*

On Electromagnetic Gain Mechanisms in Solid-State Plasmas, *M. R. Wohlers*

Temperature Sensitivity of Compound Diode-Transistor Structure, *C. R. Hoffman*

A Piezo-Mesh-Diode Pressure Transducer, *F. Krieger, H.-N. Toussaint*

Digital Logic-Circuit Applications of Gunn Diodes, *H. L. Hartnagel*

An Epitaxial GaAs Field-Effect Transistor, *W. W. Hooper, W. I. Lehrer*

Optics and Quantum Electronics

Harmonic Mixing and the Heterodyne Detection of Laser Radiation, *L. Frenkel*

A New Laser Line in Tin Using Stannic Chloride Vapor, *W. C. Carr, R. W. Grow*

Comments on "Laser Wave Propagation Through the Atmosphere," *A. Saleh, H. Hodara*

The Far-Infrared Stimulated Emission Spectrum of D_2O, *W. Q. Jeffers, P. D. Coleman*

Communication Theory

Ternary Sequence with Zero Correlation, *J. A. Chang*

A Useful Property of the Generalized Chirp Signal Ambiguity Function, *M. A. Lipman*

Control Systems and Cybernetics

Multivariable Control System Synthesis Utilizing the Generalized Inverse of a Matrix, *W. S. Schaffer*

Quantization Error Bounds for Hybrid Control Systems, *A. K. Newman*

Miscellaneous

CORAD (Color Radar), *M. G. Kaufman*

Evaporation of Electric Wire Electrodes Caused by AC Arc Discharge of Heavy Currents, *M. Sugawara*

Magnetic Field Shaping for Linear Dispersion in YIG Pulse Compression Filters, *R. W. Damon, H. van de Vaart*

High-Voltage Distribution Measurements Using Different Sphere Gaps, *M. K. Gohar*

Increased Resistance of Crystal Units at Oscillator Noise Levels, *M. Bernstein*

IEEE Transactions on Aerospace and Electronic Systems

Vol. AES-3, no. 5, September 1967

The Solar System Environment, *S. Miluschewa*—The description of the planetary and interplanetary environments presented is based on the latest available experimental data, or otherwise typical, quantitative information, which can be used for the preliminary estimates of a given mission requirement.

Enhancing Maintainability of the AWG-10 Through Built-In-Test Equipment, *E. Cloud*—Multimode airborne weapons systems are now a reality. Because of the increased complexity of these systems, excessive maintenance time has become a problem. An approach to reducing maintenance time through the use of semi-automatic built-in-test equipment within the framework of an integrated maintenance program is described. Emphasis is placed on the methods and hardware involved in the built-in-test mechanization, as well as describing the

development history of this type of maintenance concept.

Correlation Function and Power Spectrum of Randomly Shaped Pulse Trains, *O. Leneman*—A new and simple technique is presented for evaluating the correlation function and the power spectrum of a randomly shaped pulse train, defined as

$$y(t) = \sum_{n=-\infty}^{\infty} h_n(t - t_n)$$

where the $\{h_n(\cdot)\}$ are random functions that describe the shape of the pulses, and where the random occurrence times $\{t_n\}$ constitute a stationary point process. The obtained results are very simple and various illustrations are given.

Calculation of Output Noise Variances for Discrete Time-Invariant Filters, *D. Russo*—Certain calculations to minimize output noise variance are introduced. Many applied problems in sampled data systems require that data be smoothed in the presence of noise for the prediction of future positions, velocities, or accelerations. Smoothing coefficients in discrete time-invariant filters are computed to minimize the output noise variance, but under the constraints that the function and derivatives be predicted ahead. The output noise variance is seen to be a function of the input noise, the number of input signals ($N + 1$) that the filter has to smooth, and the prediction time αT. Four examples are given in the derivation of smoothing coefficients for step and ramp inputs subjected to either almost white noise or Gaussian–Markoff noise. The examples illustrate the number of constraint relations that the filter-smoothing coefficients must satisfy for function and/or derivative convergence under noise-free conditions. The smoothing coefficients are also a function of the type of noise input into the system or the discrete filter. From the examples, it can be observed that as N becomes larger, the output noise variance becomes smaller, but the computation time is increased.

Performance Measures for Compressed and Coded Space Telemetry Systems, *T. Lynch*—The considerations involved in the combination of data compression and error-control coding in space telemetry are analyzed through the use of two performance measures, D and R, which are similar to those used by Shannon for his rate distortion function. The average distortion D is a function of the source probability distribution, the overall system transitional probability matrix, and a cost matrix that signifies the relative importance of different types of data errors. The rate ratio R is the reciprocal of the overall system compression ratio and includes the data expansion effect of additional timing and identification data as well as coding redundancy. The effects of the following system parameters and properties on the overall distortion and rate ratio are analyzed the error-control usefulness of natural data redundancy, the effect of errors in time information, the use of the strict monotonicity of the time information for error control, the probability distribution of the source, the bit-error probability of a binary symmetric channel, and the word-compression ratio. A rationale for comparing and choosing among three systems—uncompressed-uncoded, compressed-uncoded, and compressed-coded—is given in terms of performance measures D and R.

A New Algorithm for Strapped-Down Inertial Navigation, *J. Wilcox*—When a whole-number digital computer rather than an incremental digital computer is used to solve the strapped-down inertial navigation computational problem, the approximate direct solution of the direction-cosines matrix equation is no longer the optimal algorithm. The Euler parameters are demonstrated to afford improved accuracy and reduced computation time when used in an appropriate algorithm. A new method of classifying the transformation errors is developed and used.

System Design for Improved Extraterrestrial Communications, *E. Graham*—A proposed system for improved exo-ionospheric communications is described. The dynamic magneto-ionic character of the channel is considered, in particular, the multipath situation arising therefrom. An ideal matched filter is found, matched to the multipath structure and the dynamics of the exo-ionospheric channel. The improvement in the signal-to-noise ratio through the matched filter is calculated. It is seen to depend on the quotient of the input signal to the bandwidths of the "measuring" filter and the "integrating" filter. Further advantages are shown to accrue from signal processing at the transmitter involving both increases in range, and, in particular, secure coding possibilities.

CAVORT: A Radar Pulse Train Optimum Processor for Accelerating Targets, *T. Kibbler*—The CAVORT analog radar signal processor for matched filtering of coherent pulse trains from targets displaying significant radial acceleration is described. CAVORT employs a scanning technique to search repeatedly through trial pairs of values for Doppler and Doppler rate. When a target appears, it is detected, and the best-fitting pair of values determined. The principle of operation is illustrated, using photographs of waveforms generated by the equipment. The results of satellite observations are included. It is demonstrated that the experimental CAVORT, which integrates half-second segments of signal, gives satisfactory estimates of acceleration.

On Processing Optical Images Propagated Through the Atmosphere, *R. Harger*—The problem of how to process coherent optical images that have propagated through a turbulent atmosphere is considered. It is assumed that either the object or its (free-space) scattered field at the receiving aperture is known, except for unknown parameters that are to be estimated. Isotropic and homogeneous turbulence as discussed by Tatarski and Cernov is assumed. It is assumed that a very short (in time) reception is made, that the turbulence-induced complex phase errors are either small or have a correlation distance short relative to the receiving aperture extent, and that the object is within an isoplanatic region. The method of maximum likelihood (ML) is used as a criterion; its applicability is discussed. The ML image-processing structure is found and is nonlinear. Asymptotic cases are examined; among other conclusions, it is shown that the ML processing of independent receptions is more complex than an ML processing of the sum of the receptions. A coherent optical system that realizes the ML image processor is described; it includes the capability to generate the scattered field. Simplifications are pointed out.

Correspondence

Effectiveness, *C. F. Carrol*

Author's Reply, *O. A. Meykar*

Consideration of Comparative ECM Relationships in Weapons Systems Synthesis, *C. Strother, Jr.*

Effect of Hard Limiting in the Presence of Large Out-of-Band Interfering Signals, *R. Ottinger*

Prevention of Transmission Buffer Overflow in Telemetry Data Compressors, *J. Medlin*

IEEE Transactions on Automatic Control

Vol. AC-12, no. 4, August 1967

Simplified Processing of Star Tracker Commands for Satellite Attitude Control, *R. D. Showman*—A method for using gimbaled star trackers to obtain useful attitude control signals is presented. Gimbaled trackers are required if the spacecraft is to be pointed in an arbitrary direction and if any suitable star is to be chosen as a guide star for the star tracker. With the trackers locked to their guide stars, deviation of the gimbals from their commanded angles provides a measure of the error in vehicle attitude. Since the errors are generated about axes that are not necessarily mutually orthogonal or aligned with the spacecraft's control axes, they must be processed to make them useful as control signals. A realizable approximation of the nonlinear processor required to generate vehicle attitude errors from the gimbal angle error measurements is developed. The approximate processor is simple enough for use on board current spacecraft and allows satisfactory performance over as wide a range of star tracker gimbal angles and satellite attitudes as desired.

Design of a Digital Controller for a Tracking Telescope, *R. A. Volz, L. F. Kazda*—The application of certain aspects of modern control theory to the design of a large tracking telescope that is digitally controlled is discussed. Two of the most important criteria are tracking accuracy and response time. The system is also constrained by saturation effects on the control variable. State-transition techniques that have finite settling times over a broad class of inputs are used in conjunction with a suitable inequality condition to obtain a control with near-minimum time response. Digital simulation has shown that the design obtained has high accuracy and does not exceed the saturation limitation on the control variable.

A Time-Optimal Adaptive Control System Via Adaptive Switching Hypersurface, *Y. S. Lee*—A technique for synthesizing a time-optimal adaptive control system is presented. It consists of combining off-line memorization with simple on-line calculations to determine the control signal. The adaptive switching hypersurface consists of images of switching points of each plant in the extended state space (the present and past state variables). The approximation is obtained by linearizing the projection of the adaptive switching hypersurface in a subspace, and by finally storing the parameters of the hyperplanes thus obtained in memory. The on-line calculation corresponds to a simple function generator, which consists of the memory containing the values of parameters of the hyperplanes and a linear interpolator. The input of the function generator is the present and past state variables, and its final output is $+K$ or $-K$. The technique is applied to the pitch axis adaptive regulator control of the F-101B aircraft in various flight conditions, and simulations of the system by the hybrid computer are obtained.

Design of Approximately Optimal Feedback Controllers for Systems with Bounded States, *G. N. Saridis, Z. V. Rekasius*—Implementation is one of the most pronounced difficulties in designing optimal feedback controllers to prevent the state variables of the system from exceeding predetermined bounds. A method to obtain approximately optimal feedback controllers based on the geometric features of the optimal open-loop solution of the bounded state variable problem is presented. Easily instrumentable controllers are designed and successfully tested on various plants to furnish a value of the performance criterion close to the optimal. Typical examples illustrate the approach.

Design of Piecewise-Linear Switching Functions for Relay Control Systems, *D. K. Frederick, G. F. Franklin*—The design of piecewise-linear switching functions is investigated for linear, constant, lumped systems with a single ideal relay controller with respect to a transient response (minimum-time) performance

criterion. A design method is presented that consists of a series of steps leading finally to the optimization of parameters by a gradient or other search technique suitable for computer implementation. The preliminary steps are devoted to reducing the dimensionality of the parameter space that must be searched, defining the criterion function so as to yield a surface that is reasonably smooth and free of relative minima, and insuring that the search is started with a feasible parameter set. It is concluded that easily implemented piecewise-linear switching functions can be designed so as to yield improved performance, both in terms of settling times and region of stability in the state space, over that attainable with linear switching functions. The complexities of the performance surface are such, however, that it is felt that frequently the determination of a switching function by the heuristic guides described constitutes an adequate design without parameter optimization.

An Interior Penalty Method for Inequality Constrained Optimal Control Problems, *L. S. Lasdon, A. D. Waren, R. K. Rice*—A penalty function approach to the solution of inequality constrained optimal control problems is presented; it begins with a point interior to the constraint set and approaches the optimum from within, by solving a sequence of problems with only terminal conditions as constraints. Thus, all intermediate solutions satisfy the inequality constraints. Conditions are given that guarantee that the "unconstrained" problems have solutions interior to the constraint set and that in the limit, these solutions converge to the constrained optimum. For linear systems with convex objective and concave inequalities, the unconstrained problems have the property that any local minimum is global. Further, under these conditions, upper and lower bounds in the optimum are easily available. Three test problems are solved and the results presented.

A Game Theoretic Approach to Optimal Control in the Presence of Uncertainty, *R. K. Ragade, I. G. Sarma*—The optimal control problem, in the presence of uncertainty in the plant, is formulated as a game between the uncertainty and the control variables. This approach gives an optimal control strategy that is effective even under the "worst" conditions of uncertainty. The optimal control of a second-order plant with uncertainty in frequency brings out several interesting features. In particular, the existence of a barrier demarcating the controllable and uncontrollable regions in the phase plane is revealed, which is absent in the corresponding one-sided optimization.

Controllability and Observability of Composite Systems, *C. T. Chen, A. C. Desoer*—The controllability and observability of the parallel and the tandem connection of two linear time-invariant differential systems are studied. The Jordan form representation is used and it is not assumed that the eigenvalues of each representation are simple or that the two sets of the eigenvalues are disjoint. The controllability and observability of the composite representations require only testing the linear independence of some constant vectors. Some sufficient conditions require just the transfer function matrices.

An Algebraic Solution to the Spectral Factorization Problem, *B. D. O. Anderson*—The problem of giving a spectral factorization of a class of matrices arising in Wiener filtering theory and network synthesis is tackled via an algebraic procedure. A quadratic matrix equation involving only constant matrices is shown to possess solutions that directly define a solution to the spectral factorization problem. A spectral factor with a stable inverse is defined by that unique solution to the quadratic equation that also satisfies a certain eigenvalue inequality. Solution of the quadratic matrix equation and incorporation of the eigenvalue inequality constraint are made possible through determination of a transformation that reduces to Jordan form a matrix formed from the coefficient matrices of the quadratic equation.

A Nonlinear Discrete System Equivalence of Integral Pulse Frequency Modulation Systems, *E. I. Jury, J. G. Blanchard*—A study of the effect of integral pulse frequency modulation (IPFM) on single-input single-output feedback control is attempted. For zero input such systems can be reduced to a nonlinear discrete system. The Lagrange stability concepts are used for the stability study of such systems. A step-by-step procedure is devised for the construction of the state trajectories of the IPFM system. This has been applied to a second-order plant where it is shown that instability, asymptotic stability in the large, and asymptotic stability in the Lagrange sense are exhibited by such systems. It is also shown that in IPFM systems, the periodic oscillation that exists depends on the initial state. The equivalence concepts of such systems are reviewed critically, and the limitations of the method are pointed out. Further research in this area of feedback modulation is proposed and discussed.

Bounded-Input Bounded-Output Stability of Nonlinear Time-Varying Discrete Control Systems, *J. C. Lin, P. P. Varaiya*—It is shown that a discrete control system is bounded-input bounded-output (BIBO) stable if and only if there exist Liapunov functions possessing certain properties. As an illustration, a frequency criterion is developed for the BIBO stability of a class of nonlinear discrete systems.

Short Papers

Kalman–Bucy Filter for Optimum Radio-Inertial Navigation, *B. T. Fang*
Estimation of the State Vector of a Linear Stochastic System with a Constrained Estimator, *M. Aoki, J. R. Huddle*
Linear Time-Lag Systems with Side Constraints, *D. H. Chyung*
On the General Functional Matrix for a Linear System, *S. Barnett, C. Storey*
Identification and Control of Linear Discrete Systems, *J. B. Farison, R. E. Graham, R. C. Shelton*
Finding the Stability and Sensitivity of Large Sampled Systems, *F. P. Imad, J. E. VanNess*
The Transient Behavior of Autonomous Nonlinear Control Systems, *L. Castrucci*
Stability of Feedback Systems Containing a Single Odd Monotonic Nonlinearity, *K. S. Narendra, Y. S. Cho*
Some Aspects of the Lur'e Problem, *M. A. L. Thathachar, M. D. Srinath*

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A Graphical Method for Calculation of Transfer Functions, *C. Karybakas*
A Switching Policy for Predictive Control Systems, *W. G. Rae*
Some Comments on "Extremum Control of Continuous Systems," *A. L. Riemenschneider, E. J. Mastascusa, M. H. Hamza*
On a Decomposition Technique for Multilevel Control Systems, *T. Sato, A. Ichikawa*
Functional Reproducibility and the Existence of Classical Sensitivity Matrices, *M. K. Sain*
A General Proof of the P_n Matrix and Its Inverse, *C. F. Chen, H. Chu*
Comment on "A Remark on Routh's Array," *J. Lehoczky, F. Csaki*
The Routh Canonical Form, *G. V. S. S. Raju*
On the Construction of Liapunov Functions, *A. Huaux*
On the Inapplicability of the Popov Stability Criterion in Certain Classes of Control Systems, *S. C. Pincura*
Analysis of Nonlinear Sampled-Data Systems Using z-Transform Method, *Y. L. Chen, K. W. Han*
Deadbeat Response of Time-Delayed Systems with Minimal Overshoot Compromise, *V. Lorchirachoonkul, D. A. Pierre*
Note on Control of Multiple-Input Discrete Systems, *W. J. Hankley, J. T. Tou*
Comments on "The z Transform of an Impulse Function," *W. L. Montgomery, J. M. Davis, D. F. Wilkie, R. K. Cavin III, D. L. Chenoweth, C. L. Phillips*
On the Solution of Error Covariance Difference Equation by Means of Canonical Decomposition and z Transform, *T. Nishimura*
Kalman Estimator and Sample Mean, *J. D. Irwin, J. C. Hung*
Observability of Mean Values, *B. E. Bona*
On the Equivalent Input–Output Representation of State-Variable Systems, *L. G. Birta*
Controllability and Observability of Feedback Systems, *C. A. Desoer, C. T. Chen*
Note on "Secant Correction for Tracking Pedestals," *F. L. Bacchialoni*

Book Reviews

"Optimal Control," by R. Oldenburger, *reviewed by G. F. Franklin*
"Approximate Analysis of Randomly Excited Nonlinear Controls," by H. W. Smith, *reviewed by G. Zames*
"Quasilinearization and Nonlinear Boundary-Value Problems," by R. E. Bellman and R. E. Kalaba, *reviewed by J. Peschon*

IEEE Transactions on Education

Vol. E-10, no. 3, September 1967

Evolution of Solid-State Amplification and Its Limitations, *V. Uzunoglu*—Solid-state amplifying devices have two common features: an inherent negative resistance, identified as the current or voltage source; and a high electric field region, which manifests itself as the output impedance. A generalized equivalent circuit is developed using these concepts. Several semiconductor amplifying devices are analyzed and their performances compared; the devices discussed include three-terminal devices, as well as two-terminal negative-resistance devices. The possibilities of increasing the gain–bandwidth product of semiconductor amplifiers is discussed and the additive-amplification technique for semiconductors is introduced.

The 16 Faces of Feedback—A Catalogue of the Basic Negative Feedback Amplifier Configurations, *B. Sklar*—Classical feedback literature refers to series and shunt feedback or voltage and current feedback, implying only two feedback configurations which may be employed with an amplifier. Actually there are four separate configurations. Also, if one examines the amplifier around which such feedback is utilized, the existence of four ideal transfer functions is seen. If the employment of each of the four basic feedback types around each of the four basic amplifier types is considered, a total of 16 different configurations results. The effect of the negative feedback in each of these 16 cases is discussed. In general, the closed-loop transfer function approximates the reciprocal of the feedback network transfer function so that any one of the four types of amplifiers may be transformed (with the proper choice of feedback) into any of the three other basic types, or into an improved version of the same type.

Digital Computer Approach to a Personal Information Retrieval System, *L. P. Huelsman, J. L. Melsa*—The information "explosion" poses a challenging problem to the engineer or scientist interested in keeping up with his field. Although many large-scale systems of information retrieval have been developed, there is a need for small-scale, personal information retrieval systems that may be easily used by an individual. What the authors feel is a highly useful solution to this problem is described.

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Aids for Logic Design Algorithm Development, *D. L. Dietmeyer, P. R. Schneider*—Teaching logic design algorithm development through computer program aids usable by a novice programmer is discussed. The basis for the method is a set of FORTRAN-compatible subroutines that perform the tedious tasks of logic function input–output and manipulation, together with some simple combinatorial operations. These routines allow the student to concentrate on analysis and synthesis algorithms, investigating and solving problems beyond the realm of feasibility of hand calculation. Typical examples are discussed.

Undergraduate Experiments in Data-Handling and Linear Systems, *D. Landgrebe*—Two related undergraduate laboratory projects that involve basic data-handling procedures (e.g. sampling, quantization, etc.) in an elementary, though nontrivial, fashion are presented. These procedures are used in the course of laboratory studies in linear system identification and correlation detection. The portions of the experiments that require techniques usually reserved for large-scale data handling have been designed so as to require relatively small amounts of data. As a result, it is possible for the student to do some calculation by hand before going to the digital computer, thus greatly aiding the learning process. The experiments also provide a realistic frame of reference for reinforcement of such classroom topics as convolution, frequency response, impulse response, auto- and cross-correlation, and others.

Symmetric Circuits and the Concept of Logical Potential, *N. R. Bell*—Symmetric circuits with more than one output can traditionally be reduced by shifting down if the outputs have certain properties. That any nontrivial symmetric circuit can be shifted down using the method described is shown. The reduction is made logical and simple to understand by means of the concept of logical potential, in which the circuit is diagrammed, and a "potential" assigned to each node in the diagram. The method shows which shifts are valid, and avoids those that result in sneak circuits. It provides an excellent tutorial approach for classroom teaching of symmetric circuit reduction in courses on logic and switching circuit theory.

The Design and Application of a Minority Logic Gate– A Senior Project, *R. Benzer, V. Rozga, W. Till*—As a senior laboratory project, 15 minority logic gates were designed and built utilizing MOS field-effect transistors. The minority gates were then used as logic modules in the design of a binary comparator, a parallel binary adder, and a ternary counter. Although the project described did not yield an economically competitive logic gate, minority logic applications were verified, student creativity was encouraged, and a facility was developed for future laboratory projects.

Modern Concepts in Engineering and Science: An Updating Program for Technical Managers and Staff, *E. A. Madlon, W. Wong*—An updating educational program for mature, experienced engineers and scientists working for the International Business Machines Corporation is described. The planning, execution, and evaluation of the program are reviewed; the problems entailed in meeting the needs of a special population are highlighted. The experience gained suggests several areas that require special attention in order for programs of this type to be effective. The program was designed for engineers and scientists having significant work experience, who have been away from formal academic training for ten years or more, and it is based on the premise that an obsolescence of knowledge does not imply the obsolescence of people.

The Responsibilities of the Engineering Instructor, *J. Choma, Jr.*—Recent technological developments have intensified the problems of educating young people for the engineering profession. Even though these developments have given birth to many areas of study in engineering, the increasing demand for engineers has, in many cases, forced engineering schools to abridge, rather than lengthen, their curriculum. The responsibility of providing a lasting and meaningful engineering education to students who are on campus for the short period of four years rests solely with the instructor. Consistently distributing lecture notes, working hard and closely with his students, and displaying a clear concern for the welfare of his students are suggested as possible ways in which the instructor can fulfill his responsibilities.

Short Papers

Topological Rules for Linear Networks and Their Application, *A. Nathan, D. Censor*

The Laplace Transformation of the Impulse Function for Engineering Problems, *G. A. Etzweiler, S. A. Steele*

Generalized Functions and a Delay Integrator with Negative Feedback, *A. Klinger*

A Note on Partial Functions, *C. H. Murrish, G. W. Smith*

Useful Relations for Partial Fraction Expansion of Proper Rational Functions and Transition Matrices, *H. M. Power*

A Stability Criterion Based on the Return Difference, *C. F. Chen, N. F. Tsang*

A Simple Graphical Method for Plotting the Field Pattern of Linear Antennas, *M. F. Moad*

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Comments on "On the Natural and Forced Response of Linear Systems," *K. R. Rao, J. Fitzer, A. F. Pflanzer, P. H. Alexander*

Further Comments on "Some Surprising Examples of Nonlinear Systems," *A. E. Durling, K. R. Rao*

Solution of Higher-Order Linear Differential Equations with Constant Coefficients, *C. W. Jiles, K. R. Rao*

A Note on the Integration of Poisson's Equation, *D. T. Thomas*

Simplified Analysis of the Line Regulation of a Series-Regulated Power Supply, *I. Feerst*

IEEE Transactions on Electron Devices

Vol. ED-14, no. 7, July 1967

Small-Signal Power Flow and Energy Density for Streaming Carriers in the Presence of Collisions, *B. Vural, S. Bloom*—The Poynting theorem, or equation of continuity relating energy density and power flow, is extended to include the effects of diffusion and collisions. It is shown that the increase in the thermal power due to diffusion is offset by a decrease in electrokinetic power. The effects of collisions on the electrokinetic power and energy density are examined in detail in the absence of diffusion. It is found that the kinetic power is zero in isolated streams when collisions are frequent ($\nu > 2\omega_p$). However, when such streams couple to "circuit-like" positive-energy waves (as in the acoustic amplifier), the stream's kinetic power becomes finite; in particular, it becomes negative if the stream drifts faster than the wave. Thus the usual picture, used in collision-free theory, in which the active wave must carry negative power, is preserved. It is also shown that, on the other hand, if the stream is lossless but interacts with a lossy and nonpropagating medium (as in a stationary collisional plasma), then the stream's finite-energy waves are coupled by the lossy medium. In contrast to the previous case where both systems propagate, it is now the negative-energy wave that grows. It is found that the electrokinetic energy density in a collision-dominant stream is negative for both modes due to collisional losses.

Space-Charge Wavelengths in Dense, Scalloping Electron Beams, *G. M. Branch, Jr., T. G. Mihran, W. Neugebauer, W. J. Pohl*—The discrepancies between measured and calculated small-signal space-charge wavelengths are discussed. It is shown that conventional methods of calculation are inadequate, causing errors up to 40 percent in a typical case. It is demonstrated that these errors cannot be explained by beam scalloping action, and that they are most severe when a high-perveance beam is used at low voltages with a high magnetic field under conditions of low interception. Although these effects would not be noticed in klystrons with relatively short drift lengths, they may in many cases explain the critical variation of gain and efficiency with magnetic field. A more accurate method of calculating space-charge wavelengths is developed, and the effectiveness of this method is demonstrated by a comparison with measurements.

Computer Calculation of Deflection Aberrations in Electron Beams, *C. C. T. Wang*—The aberrations of a magnetically deflected electron beam have been investigated in detail using an IBM 7094 computer. The computer programming is applicable to the case of one-dimensional deflection through small angles. The beam is treated as a group of electrons having no internal interactions, no energy spread, and producing no external fields. The field distributions that would produce minimum total aberration for a range of specified working distances, maximum deflection distances, coil widths, and coil openings are calculated. The aberrations produced by these ideal fields and by fields that deviate from the model are predicted. Typically, for a working distance of 3 in (7.62 cm), field coverage of 11 mm, and beam convergence angle of 3.54×10^{-3} rad, the maximum increase in spot diameter is of the order of 0.05 micrometer. Theoretical limitations on the minimum aberration of a specific deflection system are established. The aberration is expected to be further minimized if dynamic astigmatic correction is applied, as described.

Noise Measurements on a Magnetron Injection Gun Beam, *G. T. Konrad*—The results of noise measurements conducted on a helix-type traveling-wave amplifier containing a magnetron injection gun are described. A minimum noise figure of 15.3 dB was observed at 760 MHz with an approximate beam power of 1600 watts. The noise figure was minimized by an adjustment of the magnetic field, which determines the transit time of the electrons through a drift region. This optimizes the magnitude and phase of the standing noise waves at the helix input.

High-Frequency Noise of the Junction Field-Effect Transistor, *F. M. Klaassen*—Based on Geurst's treatment of the high-frequency value of the admittances of the junction field-effect transistor, the high-frequency noise of the device has been computed, assuming that the noise source is of thermal origin. By applying an appropriate series expansion of the current it is possible to express the noise of the drain and gate current in terms of known quantities, as steady-state transconductance, gate capacitance, and frequency. At low frequencies the noise spectrum of the drain current is independent of the frequency and much larger than the noise of the gate current; however, at high frequencies the noise spectra of the gate and drain current both vary by ω^2 and are of the same order of magnitude.

An Investigation Into Transistor Cross Modulation at VHF Under AGC Conditions, *J. te Winkel, B. C. Bouma*—The cross-modulation behavior of a transistor is studied for the case where it is operated in the VHF region and gain control is effected by driving it into saturation. It is shown that the observed increase in cross modulation can be attributed to the

fact that in the saturated condition the stored charge in the transistor will depend nonlinearly on the collector current. The cross-modulation factor is calculated assuming an arbitrary functional relation between stored charge and current. A relation between the cross-modulation factor and the change of the cutoff frequency with current then will exist, allowing experimental verification. Close agreement is found between measured and calculated values.

A High-Performance Lateral Geometry Transistor for Complementary Integrated Circuits, *D. F. Hilbiber*—The lateral geometry transistor has shown itself to be highly useful in the realization of low-frequency integrated circuits. This simple structure has been limited essentially to dc applications, however, by bandwidth and switching time performance. The p-n-p device described substantially overcomes these deficiencies by the addition of an n+ diffusion directly beneath the emitter region. As a result of the steeper gradient at the bulk, or planar, portion of the emitter-base junction, injection occurs primarily near the surface. It is possible to control the dimensions of the buried layer such that injection of carriers greater than a few micrometers from the collector will be minimized. A further consequence of the n+ region is the introduction of a graded base such that minority carrier transport is enhanced. The improved transistor structure has demonstrated the feasibility of obtaining an f_T of 10 to 20 MHz at collector currents of 100 μA and rise, fall, and storage times in the tens of nanoseconds.

The Characterization of the Static Behavior of p-n Junction Devices, *D. E. Fulkerson*—An examination is made of the static behavior of certain p-n junction devices that are governed by Van Roosbroeck's differential equations. It is found that this set of first-order differential equations accurately predicts semiconductor static behavior in both the bulk and the transition regions. The purpose of this model is to find the hole and electron concentrations, hole and electron currents, and electric field as functions of position and external excitation. Use is made of the quasi-neutrality approximation in the bulk regions and the quasi-equilibrium Boltzmann relations (QEBR), which relate the hole and electron concentrations at transition region edges to the applied voltage across the transition region. The unijunction transistor with intrinsic base, p-i and p-i-n diodes, and a new current gain device are examined using these concepts, and the results are compared with experiment. By applying boundary conditions only at the ohmic contacts, a p-i diode problem is solved on a computer. One especially important point in this problem is that quasi-neutrality of the base and the QEBR are not imposed upon the problem. However, the final results indicate that these concepts are good approximations, except for extremely short devices.

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Tunable, High-Power Ferrite Frequency Doubler, *M. Weiner*

Reverse Transient in p-n-p-n Triodes, *T. S. Sundress*

Nondestructive Determination of MOSFET Gate Breakdown Voltage, *D. F. Hilbiber, R. C. Lucas*

CW Three-Terminal GaAs Oscillator, *K. G. Petzinger, A. E. Hahn, Jr., A. Matzelle*

Definitions of Terms for Integrated Electronics

IEEE Transactions on Electron Devices

Vol. ED-14, no. 8, August 1967

Pulse-Driven Silicon p-n Junction Avalanche Oscillators for the 0.9- to 20-mm Band, *L. S. Bowman, C. A. Burrus, Jr.*—The fabrication of pulse-driven, diffused silicon p-n junction avalanche oscillators that have been operated at frequencies from 15 to 341 GHz is described. The experimental behavior of a large number of oscillators has been correlated with readily measurable properties of the p-n junctions, leading to first-order design parameters for construction of oscillators of this type usable at various frequencies into the submillimeter-wave region. Maximum peak power outputs ranged from 2 watts near 15 GHz, to 75 mW at 115 GHz; the estimated peak power at 300 GHz was of the order of 1 mW.

Design Calculations for Reverse Bias Characteristics for Microwave p-i-n Diodes, *H. M. Olson*—The derivative of a set of design formulas for predicting the impedance of diffused p-i-n diodes as a function of reverse bias voltage is presented. The diode is divided into five regions, and appropriate approximations are made in each region to simplify the integration of resistive and reactive contributions to the total impedance. Using these formulas, curves of series resistance and capacitance versus voltage are computed for an experimental diode reported by Senhouse. The curves agree well with others obtained using more complicated methods of integration. In addition to being useful for design calculations, the formulas derived offer insight as to the effects of frequency on diode impedance and the relative contributions of the various regions of the diode to the total impedance.

Optical Microprobe Response of GaAs Diodes, *K. L. Ashley, J. R. Biard*—GaAs p-n junction photocurrent response is obtained from an optical microprobe with a dynamic range of at least three decades and a light-spot diameter of about 1.3 μm. The results are found to correlate well with the appropriate theoretical response, which includes surface recombination and assumed infinite absorption coefficient. Minority-carrier diffusion lengths computed from the data are typically 3.5 and 0.7 μm for holes in n-type material doped 10^{17} and 1.4×10^{18} cm^{-3} and 1 μm for electrons in $>10^{18}$ cm^{-3} doped p-type material. Estimates of carrier lifetimes are made and the deviation of surface recombination velocity between devices is demonstrated.

The "Hourglass" Energy Diverter, *S. Schneider, A. J. Buffa*—A new design for a series spark-gap array for energy-diverter usage has been developed. The electric circuit of this array differs from previously reported energy-diverter designs in two respects. First, the capacitors from each electrode to ground are eliminated, and second, the interelectrode capacitances of the gaps are not all equal. By varying the interelectrode capacitances of each gap in accordance with predetermined requirements, it was possible to study several triggering modes. In particular, two triggering modes were investigated: a "constant overvoltage" mode and an "increasing overvoltage" mode.

Eigenvalues of Characteristic Noise Matrix of an Electron Beam with Half-Maxwellian Velocity Distribution, *H. A. Haus, D. L. Bobroff*—A method is devised for determining the eigenvalue spectra of the characteristic noise matrix of electron beams with continuous velocity distributions. It is found that for an electron beam with a half-Maxwellian velocity distribution all positive eigenvalues are equal to $kT\Delta f$ and all negative eigenvalues approach zero. This finding is in agreement with the phenomenon of noise reduction in an electron beam drifting at a low average velocity (an average velocity comparable to the velocity spread).

High-Voltage Breakdown of Titania in Vacuo, *C. G. Englefield, V. J. Harwood, L. W. Toso*—The electrical breakdown of titania in a vacuum using static electric field is investigated experimentally by examination of current and temperature variation at different applied voltages. Thermal instability is found to occur at voltages above a critical value. This leads to sufficiently high temperatures to cause the reduction of the titania into a lower-order semiconducting oxide, which carries the breakdown current. The breakdown of titania and a vacuum gap in series is also investigated. Evidence gathered from temprature and current readings suggests that, at high voltages, part of the voltage originally across the vacuum gap appears across the titania. Evidence to support this theory is obtained from measurements of the mechanical force appearing across the vacuum gap which enable the voltage redistribution to be calculated. The voltage redistribution is due to an excess charge appearing on the surface of the ceramic, due to prebreakdown currents in the vacuum gap. When the voltage across the titania reaches a large enough value, thermal instability occurs, leading to breakdown of the titania.

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Generalized Turn-On Criterion of p-n-p-n Devices, *E. S. Yang, J. G. Skalnik*

Time-Varying Deflection of Electron Beams, *C. C. T. Wang*

Recombination Centers in Silicon Transistor Emitter-Base Junctions, *C. Y. Bartholomew*

Correction to "Nonreciprocal Tunnel Diode Distributed Amplifiers," *R. C. Matson*

IEEE Transactions on Electronic Computers

Vol. EC-16, no. 4, August 1967

Optimum Time-Sharing of a Digital Communication Channel, *A. Shani, D. J. Cohen*—The optimum word length for the simultaneous digital transmission of a number of continuous signals in real time, through a single communication channel, is derived. The transmission introduces sampling and quantization errors; the relation between the fineness of the quantization and the sampling rate, as a function of word length, for a given capacity of the channel, is investigated. Individual word length for signals having different amplitude distribution and unequal expected frequency is also derived. It is assumed that the functions to be transmitted have known statistical properties. An example is worked out in detail for the case of normal distribution of amplitudes of the transmitted signals. The investigation is carried out for the case in which a zero-order hold circuit is used for the reconstruction of the signals, and the results are compared with the case of an optimum linear reconstruction circuit.

Error Analysis in the Computer Simulation of Dynamic Systems: Variational Aspects of the Problem, *R. Vichnevetsky*—Error analysis in the computer simulation of dynamic systems is fundamentally a variational problem. The computing errors are small variations of the computed solutions with respect to the exact solution of the differential equations being integrated. It is not surprising, therefore, that many of the mathematical tools used to perform error analysis in the computer simulation of dynamic systems are similar to those used in the variational or perturbational analysis of those systems themselves. The error-propagation equations are derived in a basic form, which makes it easier to apply such variational mathematical tools as Liapunoff's second method to analyze error stability, and Pontryagin's maximum prineiple to study "worst case" errors in computation.

Design and Use of Fault Simulation for Saturn Computer, *F. H. Hardie, R. J. Suhocki*—A system of IBM 7090 Data Processing System computer programs was developed for the purpose of normal and/or fault simulation of the Saturn

computer. The design of the simulator is described and several applications in the development of the Saturn computer are cited. The architecture, plus several important characteristics of the simulator, is presented. The ability to simulate up to 4000 Saturn instructions in either normal and/or fault environments (up to 33 faults per IBM 7090 run) is demonstrated. Simulation of single, multiple, solid, or intermittent faults, plus an automated statistical analysis of intermittent fault simulation results, is presented. The IBM 7090 execution time of a compiled logic simulator can be prohibitive. To minimize running time several programming techniques were utilized, including logic block ordering (to allow single-pass simulation), parallel fault simulation, stimulus bypassing, and functional simulation. These techniques are described. Several special forms of simulator output were developed. The use of this output and the applications of the simulator are presented, including design verification, test program evaluation, generation of a test point catalog, disagreement-detector network evaluation, disagreement-detector placement, and intermittent failure analysis.

A Computer Simulation of Electrical Loss and Loading Effect in Magnetic Recording, *W. W. Chu*—A model is presented for evaluating the electrical loss (assuming the head medium is not infinitely permeable) and loading effect of the readback process in magnetic recording. The technique is based on the fact that the readback process can be approximated as linear and that the read head is a linear frequency-variant device. After approximating the open-circuit readback signal by a Fourier series, the readback signal with loading and electrical loss is the summation of the responses produced by the harmonic components. Examples are given to evaluate the electrical loss and loading effect on the readback signal. Simulation results agree well with experimental results.

An Approach to the Assignment of Input Codes, *W. A. Davis*—An approach is presented to the problem of assigning binary input codes so that the combinatorial circuits necessary to realize the given output functions may be minimized. The approach is based on binary partitions and binary set systems, which provide a natural language for dealing with the problem. First, a lower bound is established for the realization of each output function, with the assumption that the function will not be realized directly. Then, the output partitions determined by the output functions are found and those output partitions that can be used together in a valid assignment are established. This provides a number of assignment schemes, which, in turn, can be evaluated in terms of a lower bound for the realization cost. For the scheme with the smallest lower bound, the actual realization cost is established. This provides a measure by which a number of schemes can be eliminated, since it is necessary to consider only those schemes having a lower bound smaller than the least actual cost already obtained. Using set systems, the method is extended to include output functions containing "don't cares." It is also shown how the method can be applied to the minimization of combinatorial circuits in sequential machines.

RST Flip-Flop Input Equations, *P. J. Graham, R. J. Distler*—There are several different usable combinations of the inputs of an RST flip-flop. It is shown how all of the possible combinations can be displayed simultaneously on three Karnaugh maps, facilitating the choice of the simplest input equations. The application equation for flip-flop Q characterized by a sequential problem is plotted on a map designated Q^{n+1}. Additional maps, $(Q^{n+1})^*$ and $(Q'^{n+1})'$, are derived from Q^{n+1}. Cells corresponding to prime implicants not containing the variable Q are identified on these maps, and are used to enter the properly designated arbitrary elements on the R, S, and T maps of flip-flop Q. The method is based on the following theorem: "If $Q^{n+1} = (g_1Q + g_2Q')^n$, and if $\mathfrak{F}$ is the set of all prime implicants that do not contain the literals Q or Q', then the Boolean function g_1g_2 is the union of all the prime implicants of Q^{n+1} that belong to the set $\mathfrak{F}$." A simple illustrative example is included.

Generalization of Consensus Theory and Application to the Minimization of Boolean Functions, *P. Tison*—Given two implicants of a Boolean function, a third implicant can be found by performing their consensus. This operation has been used for finding the prime implicants of a Boolean function. The consensus is extended from two to any number of terms. A property of these generalized consensus relations leads to a systematic way of finding them. It is shown that any prime implicant of a Boolean function is a generalized consensus; therefore, the algorithm for the determination of the consensus relations can be used for finding the prime implicants. This new method is simpler than the usual process of iterative consensus. It is also shown that consensus theory can be used for finding the minimal sums of a Boolean function. The methods are applicable for any Boolean function, with or without "don't care" conditions, with a single or a multiple output.

A Realization Algorithm Using Three-Input Majority Elements, *E. M. Riseman*—A modification of Akers' method of realizing Boolean functions with three-input majority gates is presented. One of the fundamental parts in Akers' procedure is the construction of a logically passive self-dual, or LPSD. A more precise construction of the LPSD is presented. In addition, a procedure is described to adapt the method to minimization of the number of delay elements. A delay element table is introduced to aid in the selection of majority gates. A second factor in reducing delay elements is limiting the number of levels of logic in the realization. Examples illustrate the substantial reduction in delay elements when these methods are employed.

Feed-Forward Threshold Logic Nets for Digital Switching and Pattern Recognition, *G. F. Hughes*—A computer-programmable algorithm is presented for the design of general feed-forward nets of threshold logic gates, which realize arbitrary digital switching functions. The algorithm is proved to be convergent for all switching functions. A simplified version of the algorithm is presented for the case of symmetric switching functions. Both algorithms are proved minimal for single-gate nets; a necessary condition is given for the symmetric algorithm to produce minimal two-gate nets when they exist. Two-gate minimality is also demonstrated for the general algorithm, for a certain class of two-gate switching functions. However, general minimality is not proved. The case of partially defined switching functions is treated. Minor alterations in the general algorithm allow its use as an adaptive pattern recognition procedure, where the input variables represent real numbers rather than Boolean variables. Experimental results are presented for both digital switching function realization and analog pattern recognition.

System Design of a FORTRAN Machine, *T. R. Bashkow, A. Sasson, A. Kronfeld*—A system design is given for a computer capable of direct execution of FORTRAN language source statements. The allowed types of statements are the FORTRAN—DO, GO TO, compute GO TO, arithmetic, READ, PRINT, arithmetic IF, CONTINUE, PAUSE, DIMENSION, and END statements. Up to two subscripts are allowed for variables and no FORMAT statement is needed. The programmer's source program is converted to a slightly modified form while being loaded and placed in a program area in lower memory. His original variable names and statement numbers are retained in a symbol table in upper memory, which also serves as the data storage area. During execution of the program, each FORTRAN statement is read and interpreted at basic circuit speeds since the machine is a hardware interpreter for these statements. The machine corresponds therefore to a "one-pass, load-and-go" compiler, except, of course, that there is no translation to a different machine language. It is estimated that the control circuitry for this machine will require on the order of 10 000 diodes and 100 flip-flops. This does not include arithmetic circuitry.

System Effectiveness as a Generalization of System Availability, *S. W. Leibholz*—Certain concepts and sample results in the techniques of system effectiveness analysis are discussed, with particular attention to availability. The contemporary concept of system effectiveness can be usefully viewed as a generalization of prior concepts relating to system availability. Central to the approach is a presentation of the need for redefinition of system availability. While on the one hand some 18 definitions are available in the literature, this latter concept is not broad enough for complex systems; the implied binary situation of a system being either UP or DOWN is not an accurate enough model for such systems. System effectiveness, which has been evolved to replace availability, arises from attempts to unify treatment of the statistics of system state behavior and transition behavior, of the performance capability associated with these states and transitions, and of the interaction of the performance statistics within the conditions of the problem. The analytic techniques developed are of particular power when dealing with redundant and modular systems. A comparative effectiveness evaluation of ten alternative computer system designs, all having the same basic performance, is exhibited; this analysis was performed with respect to a given sample functional requirement.

IEEE Transactions on Geoscience Electronics

Vol. GE-5, no. 2, September 1967

The z Transform of a Realizable Time Function, *D. J. Sakrison, W. T. Ford, J. H. Hearne*—In many seismic problems the observed signals are sampled at discrete time instants and these sampled values stored for processing in a digital computer. It may then be necessary to process these data with a digital filter. The z transform is appropriate for describing such sampled data and digital filters. It may be that in designing a filter, only the amplitude but not the phase of the appropriate filter is specified. However, the phase must be known to find the filter. If certain assumptions can be made concerning the filter, there are relations that express the phase explicitly in terms of the amplitude. Although these relations are well known for Fourier transforms, their counterparts for the z transform do not seem to be available. These relations are presented.

A Shipboard Oceanographic Data Processing and Control System, *C. O. Bowin, R. Bernstein, E. D. Ungar, J. R. Madigan*—In June 1962 a digital computer (IBM 1710) was placed aboard the Research Vessel *Chain* of the Woods Hole Oceanographic Institution. This system has made it possible automatically to sample, compute, and record the ship's heading and speed, latitude and longitude, water depth, gravity in terms of total acceleration, free-air and Bouguer anomalies, and the magnetic field of the earth. The system was expanded in November 1963 to provide on-line plotting of bathymetric gravity meter spring tension; processing of ocean surface temperature and sound velocity measurements; reduction of Loran C and VLF radio navigation data to latitude and longitude; display of

ship's position and numerical data at remote stations aboard the ship; and malfunction detection and alarm message generation. Three magnetic-disk storage units are used for data and program storage and provide the ability to merge real-time on-line computations with background off-line computations (time-sharing). Experiments are being made using three input output typewriters at remote locations on the ship. The advantages of a shipboard system are described.

Electrical Methods for Deep Subsurface Exploration, *G. F. Kinghorn*—A theoretical study has been made of the transmission of electric signals through the earth in order to devise the most promising methods for determining the electrical resistance of deep-lying formations. It was found that the most effective technique is one that apparently has not been previously proposed. Theoretical analysis indicates that this new method can provide a fairly accurate measurement of the variation in subsurface resistance at depths of interest in explorations for petroleum reservoirs and other deep-seated mineral deposits. Field tests carried out in the western part of Kern County, Calif., show that the results obtained by this method are in good agreement with the electrical resistive logs obtained from drilled wells.

Some Experiments Below Resonance with a Mechanical Parametric Amplifier, *P. W. Rodgers, T. V. McEvilly*—It is shown that the parametric action produced in a mechanical circuit by a spring with time-variable stiffness can increase the subresonant or long-period response of a pendulum. The theory of operation of such a mechanical parametric amplifier is described in terms of Mathieu's equation. The construction of the device in the form of a seismometer is described. Experimental data are given showing a two order of magnitude increase in low-frequency response.

IEEE Transactions on Industry and General Applications

Vol. IGA-3, no. 3, May/June 1967

Energy-Integrated Design of Lighting, Heating, and Cooling Systems and Its Effect on Building Energy Requirements, *G. Meckler*—The continuous control of interior environment with today's requirements for higher light levels has greatly altered the way in which energy is consumed in buildings. In order to optimize the energy input and achieve environmental control, we must utilize the systems approach. The lighting, heating, and cooling systems must be interrelated so that we can utilize available internal energy to satisfy the heating requirements and simultaneously reduce the energy input by eliminating the refrigeration and air handling associated with collecting lighting and solar radiant heat. The discussion concerns a new environmental system that utilizes nonrefrigerated water and minimum primary air distribution, eliminating the penalty of refrigerating the lighting load while having the capability of utilizing the lighting heat for heating the building and providing temperature control. A system is discussed that will utilize the heat given off by the lighting system to provide the refrigerated cooling required for the occupied space.

A New Ground Fault Protection System for Electrical Distribution Circuits, *R. R. Conrad, D. Dalasta*—Distribution circuits that are solidly grounded or grounded through low impedance present a problem relative to fast clearing of ground faults. This is especially true in low-voltage grounded Y circuits that are connected to bus ducts or long runs of metallic conduct. The problem involves sensitivity in detecting low ground fault currents as well as coordination between main and feeder circuit protective devices. Fault clearing must be extremely fast where arcing is present. Distribution system impedance characteristics are analyzed in relation to possible ground fault current magnitudes. Oscillograms are presented showing the behavior of arcs for various types of faults and fault current magnitudes. Comparisons are made between calculated and test values of minimum sustained fault currents. Fault arc characteristics determined from full-scale tests are presented. Estimated requirements for speed of clearing to limit fault arc damage are included. Correlation is obtained between needed sensitivity and the conflicting requirement of coordination of protective devices. A new sensor and relay system is described. This system was designed to fulfill all the functional requirements established, including those of economy and simplicity of design.

European Standards Affecting the Appliance Industry, *L. D. Price*—The effect of safety regulations on international trade, especially with European countries, is discussed from the viewpoint of an official observer relating the activities of international safety standards organizations. Particular emphasis is placed on the work of the International Commission on Rules for the Approval of Electrical Equipment (CEE). The several factors involved in the establishment of artificial barriers to international trade through regulatory bodies are explored. An outline is given of what has been done and what is being done to facilitate agreements on international safety standards to minimize or eliminate the problem of such trade barriers.

Pulse to Analog Voltage Converter, *F. Di-Nicolantonio*—Circuit design considerations are presented of an all-solid-state circuit that converts a digital pulse repetition rate to a corresponding analog voltage that can be used as a feedback signal in an accurate speed regulator. Integrated circuits were used in the circuit where it was advantageous to do so.

Underground Corrosion and Electrical Grounding, *O. W. Zastrow*—Underground corrosion associated with electrical grounding has caused numerous problems in operating electric systems. Much of the difficulty is due to dissimilar metal effects between buried copper and steel connected together via the grounding network. Unfortunately, these effects are widely ignored in electrical design and the requirments of electrical protection and corrosion mitigation are often seen as opposing each other. Experience has shown that both sets of requirements can be met. On electric distribution lines, the most helpful measures against corrosion include the use of galvanized steel rather than copper for grounding electrodes. Sacrificial anodes are helpful for adding additional corrosion protection where needed. Underground copper wire should be tinned or otherwise coated to avoid or minimize dissimilar metal effects. Research is in progress for determining what coatings would be best for this purpose.

A Synchronous Tap Changer Applied to Step Up Cycloconverters, *W. R. Light, E. S. McVey*—The operating principles of a transformer tap changing system are presented. The system is named "synchronous tap changer" because it changes taps in synchronism with its input signal. The purpose of a synchronous tap changer is to change the turns ratio of a transformer in a manner that will reduce the distortion content of the incoming signal. In effect, it is an active filter. The system is expected to find use in power-type systems. The application of synchronous tap changers to step-up cycloconverters is presented to illustrate the use of this scheme. The system is optimized and results of an experimental system are presented.

Building Reliability and Safety Into Underground Rural Distribution, *J. N. Thompson*—The public is interested in underground power distribution lines primarily because this is a way of putting substantially all elements of the power system out of sight. At the present time underground distribution is being promoted almost entirely on the basis of improved appearance. To the operator of a power system, however, underground distribution offers two additional attractions, both of which eventually may be more important than appearance. It is reasonable to anticipate that the underground system of today will prove to be both safer and more reliable than any overhead system. With continuing advances in the development of new equipment, further progress in these advantages can be expected.

The Analysis, Measurement, and Control of Motor-Generated 120-Cycle Noise, *E. Woodfin, R. Taylor*—An attempt to solve the difficult problem of controlling 120-cycle noise by design is discussed. A case study of an automatic washer is presented. The subject is treated in the categories of: the exciting source, the energy transmission paths, and the excited members. Prime emphasis is placed on the exciting source, which in this case is the main drive motor. An attempt is made to answer questions as to how this motor produces 120-cycle energy, how it can be measured, and how it can be controlled. Several methods of determination of 120-cycle pulsating torque are discussed with examples of typical measurements and the correlation between methods. The difficulties of correlating predictions of noise and actual noise measurements are discussed, with techniques of statistical correlation offered. A method of quality control is included which enables comparison of product performance to the engineering standard.

Demand Estimation for Sizing Distribution Transformers and Secondary Services in Rural Areas, *L. B. Altman, L. F. Charity*—Demand, energy consumption, and appliance data from 1156 rural consumers in 34 states were analyzed to determine coefficients of equations for predicting the 30-minute demands of individual consumers. Consumers in the South were found to have higher demands in relation to energy consumption than those in the North, and separate analyses were made for the two regions. The equations for predicting demand when used with appropriately programmed computers permit the automatic print-out of lists of consumers that may have overloaded transformers or services. Equations for predicting individual demands from energy consumptions are first presented. Then the more involved, but more accurate, equations for predicting demand from both energy consumption and appliance data are presented and compared with equations using only energy consumption as the demand predator. The statistical analysis and method of presenting the demand estimating equations permits the distribution engineer to select the approximate percentage of the estimates which will be higher than the actual demands.

The National Electrical Code Procedure and Revisions, *R. Lloyd*—A brief history is given of the development of the present committee structure for producing and revising the National Electrical Code. The procedure permits anyone to submit proposed revision of the code and provides a method of processing that insures a consensus and thus recognition as an American Standard. A review is made of the schedule of revision and the steps taken to insure opportunity for review by industry before adoption. Technical committees are used to solve special problems where additional knowledge is needed. The intended function of tentative interim amendments and official interpretations are explained. Changes made in the 1965 edition of the National Electrical Code include detailed coverage of multispeed

and part-winding motors, definition of unattended expansion of group motor applications, and motor disconnecting means. Other changes pertain to working space, 300-volt fuses, corrosion protection, new types of wire insulation, conduit fill and main protection for lighting, and appliance branch circuit panelboards.

Recent Developments in Large-Scale Use of Electric Light Traps for Control of Field Crop Insects, *J. P. Hollingsworth*—The theory, construction, installation, and operation of electric insect traps, which are used for experimental insect survey and control applications, are described.

Analysis of a DC Power Supply to Regulate on an Open-Loop Basis, *F. F. Judd*—Telephone equipment being used for data transmission, and housed on telephone customer premises, requires miniature ac to dc power supplies. The miniaturization of a dc power supply associated with this equipment has been facilitated by the use of pulse modulation techniques. An analysis is presented of an open-loop regulated dc power supply operating from a commercial ac source. The analysis illustrates how open-loop regulation has been achieved through the use of pulse modulation techniques. The pulse modulation is achieved with a parallel inverter operating into a 2-core transformer at a 20-kHz switching rate. The analysis includes the cases where (1) under ideal conditions there is no error in the pulse duration, (2) the error in pulse duration is a constant finite amount, and (3) pulse-duration error varies on a periodic basis. Both calculated and measured results are presented based on tests made on a breadboard model of the open-loop inverter regulator.

IEEE Transactions on Information Theory

Vol. IT-13, no. 3, July 1967

Asymptotic Performance and Complexity of a Coding Scheme for Memoryless Channels, *J. Zic*—Decoding complexity need not grow exponentially with the code block length at rates close to channel capacity; the expediency of the approach of embedding codes in each other is shown. It is demonstrated that it is possible to communicate over a memoryless channel of capacity C at any rate $R < C$ with a probability of error of less than $2^{-E(R)v}$, $E(R) > 0$, per block of a length approximately proportional to v^2 and with a computational decoding complexity per digit which is asymptotically proportional to v^{α}, when v is large, being finite, or $R < C$. ($\alpha \to \infty$ as $R \to C$ $\alpha \to 2$ as $R + 0$).

A Partial Ordering of Discrete, Memoryless Channels, *H. J. Helgert*—The structure of a partial ordering of discrete, memoryless communication channels is discussed. These are identified with equivalence classes of stochastic matrices into which the set of all stochastic matrices is partitioned by a relation of matrix inclusion. The relation carries over to channels and induces a partial ordering on them, having the property that if K_1 and K_2 are channels such that K_1 includes K_2, then if a code exists for K_2, there exists a code for K_1, whose probability of error is never greater than that of the code for K_2. Results are derived that specify the equivalence classes of stochastic matrices corresponding to the binary and the symmetric channels and resolve the structure of the partial ordering between the channels.

Reinforced Prefixed Comma-Free Codes, *C. V. Ramamoorthy, D. W. Tufts*—Signal flow graph methods are applied to the problem of counting the number of allowable code words for certain classes of prefixed comma-free codes. This method can be applied whenever the distance between the prefix and other A-tuples in the code word is a prescribed function of the position of the A-tuple. Such codes can have desirable synchronization properties without leading to very small code word sets.

A Statistical Theory of Reverberation and Similar First-Order Scattered Fields, Part I, *D. Middleton*—A theory of reverberation and related first-order scattered fields is developed, based on the assumption of weak inhomogeneities (i.e., primary scattering only), and a consequent representation in terms of Poisson point processes in space and time. Both surface and volume reverberation are included, separately and together, for general geometries, source and receiver at the same and different locations, and arbitrary transmitting and receiving apertures. A combination of field and ray theory is employed to obtain a characteristic scattered waveform, where the inhomogeneous medium is replaced by a homogeneous and isotropic one in which a spatially and temporally random ensemble of point scatterers is embedded. The effects of the scattering mechanism are described generally by a linear, time-varying filter response. Broadband as well as narrow-band signals and reverberation are included in the model, which is capable of handling general apertures, illuminating signals, Doppler of the scatterers, multiple sources and receivers (overlapping beams), and a characteristic time-varying scatter mechanism, that reveals in detail the inherent nonstationarity of the reverberation. Shadowing effects of "rough" surfaces are included, and a variety of important special results, such as the case of narrow-band excitation and simple (time- and frequency-independent) scattering are also described. The emphasis is on broadband (frequency-dependent) structures, and their associated space–time operators.

A Statistical Theory of Reverberation and Similar First-Order Scattered Fields, Part II, *D. Middleton*—The second-order statistics (intensities, covariances, and spectra) of reverberation processes are determined in detail. In addition to the fluctuation, or purely random component of the received scatter process, an average or purely deterministic component often exists and may be significant, particularly for scattering from surfaces. Particular attention is given to narrow-band signals. A variety of expressions for the covariances of the slowly varying components of the received reverberation is developed in detail, for both surface and volume scatter. These results are very simply combined (additively in the means, variances, etc.) to yield analogous results for the complete, or composite reverberation process. Conditions for normality are given and a number of new results for the probability densities of such nonstationary, narrow-band Gaussian processes are obtained. The first-order statistics of the envelope and phase of the received scattered return are also derived, for general narrow-band signals, extending the earlier work of Rayleigh, Rice, Hoyt, Nakagami, Middleton, and Beckmann. Many special cases for arbitrary illuminating signals are considered, including an ambient noise model, an approach to complex (distributed) targets, uniform beams, multiple receivers, transmitter and receiver at the same location, large and small Doppler, etc., where the general formulation is broadband, given in terms of frequency-selective apertures, time-varying dynamic cross sections, and arbitrary input signal waveforms. A number of second-order statistical properties of the medium response are defined and evaluated, which are needed for the combined theoretical and experimental exploration of the medium itself.

Performance of an M-ary Orthogonal Communication System Using Stationary Stochastic Signals, *A. J. Viterbi*—The performance of a communication system that transmits for T seconds the real part of a sample function of one of M stationary complex Gaussian processes whose spectral densities are all frequency translations of the function $S_\xi(f)$ is considered. At the receiver white Gaussian noise of one-sided density N_0 is added. The center frequencies of the processes are assumed to be sufficiently separated that the M covariance functions are orthogonal over T. Exponentially tight bounds are obtained for the error probability of the maximum-likelihood receiver. It is shown that the error probability approaches zero exponentially with T for all rates $R = (\ln M)/T$ up to

$$C = \int_{\infty}^{\infty} [S_\xi(f)/N_0]df - \int_{\infty}^{\infty} \ln [1 + S_\xi(f)/N_0]\, df$$

which is shown to be the channel capacity. Similar results are obtained for the case of stochastic signals with specular components.

Asymmetric Signal Design for the Coherent Gaussian Channel, *B. Dunbridge*—Signal design theory is concerned with the problem of determining transmitter signal waveforms such that the probability of correct reception (or some other appropriate measure of communication efficienoy) is maximized. The selection of signals must be performed under specified constraints of signal power and bandwidth and channel noise disturbance. Three cases are treated for the coherent Gaussian channel: (1) white noise, equal signal energies, unequal message probabilities; (2) white noise, average signal power bounded, equal message probabilities; and (3) colored noise, average signal power bounded, equal message probabilities. In each problem, necessary general conditions for signal optimality are derived, and specific solutions obtained for small and large signal-to-noise ratios (SNRs). Complete solutions are indicated for the case of three messages. It is shown that the regular simplex codes are always global solutions at large SNR. Other results are also presented.

New Calculations for Echo-Ranging Ambiguity, *D. E. Weston*—In correlation echo ranging the ambiguity, or square of the signal autocorrelation envelope, is important, and two new approaches are presented that speed up general ambiguity calculations. Some signals such as linear FM can be represented by lines in a frequency–time plot, and for two such lines the cross ambiguity is associated with the point of crossing and depends on the angle of crossing. This method is extended to curved lines, including lines that touch rather than cross. Other signals have a noiselike modulation, and may be conveniently described by a distribution of spectral intensity in the frequency–time plot. For two such noise signals the mean value of the cross ambiguity depends very simply on the overlap of the two distributions. In the limit the two approaches are shown to give answers consistent with one another. In one illustrative application it is shown that, with symmetrical pulse forms, a high ambiguity at the extremes of the ambiguity diagram is always accompanied by an ambiguity concentration near the origin. In another example the ambiguity diagrams and general behavior are calculated for straight and slightly curved lines (FM pulses), for both the narrow-band and wide-band cases.

A Projection Method for Signal Detection in Colored Gaussian Noise, *T. Kailath*—The problem of the detection of known signals in colored Gaussian noise is usually studied through infinite-series representations for the signals and noise. In particular, the Karhunen–Loève (K-L) expansion is often used for this purpose. Such infinite-series methods, although elegant, often introduce mathematical com-

plications because they raise questions of convergence, interchange of orders of integration, etc. The resolution of these problems is difficult and has led, when the K-L expansion is used, to the introduction of subsidiary conditions whose physical meaning is often unclear. A method of reducing the detection problem to a finite-dimensional form where many of the difficulties with the infinite-series K-L expansion do not arise is presented. The resulting simplicity provides more direct derivations of and more physical insights into several earlier results. It has also suggested some new results. The method is essentially based on the use of a projection in a special kind of Hilbert space called a reproducing kernel Hilbert space.

The Joint Estimation of Signal and Noise from the Sum Envelope, *T. R. Benedict, T. T. Soong*—The separate estimation of carrier strength and of narrow-band additive noise strength from N envelope samples is considered. The mathematical problem is one of the joint estimation of the two parameters in the Rice probability density function. The estimation is useful, for example, in the radar analysis of targets containing both specular and distributed components. In the mathematical analysis, theoretical Cramér–Rao lower bounds on the standard deviation in unbiased estimation are first determined. Estimation procedures based upon the method of maximum likelihood and two simple methods of moments are then developed. An error analysis for each procedure is performed by Monte Carlo simulation. For the purpose of comparison, two direct averaging methods are also analyzed. Results are extended to the case where an additional noise is also present, but with known strength. It is also shown that the time average of a slowly-varying carrier strength can be estimated despite the presence of noise.

On the Design of Optimum Radar Waveforms for Clutter Rejection, *D. F. Delong, Jr., E. M. Hofstetter*—The problem considered is that of designing radar signals and receivers that are optimum for detecting a point target masked by a background of clutter returns and thermal noise. The problem of choosing an optimum signal when no constraints are placed on the type of signals allowed is discussed briefly; however, signals and receiver impulse responses that are uniformly spaced, phase and amplitude-tapered pulse trains, are mainly considered. Expressions for the signal-to-interference ratio obtained when a signal is used with its matched filter (ρ_{mf}) and with the optimum filter or clutter filter (ρ_{cf}) are derived together with an explicit expression for the clutter filter. An iterative technique for maximizing ρ_{cf} is devised. This scheme has the useful property that it generates a sequence of signals whose ρ_{cf}'s form a monotone, nondecreasing sequence. This is followed by an application of the calculus of variations to derive the Euler equations for the stationary points of ρ_{cf} and ρ_{mf}. The form of the Euler equations suggests iterative techniques for their solution; in fact, the technique suggested for the solution of Euler equation associated with ρ_{cf} is essentially the iterative technique that was described above. Some results aimed at establishing conditions under which the performance of the optimum signal-filter pair can be achieved by means of a matched filter, i.e., conditions under which $(\rho_{mf})_{\max} = (\rho_{cf})_{\max}$, are presented.

Chernov Bounds for Channels with Infinite Memory, *M. M. Gouttmann*—The problem of Chernov bounding is analyzed for symmetric channels with input alphabet of arbitrary finite size or erasure channels with no cross over errors whose memory may be described in terms of the noise sequences by an infinite ergodic irreducible aperiodic Markov chain. Necessary and sufficient conditions are described that guarantee the existence of an exponential upper bound to the probability of error for block coding. These conditions are given in terms of the transition matrix of the Markov chain. It will be observed that, although their application involves merely an inspection of the transition matrix, they are based on the topology of the Markov chain and the convergence of sequences of transition probabilities.

A Comparison of Arbitrary and Symmetric Channels on the Basis of Capacity, *H. J. Helgert*—Certain upper and lower bounds on the capacity of arbitrary discrete, memoryless channels are discussed. A given channel is related to an n-ary symmetric channel through a series of operations on the channel matrix, none of which can increase capacity. The bounds are then obtained from the known formula for capacity of a symmetric channel.

Distortionless Data Transmission with Minimum Peak Voltage, *F. Amoroso, M. Montagnana*—Knowing that the tails of the ideal $\sin \pi t/\pi t$ pulse represent a divergent series, the problem is stated of finding distortionless band-limited waves that give rise to a minimum of the worst peaks of voltage that can appear on the channel in unit-height binary transmission. The optimization problem is then solved for all sampling rates up to one half the Nyquist rate by the *unique* wave that never gives rise to more than one volt on the channel, just the magnitude of the data bits themselves. An upper bound is established on the worst channel voltage at higher rates by means of a class of pulses whose spectrum reduces to the optimum when the sampling rate parameter is chosen to be one half the Nyquist rate. A time-domain optimization principle is stated that deals with zero manipulation, and the implications for the concept of dimensionality are discussed. The principal results are related to other system concepts, including timing-jitter immunity and duobinary transmission.

On a Class of Linear Time-Varying Filters, *P. A. Franaszek, B. Liu*—A special class of linear time-varying filters, members of which are commonly employed in practice, are discussed. Some of these filters share a number of desirable properties with linear stationary systems, the most important of which is the preservation of wide sense stationarity of stochastic inputs. An application to the problem of transmitting a continuous signal over a sampled data channel is included. Some results coincide with those for a multichannel system with simultaneous optimum stationary presampling and postsampling filters.

On Probability Distributions for Filtered White Noise, *S. S. Wolff, J. L. Gastwirth*—When white noise generated by an underlying Poisson process is filtered by any member of a large class of stable (not necessarily linear nor stationary) filters, the first-order probability distributions of the filter output is infinitely divisible. The Kolmogorov canonical form for the characteristic function is displayed and related to the parameters of the white noise and of the filter. In certain linear stationary cases, subclasses of the infinitely divisible distributions are identified. An invariance property of the bilateral exponential distribution is demonstrated.

Sequential Recognition Using a Nonparametric Ranking Procedure, *K. S. Fu, Y. T. Chien*—In the problems of statistical pattern recognition, it has become increasingly known that there are many applications in which parametric assumptions regarding the pattern statistics are not justified. A nonparametric design of a sequential recognition machine that uses the optimum property of Wald's sequential probability ratio test (SPRT) is treated. For the case of binary classification, a sequential ranking procedure is found useful in a two-sample problem in which we wish to test the hypothesis against the Lehmann alternatives, based on the successively ranked observations. The test procedure is then analyzed in terms of the performance criterion, which in this case is the expected number of observations, with specified error probabilities. A generalization procedure of multiple classification is also given as a direct extension. Computer-simulated experiments have illustrated the effectiveness of this test procedure in the recognition of handwritten English characters, where the nonparametric method seems to be necessary and appropriate.

Networks of Gaussian Channels with Applications to Feedback Systems, *P. Elias*—Networks (directed graphs) having one input node, one output node, and an arbitrary number of intermediate nodes, whose branches are noisy communications channels, in which the input to each channel appears at its output corrupted by additive Gaussian noise are discussed. Each branch is labeled by a nonnegative real parameter that specified how noisy it is. A branch originating at a node has as input a linear combination of the outputs of the branches terminating at that node. The channel capacity of such a network is defined. Its value is bounded in terms of branch parameter values and procedures for computing values for general networks are described. Explicit solutions are given for the class D_0, which includes series-parallel and simple bridge networks and all other networks having r paths, b branches, and v nodes with $r = b - v + 2$, and for the class D_1 of networks, which is inductively defined to include D_0 and all networks obtained by replacing a branch of a network in D_1 by a network in D_1. The general results are applied to the particular networks that arise from the decomposition of a simple feedback system into successive forward and reverse (feedback) channels. When the feedback channels are noiseless, the capacities of the forward channels are shown to add. Some explicit expressions and some bounds are given for the case of noisy feedback channels.

Nonlinear Transformations of Random Processes, *N. Abramson*—A general method of calculating the mean-square bandwidth (and other spectral moments) of an arbitrary zero-memory nonlinear transformation of a stationary random process is shown. The method is valid when the original process is an arbitrary combination of other random processes. It can be used to determine the mean-square bandwidth (or the spectral moments) of the transformed process either before or after that process is passed through a bandpass filter. Five examples of the application of this method are provided simplifying and generalizing known results, as well as providing new results.

Information Rates in Sampling and Quantization, *W. C. Kellogg*—A computer-sided analysis of a digital communications system has been conducted. Salient results compare the performance of approximately optimum PCM systems with the rate-distortion function, under the assumptions of Gaussian inputs and mean-square-error distortion measure. The calculated distortion is greater than the theoretical minimum by two or three decibels in most cases. The results presented also illuminate the tradeoff between sampling rate and number of quantization levels in a channel of fixed capacity. The presampling and reconstruction filters are represented in the computer by their impulse responses; that is, filtering of signals is accomplished by evaluating the convolution intergrals numerically. Impulse responses with durations of 20 sample times or fewer are long enough to model most known results in optimum filtering of sampled stationary random functions. Procedures are described for computing the autocorrelation function of the quantizer output, and the cross correlation between the quantizer output and a signal correlated with the input. The procedure

adopted is the naive one of integrating numerically the appropriate bivariate normal distribution.

Truncated Sequential Hypothesis Tests, *J. J. Bussgang, M. B. Marcus*— Through a careful examination of the equations by which Wald determines the values of the boundaries for tests of sequential hypotheses, interesting relationships for the conditional probability distributions of the stage at which the test terminates are obtained. Thus, sequential tests in which the boundaries are functions of the sample number can be studied. Tests with convergent boundaries are shown, and a set of boundaries that approach those of a truncated Wald test are investigated. Approximate expressions for the expected sample number and probabilities of error are obtained for the tests considered. The obtained approximations apply best for gently tapering slopes. Extensions of our method can be applied to evaluate various *ad hoc* schemes for truncating tests and to the theory of tests with a varying parameter.

Correspondence

Correlation Function Bounds for Aperiodic Signals, *R. D. Yates, G. R. Cooper*

The Minimum Optimal Linear Decision Rule Based on First- and Second-Order Statistics, *K. A. Belser*

On the Generalized Karhunen–Loeve Expansion, *K. S. Fu*

On the Asymptotic Behavior of the Approximations for the Probability of Error and the Entropy of a Stationary Random Process, *C. T. Wolverton, T. J. Wagner*

Performance of N-Orthogonal Codes, *A. J. Viterbi, J. J. Stiffler*

On the Optimum Coincidence Procedure in the Presence of a Fluctuating Target, *G. Grasso, P. F. Guarguaglini*

The Correlation Function of a Sequence of Roots of 1, *R. Turyn*

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Decision Making in Markov Chains Applied to the Problem of Pattern Recognition, *J. Raviv* – In many pattern-recognition problems there exist dependencies among the patterns to be recognized. In the past, these dependencies have not been introduced into the mathematical model when designing an optimal pattern recognition system. The optimal decision rule is derived under the assumption of Markov dependence among the patterns to be recognized. Subsequently, this decision rule is applied to character-recognition problems. The main idea is to balance appropriately the information that is obtained from contextual considerations and the information from measurements on the character being recognized and thus arrive at a decision using both. Bayes' decision in Markov chains is presented and this mode of decision is adapted to character recognition. A look-ahead mode of decision is presented. The problem of estimation of transition probabilities is discussed. The experimental system is described and results of experiments in which English legal text and names were used are presented.

Line Spectrum of Series of Time-Correlated Pulses Having Random Shape and Amplitude, *P. Mazzetti, G. P. Soardo*—The most general case is examined of series of pulses having a line spectrum besides a continuous one, characterized by the following conditions: (1) Pulses are distributed in time according to an arbitrary distribution function $P(x)$, x being the time interval between two consecutive pulses. (2) The time intervals x relative to different pairs of pulses are uncorrelated. (3) Pulse shape is random and no correlation exists between shapes of different pulses. However, an arbitrary correlation can exist between a pulse amplitude and the time interval separating this pulse from the preceding one. It is shown that under these conditions a line component can be present only in the spectrum of series of pulses whose distribution function $P(x)$ has the form: $P(x) = \sum_m b_m \cdot \delta(x - x_m)$. A simple expression giving the intensity of the lines is derived by means of an integration method in the complex plane, which can be applied to similar calculations in more general cases. As an application it is shown that the power spectrum of series of pulses that have a distribution function $P(x)$ of the said form, and are moreover characterized by a random pulse position modulation, can be easily obtained from the derived general results.

Optimal Nonlinear Filtering for Independent Increment Processes— Part I, *J. R. Fisher, E. B. Stear*—A new formulation of the multidimensional optimal nonlinear filtering problem is presented. This formulation permits generalization and unification of some well-known recent results on optimal nonlinear filtering theory. Specifically, the problem investigated is that of determining the conditional probability density function of $\mathbf{x}(t)$ given $\{\mathbf{y}(\tau); t_0 \leq \tau \leq t\}$, where $\mathbf{x}(t)$ is the n-dimensional state vector of a nonlinear system perturbed by an independent increment noise process, and $\mathbf{y}(t)$ is an m-dimensional measurement vector that is a nonlinear function of $\mathbf{x}$ and contains additive independent increment noise process. The results are obtained through use of characteristic functions and the theory of independent increment processes. The foundation for the treatment of general independent increment noise processes is given, but the final results are restricted to Gaussian independent increment noise processes. It is shown that the results for the linear Gaussian case can be obtained in two different ways, one of which cannot be used for the general case. Some important properties of general independent increment processes and a special property of Gaussian independent increment processes are discussed.

Optimal Nonlinear Filtering for Independent Increment Processes—Part II, *J. R. Fisher, E. B. Stear*—A new basic stochastic integro-partial differential equation for the conditional probability density function for the state of a nonlinear dynamic system with disturbance noise given noisy nonlinear measurements of the state is derived under the less restrictive assumption that the disturbance noise is an arbitrary independent increment process with an infinitely divisible distribution, and the measurement noise is a Gaussian independent increment process with an infintely divisible distribution. It is then shown that, under proper restrictions, this basic equation reduces to either the Fokker–Planck equation for diffusion processes or the Kolmogorov–Feller equation for jump processes. Also, it is shown that this basic equation contains earlier results as special cases. Next, it is shown how the result represented by this basic equation can be easily extended to include the case where the disturbance noise is a Markov process of the type initially assumed for the state of the dynamic system. Finally, it is shown that, in contrast to earlier results for the linear Gaussian case, it is not generally possible to extend the result represented by this basic equation to include either the case where the measurement noise is a Markov process of the type initially assumed for the state of the dynamic system, or the case where the covariance matrix of the Gaussian measurement noise is singular. However, some incomplete results indicating when such extensions might be possible are given.

A Partial Spectrum Approach to the Analysis of Quasi-Stationary Time Series, *R. L. Snyder*—The notion of a stationary random function is generalized to include random functions whose statistical properties vary slowly with time. A criterion for quasi-stationarity is proposed, and two methods for the spectral analysis of quasi-stationary time series are presented. The first of these, the method of partial series, is equivalent to treating the series as stationary in each of several subseries. The second, the method of partial spectra, involves an expansion of time-dependent local energy spectrum in orthogonal functions of the interval of analysis. An estimate of the coefficient of the nth-order function is given by the cosine transform of the time-wise cross-correlation of the series with the product of the series and the nth-order function. The statistical reliability of this estimate and of the reconstructed spectral estimate is investigated, and a numerical example from a field study of the wind generation of ocean waves is presented.

A Search Procedure for Finding Optimum Group Codes for the Binary Symmetric Channel, *N. Tokura, K. Taniguchi, T. Kasami*— A systematic procedure for finding optimum error-correcting group codes for the binary symmetric channel with m check digits and a minimum distance not less than d_0, where m and d_0 are given integers, is presented. Some new schemes for reducing the computing time are used. The search procedure is readily programmable for computer execution and several programs were carried out on an IBM 7044. The newly found seven optimum triple-error-correcting group codes and six optimum double-error-correcting group codes including five quasi-perfect double-error-correcting codes are tabulated. Also, a list of optimum shortened cyclic codes found by a similar procedure is presented. The efficiency of the search procedure is demonstrated by the fact that the program yielded the new codes in a fairly short time.

Limit Distribution of the Minimum Distance of Random Linear Codes, *J. N. Pierce*—The distribution of the ratio of minimum distance to code length of a random linear code approaches a step distribution as the code length becomes arbitrarily large at fixed code rate. The location of the step is at the smaller value of p satisfying $1 + p \log_2 p + (1 - p) \log_2(1 - p) = k/n$.

On Linear Unequal Error Protection Codes, *B. Masnick, J. Wolf*—The class of codes discussed has the property that its error-correction capability is described in terms of correcting errors in specific digits of a code word even though other digits in the code may be decoded incorrectly. To each digit of the code words is assigned an error protection level f_i. Then, if f errors occur in the reception of a code word, all digits that have protection f_i greater than or equal to f will be decoded correctly even though the entire code word may not be decoded correctly. Methods for synthesizing these codes are described and illustrated by examples. One method of synthesis involves combining the parity check matrices of two or more ordinary random error correcting codes to form the parity check matrix of the new code. A decoding algorithm based upon the decoding algorithms of the component codes is presented. A second method of code generation is described that follows from the observation that for a linear code, the columns of the parity check matrix corresponding to the check positions must span the column space of the matrix. Upper and lower bounds are derived for the number of check digits required for such codes. The lower bound is based upon counting the number of unique syndromes required for a specified error-correction capability. The upper bound is the result of a constructive procedure for forming the parity check matrices of these

codes. Tables of numerical values for the upper and lower bounds are presented.

Correspondence

Decoding of Bose–Chauduri–Hocquenhem Codes and Prony's Method for Curve Fitting, *J. K. Wolf*

A Unified Approach to the Detection of Fluctuating Pulsed Signals in Noise, *E. H. Moore*

Some Comments on *N*-Orthogonal Codes, *G. Einarsson*

A Comparison Between Pattern Classification Approaches, *T. J. Wagner, J. M. Pitt, B. F. Womack*

The Number of Different Possible Compact Codes, *E. Norwood*

Generating Random Numbers Having Probability Distributions Occurring in Signal Detection Problems, *G. M. Dillard*

Transmission of Analog Waveforms Through Channels with Feedback, *J. P. M. Schalkwijk, L. L. Bluestein*

Optimal Binary Sequences for Spread Spectrum Multiplexing, *R. Gold*

Average Digit-Error Probability After Decoding Random Codes, *J. N. Pierce*

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Chemical Vapor Deposition of Epitaxial Garnet Films, *J. E. Mee*—The chemical vapor deposition of single-crystal metal oxides has recently been extended to the growth of certain epitaxial garnets, in particular YIG on YAG and GdIG on YAG. The light green, transparent films are ~ 3 micrometers thick and are limited in area only by the area of the available YAG seeds. On (100) seeds, the YIG deposits display tiny fingerprint-type magnetic domains as revealed by Bitter patterns and by the Faraday magnetooptic effect; this is in contrast to manganese ferrite films of similar thicknesses that have very large domains in which the magnetic vectors assume the ⟨110⟩ secondary easy axis in the plane of the film. The growth method involved the high-temperature hydrolysis-oxidation of the mixed vapors of the pertinent metal halides at the seed surface. The necessary conditions for single-crystal growth are compared with those for other metal oxides, in particular the ferrites. The present state of the films regarding composition, quality, and magnetic properties is given.

Magnetic Recording Theories: Accomplishments and Unresolved Problems, *D. E. Speliotis*—The published theoretical treatments on the magnetic recording process are reviewed with particular emphasis on the validity of the models and the assumptions on which they are based. It is concluded that the existing theories fairly well describe the geometrical aspects of recording—transducer to medium spacing and gap lengths—but are deficient in describing analytically the magnetic state of the recording medium before and after demagnetization. Calculated magnetization distributions by harmonic analysis for different recording media support the fact that the usually assumed linear and arctangent magnetization transitions are only rough approximations of the magnetic state of a recording medium between regions of opposite magnetization. Additional shortcomings of our theoretical understanding are indicated by the assumptions of uniform magnetization through the recording medium thickness, neglecting the perpendicular component of the magnetization, and not taking into account finite track widths and magnetostatic interactions between adjacent transitions.

A Novel Technique for the Measurement of Demagnetizing Fields in Longitudinal Recording, *J. C. Mallinson*—The maximum losses occurring at very short wavelengths due to demagnetization in γ Fe_2O_3 tape have been calculated to be rather small (4.5 dB and 8 dB for magnetic and nonmagnetic head reproduction, respectively) and they are therefore difficult to measure in the face of the relatively large and indeterminate spacing loss. A method is described for testing a particular tape in free space that avoids the difficulty. Essentially, a determination of the incremental remanent susceptibility of the tape is made. Because the remanence curve is so highly nonlinear, this susceptibility is uniquely associated with the demagnetizing field within the tape. Whereas the demagnetizing fields thus found agree with theory for wavelengths greater than one mil, they decrease, contrary to expectations, at the shorter wavelengths.

Thin Evaporated Films with High Coercive Force, *J. P. Lazzari, I. Melnick, D. Randet*—A technique allowing the preparation by vacuum evaporation of a material usable as a storage medium in digital magnetic recording is described. It consists of the evaporation of successive chromium and cobalt layers on a substrate, the nature of which seems indifferent. The coercive force can be adjusted from 200–600 Oe by adjusting the cobalt layer thickness. Superimposing identical double layers of chromium-cobalt allows one to obtain the required amount of flux. Such a multiple-layered film gives properties identical to those of a homogeneous magnetic material with a coercive force between 200–600 Oe and an induction better than 10 000 gauss. These properties are isotropic. High squareness of the hysteresis cycle, with $Mr/Ms > 0.95$, is achieved.

A Study of Peak Shift in Thin Recording Surfaces, *J. R. Morrison, D. E. Speliotis*—One of the most severe limitations on high-density digital recording is imposed by peak shift, which is defined as the outward displacement of the readback signal peaks corresponding to a recorded bit pattern of two successive ones followed and preceded by a number of zeros. Results of an experimental study of peak shift in thin metallic media are presented, along with a correlation of the measured percent peak shift with the magnetic properties and the thickness of the media. It was found that the percent peak shift at a specified bit density varies proportionally with the thickness to the coercivity ratio for coercivities larger than 250 Oe. For lower coercivities, the remanent magnetization of the recording surface becomes increasingly significant in adversely affecting the peak shift, with a corresponding decrease in the importance of thickness. By superposing isolated pulses it was possible to predict the percent peak shift up to extremely large bit densities.

Factors Influencing Write Current in NRZ Recording, *C. B. Pear, Jr.*—The concept is advanced that the write head current amplitude that produces maximum output for a given set of recording conditions can be determined by three nearly independent factors. The first is a static factor related to the head geometry and reluctance at very low frequencies. The second is a time factor related to the tape speed and transient response of the head, and the third, a density factor, is determined by the recorded bit density. The time and density factors can be expressed by a set of normalized curves that are relatively independent of head characteristics.

Effects of the Writing Process and Crosstalk on the Timing Accuracy of Pulses in NRZ Digtial Recording, *A. V. Davies*—The position at which a NRZ transition is recorded is dependent on the write current the effect of increasing the current being to shift the recorded position beyond the trailing gap edge. The shift is more marked with a thick medium than a thin coating, and is worsened if the write head pole tips are approaching saturation. If the recording field changes magnitude when reversed, positive pulses become displaced relative to negative and pulse pairing occurs. It is pointed out that when recording different patterns on adjacent tracks, peak shifts can occur due to writing crosstalk aiding or opposing the head field, and the shifts may well impose an upper limit to track density.

Thyristor Converters Using Saturable Reactors, *S. B. Dewan, G. J. Bendzsak*—In dc to ac and ac to ac series converters, the thyristors are turned off by the ringing components, the inductance L, and the capacitance C. For fixed values of the load resistance R and the output frequency f_0, the best values of L and C for the minimum thyristor derating are developed. If L and C are infinitely variable, the optimum performance can be obtained at any value of R and f_0. Continuous control of the value fo the ringing capacitance C is usually uneconomical in large power applications. On the other hand, the output frequency f_0 can be allowed to vary in some applications (e.g., heating). It is shown that if f_0 is allowed to vary and two saturable reactors are used, a wide load range can be supplied with the optimum utilization of the thyristors. The theoretical results are verified on an experimental model of an ac to ac converter using two saturable reactor.

Nonlinear Reactors as Protective Elements for Thyristor Circuits, *D. A. Paice, P. Wood*—Control of rate of change of current and voltage in thyristor power circuits is provided in diverse ways according to the special features of the particular problem and the ingenuity of the designer. It is shown that the use of a nonlinear reactor in series with the thyristor provides advantages in some surge suppression networks, and a design technique is presented for these reactors. Characteristics of a basic damping circuit are presented in the form of nondimensional design curves, and a relationship is established between the losses of a surge suppression network and the thyristor $\delta i/\delta t$ and $\delta V/\delta t$ capabilities.

High-Voltage Multiple-Phase Thyristor Chopper for Traction Motor Control, *E. Ohno, M. Akamatsu*—The dc chopper drive of traction motors using thyristors has many advantages such as the improvement of efficiency, stepless control of motor current, and the elimination of mechanical contactors and the associated maintenance. A considerable amount of literature has been published concerning chopper circuitry and its application to dc motor control. There are some problems to be solved, however, for the actual application in electric railways; the first is the realization of a high-voltage chopper, the second is the reduction of inductive interference, and the third is the reduction of weight and cost of chopper equipment. The characteristics of a multiple-phase chopper circuit developed for traction motor control system are described. The multiple phase chopper with common load has proved to have the excellent property of reducing the higher harmonic components both in input current and in output current. This results in reducing the inductive interference and minimizing the weight of the smoothing reactor.

The Thyristor Commutatorless Motor, *E. Ohno, T. Kishimoto, M. Akamatsu*—The commutatorless motor (CLM) is a type of a dc motor whose commutator is replaced by the thyristor power converter. The thyristors are switched by the signals from a position sensor connected to the rotating shaft of the synchronous motor. Therefore, the CLM never loses synchronism and has the good speed characteristics of a dc motor. The

current-type CLM, having a current smoothing reactor, was studied and found to have better characteristics than the voltage type. Two kinds of the current-type CLMs are described; one is the dc CLM using an inverter, the other the ac CLM using a cycloconverter.

Thyristor-Controlled Single-Phase Variable Inductor, *P. C. Sen, P. P. Biringer, R. S. Segsworth*—A system is described that provides a smoothly variable inductor using thyristors to switch the input current and a unique technique to reduce undesirable harmonics. The basic principle is outlined and the theory of harmonic reduction is developed. Operation of the circuit is described and mathematical analysis is obtained for the system. The circuit parameters are optimized for minimum harmonic contents in the input current over a wide range.

A Frequency Control Technique Applicable to Either Voltage- or Current-Feedback Magnetically Coupled Switching Transistor Oscillators, *E. T. Moore, T. G. Wilson, J. N. McIntire, D. N. Cox*—Through the use of nonlinear circuit techniques similar to those normally associated with series-connected magnetic amplifiers, it is possible to modify the basic circuits of almost all of the numerous types of magnetically coupled switching-transistor multivibrators so as to provide for frequency control of these circuits by means of a low-level dc control signal. Using two well-known types of such inverter circuits as examples, the basic principles involved in this frequency-control technique are described and the operation of two test circuits discussed. A primary advantage of this frequency-control method is its physical simplicity and low cost.

A Static DC to Sinusoidal AC Inverter Using Techniques of High-Frequency Pulse-Width Modulation, *Y. Yu, T. G. Wilson, I. M. H. Bábai, S. Y. M. Feng, E. T. Moore*—A dc to sinusoidal ac inverter is described in which high-frequency pulse-width modulation is used to provide a low-frequency sine-wave output without the need for either a low-frequency power transformer or for low-frequency filter components. The inverter is physically simple and has low weight and small size. From a practical viewpoint the usefulness of this inverter is further enhanced by its self-regulating property. An analysis of this circuit and its output waveform is also given, which provides the mathematical basis for the experimentally observed test results. In addition to the proof of the self-regulating property, it is further proved analytically that the amplitudes of the harmonics of the sinusoidal output voltage are very small with respect to the amplitude of the fundamental voltage.

High-Power Step-Recovery Diodes and Saturable Inductors in Radar Pulse Modulators, *P. R. Johannessen*—Step-recovery diodes are characterized by two distinct reverse recovery phases. During the first phase the minority charge is removed at a low reverse voltage, and during the second phase the reverse voltage builds up rapidly giving rise to the name "step recovery." If such a diode is operated cyclically, the minority charge injected by the forward current is preserved and the minority charge is recovered during the first phase of the reverse recovery interval. This situation is the dual of a nonlinear inductor with rectangular hysteresis loop core material operated cyclically in and out of saturation. Thus, the step-recovery diode can be used to construct a pulse compression network that essentially is the dual of the nonlinear magnetic pulse compression network. The nonlinear dielectric pulse compression network that uses step-recovery diodes can efficiently generate high-power pulses down to pulse widths of a few nanoseconds. In addition the dielectric network provides much higher pulse compression per stage, thus reducing the volume, weight, and number of components.

Cryotron-Based Random-Access Memory, *A. R. Sass, W. C. Stewart, L. S. Cosentino*—Recent progress in the design of large-capacity cryoelectric random access memories is described. Three-wire cryoelectric memory cells and the hybrid AB system organization that utilizes coincident-current selection are examined from the standpoint of batch fabrication requirements, redundancy, electrical parameters, tolerances, and noise immunity. The advances that have been made with experimental subsystems are described in relation to previous work and are shown to place cryoelectrics as a strong contender in the achievement of a system whose capacity is 10^8 bits or larger.

Flux Shuttling—A New Method for the Nondestructive Readout of Superconductive Memory Cells, *A. R. Sass, E. M. Nagle*—A novel technique for the nondestructive readout of a superconductive memory cell is described. The method is of rather general applicability since it can be utilized for the NDRO of many of the known persistent current cells. A description of the technique in comparison with previous NDRO methods as well as experiments on a memory cell that utilize this new NDRO technique are discussed. The possibility of using this scheme for random access and associative memories is briefly examined.

Contribution to the Use of Superconducting Shields for Magnetic Field Shaping, *R. Minet, H. A. Combet, J. Y. Le Traon, J. Schmouker*—The low field diamagnetism of superconductors has often been used to design quasi-ideal magnetic circuits especially for traveling-wave maser (TWM) magnets. An analogical approach to the calculation of the efficiency of such nonideal cylindrical superconducting shields is presented. In most cases, the problem reduces to a two-dimensional Laplace equation with given boundary conditions. The logarithmic complex potential log $(Bx\text{-}iBy)$ has been used to obtain the field homogeneity and disorientation. Partially penetrated shields may be replaced by perfect equivalent ones. The analog measurements on conducting paper permit quick iterations of the solution. Various field component measurements have been done on TWM magnets using bismuth thin-film Hall probes and found to be in good agreement with the analog measurements.

An AC Quench Phenomenon in Hard Superconducting Wires, *L. A. Finzi, T. W. Grasmehr*—The process leading to the quench of superconductivity in a nonideal type II superconducting wire carrying an audio-frequency alternating transport current in a normally applied static magnetic field was studied. The quench of superconductivity was found to initiate from particular points of 10-mil-diameter Nb 25 percent Zr wire in repeated tests. In the course of the experimentation a nucleation site was closely bracketed by potential probes and the voltage response of this segment at currents less than the quench current was studied. Utilizing a limited current density model to describe the ac conduction process, the previous voltage response measurements were used to calculate values for the model parameter J_c. The model was extended to include heating effects and a regenerative process that leads to a quench of superconductivity. Quench current prediction based on voltage measurements prior to the quench at a single frequency agree favorably with measured quench currents over a relatively wide frequency range.

The Use of Superconducting Coils as Energy Storage Elements in Pulsed System Operations, *E. J. Lucas, Z. J. J. Stekly, A. Foldes, R. Milton*—The possible reductions in the size and weight of energy storage systems through the use of superconducting coils in place of capacitors indicate that superconducting coils offer significant potential for use in pulsed operations. Two systems utilizing superconducting coils have been built and successfully tested. The first system described made use of an 8.35-mH coil that was charged to a maximum current of 1350 amperes and discharged into a 2.5-ohm resistive load. This system was then repetitively pulsed at a 10-second rate for a series of ten 3200-joule pulses. The second system made use of a 1.92-mH coil. This system was charged to a maximum current of 8000 amperes in three seconds and discharged into a 0.5-ohm resistive load. Both coils were wound with a copper-stabilized NbZr conductor.

Worm Motion of Domain Walls in Permalloy Films, *T. Kusuda, S. Konishi, Y. Sakurai*—Abnormal wall motion in Permalloy films was observed by Kerr magnetooptic apparatus under hard axis pulse drive with nanosecond rise time. Although this phenomenon is like creeping, the observed domain tip and sidewise motion is not monotonous, but looks like worm motion. Each domain expands and shrinks quasi-periodically, and the net magnetization along the easy direction is never constant. This phenomenon depends closely on the field strength and pulse width as well as the rise time of the drive pulse. The thickness range of the films observed was from 330 Å to 3500 Å, and for the films of thicknesses below 860 Å, worm motion never occurred. This suggests that the Bloch wall configuration is essential for such motion, and this was also verified by Bitter patterns. Worm motion was detected not only by Kerr magnetooptic apparatus, but also as a change of amplitude of transverse induced voltage measured with a strip line and sampling oscilloscope system. A theoretical velocity of walls during worm motion was estimated assuming a simple model for Bloch walls and comparing it with experimental results. The so-called creeping in the Bloch wall thickness region was found to be closely related to the worm motion of domain walls.

Dynamic M-H Loop Study of Energy Losses in Thin Ni-Fe Films, *H. C. Bourne, Jr. W. L. Walters*—Dynamic energy losses in thin Ni-Fe films during magnetization reversal under sinusoidal magnetic drive fields of 15 Oe peak at frequencies up to 50 kHz have been studied by direct observation of the dynamic M-H loop. Empirically it is found that the energy losses depend neither upon frequency alone nor on peak drive field alone, but rather upon the slope S in Oe/s of the drive field at the instant of magnetization reversal. Energy losses are proportional to $(S)^{1/2}$ for small S and to S for large S up to $S = 5 \times 10^6$ Oe/s, the apparatus limit. Simultaneous observation of easy-axis and hard-axis pickup loop voltage waveforms indicates that magnetization reversal occurs by coherent rotation for large S and by domain-wall motion for small S. Observed behavior of the energy losses is shown to be in conformity with the classical descriptions of domain-wall motion and coherent rotation.

Experimental Evidence for Radical Dependence of Induced Anisotropy in Cold Drawn Permalloy Wires, *F. C. Rossol*—Measurements of the induced anisotropy in cold drawn niobium-silver Permalloy wires of about 1-mil diameter show that there is a marked radial dependence with the anisotropy increasing rapidly inside of the cold drawn wire. Further, most of the structure in the radial dependence of the anistropy is removed if the wire is given a mild anneal. Measurements are made by etching away outer layers of material and using a magnetic resonance technique to

measure the effective anisotropy within the skin depth below the surface of the remaining wire. The disappearance of the strong radial dependence of the anisotropy on annealing together with the behavior of the anisotropy in the annealed wire under an externally applied tension leads to the conclusion that the radial variation of anisotropy observed in the unannealed wire arises from residual stresses.

Analog Simulation of Flux Reversal in Thin Magnetic Films by Uniform Rotation, *J. D. Gassaway, H. G. Smith*—Results of an analog computer study of flux reversal in thin magnetic films are presented. The computer diagram is given for the simulation of the Landau–Lifshitz equation of motion of the magnetization vector. Solutions of these equations were obtained for pulse fields applied parallel and perpendicular to the easy axis of a film with uniaxial anisotropy. Switching curves are given that show the effect of varying the relaxation frequency λ. The switching time varies by a factor of 3 as λ is varied from 10^8 to 5×10^8 Hz. The various definitions of switching time reported in the literature are also compared. Nonlinear resonance curves are presented for λ values of 10^8 and 1.5×10^8 Hz. The curves represent solutions for the angular velocity of the magnetization when a sinusoidal field is applied perpendicular to the easy axis. For applied fields as large as half the anisotropy field the resonant frequency and line widths are significantly different (20 percent or more) from the small signal values that are useful for determining the anisotropy field H_K and the relaxation frequency λ. It is concluded that the analog technique is convenient for studying magnetic switching problems when the problems can be formulated in terms of ordinary differential equations. Other problems suitable for this approach are studies of flux reversal with various waveforms for the excitation field and of the interaction between coupled films or particles.

Eddy-Current-Free Switching of Permalloy Thin Films, *J. K. Watson, H. C. Bourne, Jr.*—Results are presented from an experimental investigation of large-angle flux reversal of magnetic films. The reported measurements were made with an unconventional instrument with design features that are briefly outlined. Switching characteristics for a selected film are shown, and are compared with results of others in region II at 2° transverse bias. The 6 Oe-ns reported is an order of magnitude faster than others although the switching field rise time is an order of magnitude slower. On a two-dimensional field plot, loci that define thresholds of incoherent rotation are found to have two prominent features: a disperse switching asteroid for $H_x \leq H_k$, and an extension described by $H_x H_\perp / H_k = \Delta$ for $H_x > H_k$. The width of region II, the lower threshold for region II, and the independently measured dispersion field are all approximately 0.1 Oe for the subject film. Thus $\Delta \approx 2H_k \sin \alpha_{90}$.

Ferrite Device Characteristics and Coincident Current Store Performance, *B. Gogos, J. J. Zagurskv*—A shmoo plot or failure boundary curve for a coincident-current store is a region defining the limits of drive current, both address and bit, within which the system can operate satisfactorily. Because of the nonlinear characteristics of the ferrite core, the sense circuitry, and many aspects of the drive system, the exact mathematical expression of a shmoo curve would be quite involved, and therefore is treated empirically. The effect on storage operation of nonuniformity in device properties, such as squareness and threshold, is explored. Based on distributions of certain device properties that can be related to the output parameters of a core measured under conventionally accepted 3D test conditions, constant shmoo curves are derived.

Speed Capabilities of Ferrite Cores in NDRO Operation, *J. F. Coralesk, H. F. Koehler*—Nondestructive readout of ferrite cores with switch times of 4 ns at 80-MHz repetition rates has been attained by permeability sensing the difference signal between a core at its remanent state (low permeability) and a core at its partially switched (maximum permeability) state. Limited-duration interrogate pulses exceeding core thresholds were used. A variety of coercivities, materials, and sizes were investigated. Higher permeability differences were obtained with low-coercivity cores than with high-coercivity cores. Signals of 10 mV were obtained using 21-mil cores 6.7 mils high. Although some cores yield higher difference signals, they are not well suited for memory applications because of their size and drive requirements. Variations in remanent and maximum permeability caused by reset current amplitude were observed. A method for testing and specifying a core for an NDRO application is proposed.

An 80-ns NDRO Ferrite Core Memory Design, *L. J. Bosch, R. C. Flaker, H. G. Hottenrott, N. F. Lockhart*—The use of fast-rising short-duration pulses in the design of a 1K–144-bit NDRO memory with permeability sensing leads to high-frequency considerations not normally encountered in ferrite core memories. In particular, the high-frequency character of the device must be recognized to evaluate properly cycle time capabilities and array transmission. The design of this memory centers around a two-core-per-bit word-organized array. The array was optimized with the aid of a computer analysis that considered the device, array geometry, and line termination as variables. The performance of this system has been tested by a cross-section model incorporating full-length, fully populated word and digit lines.

A Read-Only 70-ns Waffle Iron Memory, *J. F. Aviles, J. M. Bourrez, J. H. Cocquart, P. Meunier, T. Van Khai*—The implementation of a new high-speed read-only memory with waffle-iron structures, allowing ease of information change and high bit density, is described. This information is stored on a copper plate where an anisotropic Permalloy film (10 000 Å) has been electrodeposited and etched according to the data pattern. This plate is positioned into contact with a polished ferrite slab insuring flux closure paths. The storage cell utilizes the coupling between orthogonal word and sense lines obtainable through the magnetic film overlay to represent a one. At zero locations the coupling is canceled when etching away the magnetic film from the copper plate. A 512-word by 32-bit memory makes use of eight waffles. The worst-case access time, including one level of decoding, is measured to be 40 ns; the corresponding cycle time is 70 ns.

Magnetic Thin-Film Access Card System, *E. H. Schmidt, T. J. Cebulla, J. O. Holmen*—A system is described for a low-cost access card system that exhibits a high resistance to conventional decoding and inspection techniques. The system described utilizes the uniaxial anisotropic characteristics of thin magnetic films deposited onto a code card and then encapsulated. Methods of depositing the magnetic materials are discussed and card fabricating and coding techniques are described. Mathematical equations are given for the binary "one" and "zero" output voltages from the sensor as a function of the system parameters. Experimental data are given for several magnetic samples. Comparisons are made between the calculated and experimental results. Four-pole transducer configurations for maximum prevention of code simulation are described.

A Novel Memory Based on the Use of Magnetic Wires with Re-entrant Hysteresis Loops, *P. I. Bonyhard*—Magnetic wires possessing highly re-entrant hysteresis loops can be utilized as general-purpose memory elements. How information is stored by locating a reversal of magnetization in either of two positions along a length of wire corresponding to the memory region is described. There are a number of different memory configurations possible. Several of these have been built and found to operate with large margins. The element is relatively slow, with practical cycle times greater than 10 μs, but it lends itself to inexpensive construction techniques. The high ratios attainable between nucleation and wall motion threshold fields are reflected in similarly high drive current margins and, consequently, hold promise of a high yield in manufacture and thereby low cost. The effective memory speed can be increased by the use of fast nondestructive readout. A unique feature of the element is that time coincidence of drive pulses is unnecessary.

Threshold Fields for Domain-Tip Propagation, *R. J. Spain*—A model is presented for controlled domain-tip propagation, which is used for the construction of magnetic thin film memory and logic devices. The technique, called DTPL, utilizes the dependence of the direction of tip propagation upon the magnitude and direction of the applied field and the magnetostatic interaction between channeled domain tips brought into proximity of one another. In a DTPL device domain-tip propagation channels are, in general, oriented at various angles with respect to the easy axis. With the model for DTPL presented, the threshold for tip propagation can be calculated as a function of channel width and orientation and the direction of the applied drive field.

Functional Domain Wall Propagation Wire Devices for Use in Digital Applications, *R. A. Kaenel*—A new type of anisotropic Permalloy wire was disclosed recently within which reverse magnetized domains can be created and propagated by controlled fields. It offers a flexible yet simple technology that is especially suitable for realizing frequently used functional logic packages. The domain wall propagation phenomenon of such wires is reviewed and attractive device applications outlined. An attempt is made at characterizing this type of wire according to its logic capabilities and at assessing the merits of the associated technology.

A Parallel-to-Serial Converter Utilizing the Property of Domain Wall Motion in Permalloy Wires, *R. F. Fischer, J. Giacchi, R. A. Kaenel*—The domain wall motion phenomenon in some Permalloy wires offers the possibility of magnetically realizing useful functional packages. Several low-current devices of lengths below 300 bits were developed that exploit this phenomenon. A parallel-to-serial converter is described and the technology associated with fabricating this and other low-current functional devices is discussed. The converter is capable of accepting 64 bits of parallel data in 10 μs and delivering it sequentially upon command at the rate of up to 50 kbits/s.

A Character Recognizer Utilizing Domain Wall Motion in Permalloy Wire, *J. L. Smith, R. V. Gunther, R. A. Kaenel*—A 20-bit sequential character recognizer utilizing domain wall wire technology is described. The recognizer is especially well suited for use in portable battery-operated systems because no standby power is dissipated and the operating voltage is only 2 volts. During code transmission the energy required per bit is approximately 1 μJ. The device is coded by punching an appropriate set of holes in a plastic strip. It can be fully tested before coding, which allows mass production of the

device with individual field coding made highly practical.

Hall-Effect Devices, *M. Epstein*—The Hall effect and magnetoresistance in solids are discussed in terms of the Lorentz force on current carriers. The advances in thin-film high-mobility semiconductors are related to the increased utilization and developments of Hall-effect devices. The design of such devices depends, in most cases, on the associated magnetic structures. Several examples of applications of Hall-effect and megnetoresistive devices to measurements, communications, and controls are presented. Limitations in performance due to magnetic structures, current noise, and various other galvanomagnetic and thermomagnetic effects, are discussed to indicate the range of capabilities.

A New Detecting Means with Lead Characteristics in a Carrier-Type Control System, *S. Nyudo, K. Katsura*—In a carrier-type control system, necessary operation usually is conducted after demodulating a modulated actuating signal once to a dc signal. This demodulation undesirably retards a signal. Using a general principle, the value of a modulated signal can be determined during a half-cycle of a carrier wave. A reactor with a rectangular magnetization loop can easily integrate a voltage, add or subtract a flux change and a voltage integration, and store this information. A circuit is described that employs saturable reactors; an error can be measured during a half-cycle, and a large output corresponding to the (proportional plus derivative) value of an error can be obtained.

New Magnetic Amplifier Improves EMF to Current Converter, *H. E. Darling*—The all-solid-state millivoltage to current converter described meets the exacting dependability, accuracy, and stability demanded of industrial process controls. It has a minimum input span of 2 mV direct current, an output current range of 10–50 mA direct current that is virtually independent of load resistance, and complete electrical isolation between input and output. It is intended primarily for use with thermocouples. A new design of the input magnetic amplifier stage results in a very low overall noise figure, a high current gain, and a high effective input impedance (as much as 100 Ω) relative to thermocouple resistance. The converter consists of two separate precision amplifiers in cascade, each stabilized by a large amount of feedback. Zero elevation and cold junction compensation are provided as needed with the aid of a precision Zener diode regulator circuit.

Some Applications of a Magnetic Amplifier to Plant Instrumentation, *C. Kawaguchi, T. Ito, K. Ara*—Failure of an instrument in a plant not only leads to unwanted shutdown of the plant, but also adversely influences plant safety and economy. By the redundancy and decision by majority system which employs a magnetic deviation detector and averaging unit, the reliability of plant instrumentation can be considerably improved. A description is given of its components, i.e., the magnetic deviation detector, magnetic operational applifier, magnetic ON-OFF switch in circuit, 2-frequency-type magnetic amplifier for low-level signals, and magnetic multiplier and divider. The principles are explained and the results of experiments with the system are presented.

Theory of Nonlinear Reactance Amplifiers, *P. R. Johannessen, W. H. Ku, J. Andersen*—A class of power amplifiers exists that uses a combination of an ac source and a nonlinear reactance as the basis for amplification. Included in this class are the varactor parametric amplifiers, the so-called dielectric amplifiers, and the magnetic amplifiers. The 3-frequency parametric amplifier is often compared to the maser amplifier since both operate on the three-frequency principle and both are used for the same application, i.e., low noise front end in microwave receivers. From a circuit point of view, however, they are quite different. A general theory of this class of amplifiers, termed "nonlinear reactance amplifiers," is developed and gain-bandwidth limitations are established by means of Bode's integral constraints and Mason's unilateral gain quantity U.

Nonreciprocal YIG Filters, *R. E. Tokheim, J. C. Hoover, R. W. Peter*—Several techniques for achieving nonreciprocity in YIG filters employing strip-line or miniature coaxial line construction are presented. Nonreciprocal filters can be designed with either single-ended or double-ended nonreciprocity. In either case, the circuit element possesses isolator and circulator properties as well as that of a ferrimagnetic filter. Experimental results have indicated that nonreciprocity greater than 10 dB over octave bandwidths is possible with passband characteristics similar to those of conventional YIG filters. The insertion loss may be somewhat higher than the latter, depending on the technique of nonreciprocity utilized. Nonreciprocal YIG filters are useful with TWT microwave receiver systems as preselectors and post-selectors and obviate the need for isolators. These filters are also useful as tunable microwave circulators in conjunction with tunnel diode amplifiers and parametric amplifiers. An individual filter may be used as a diplexer, and several filters will provide multiplexer operation. Nonreciprocal filters have been fabricated in the standard YIG filter construction and demonstrated in the YIG filter design.

Electrically Tunable Low-Pass Filter Using Permalloy Films Near Resonance, *D. T. Ngo*—A low-pass filter with electrically controllable cut-off frequency using Permalloy films near resonance has been investigated both analytically and experimentally. In a Permalloy film loaded transmission line, the wave propagation constant is strongly affected by the film's permeability. For a fixed bias field H_M, the attenuation constant α and the phase constant β are large and nonlinear at the resonance frequency f_0, but for the frequency band far below f_0, β is much larger than α and is almost linear with respect to frequency. Hence the impedance Z_0, proportional to β/ω, is constant for the previous frequency band. In a film-loaded transmission-line section terminated by Z_0, the insertion loss is very small in the passband and large near f_0, the cut-off frequency. The cut-off frequency f_0 can be varied by varying the applied field H_M. Attenuation in the stop band is provided by many sections in tandem biased at fields higher than H_M or biased by a tapered field. Such a low-pass filter has been built and tested successfully over a frequency range from 500 MHz to the 2.8 GHz. The experimental data agree very well with the analytical result.

A New Type of Magnetically Tunable Multisection Bandpass Filter in Ferrite-Loaded Evanescent Waveguide, *R. F. Skedd, G. Craven*—A description is given of a novel multisection bandpass filter. It is constructed in ferrite-loaded evanescent waveguide and can be tuned over a moderate bandwidth by a single knob control of the dc magnetic field applied to the ferrite. The basis of this type of filter is a new principle that states that full transmission of the incident energy through a finite length of waveguide below its cut-off frequency can be effected by using a terminating impedance that is the conjugate of the characteristic impedance of the evanescent waveguide. Briefly, the filter consists of a length of rectangular waveguide operated in the evanescent TE_{10} mode. A thin slab of ferrite lies along both sidewalls and in each filter section a capacitive screw is placed for tuning the filter to resonance. The magnetic field on the ferrite controls the cut-off frequency and thereby the resonant frequency of the filter. Design equations are derived and results on a three-section filter are included.

Spin Wave Relaxation Rate Measurement Under Perpendicular Pumping, *B. Desormière, E. Milot*—The RF magnetization of a ferrite biased to resonance and subject to a first-order spin wave instability is discussed. Two methods of a fully experimental measurement of the spin wave relaxation rate are derived from the theoretical results. Experiments are given that were perfofmed in a nonresonant device in order to avoid spurious transient signals. The experimental results of the two methods are shown to be in very good agreement. These results, together with the measurement of the critical field, allow experimental determination of the spin wave–uniform mode coupling constant. In addition, some results of a computer analysis of the entire process are presented and compared with experimental results.

Microwave Pulse Compression Using Magnetostatic Spin Waves in YIG Rods, *E. R. Burke, E. L. Higgins*—A microwave pulse compression filter has been obtained at S-band and room temperature by using the dispersive characteristics of propagating magnetostatic spin waves in single-crystal rods of yttrium iron garnet YIG. The maximum pulse compression ratio was 60 but higher values should be possible with faster sweep rates and more precise sweep matching than could be obtained with the equipment employed. The maximum input pulse width that could be effectively used was about 2 μs, which seems to be a natural limit of the material due to increased attenuation for longer time delays. The overall insertion loss that can be obtained using magnetostatic waves is less that that using the magnetoelastic mode of propagation.

An S-Band Digital Phase Shifter Designed for Half-Wavelength Stacking in a Phased Array Antenna, *J. K. Parks, B. R. Savage, L. J. Lavedan, Jr., W. B. Day*—An S-band rectangular waveguide digital phase shifter with TEM inputs that combines the electrical advantages of waveguide design with the compactness of a strip transmission line structure is described. A 4-bit, nonreciprocal S-band model is presented that combines the electronic drives and the microwave structure in a 1.8-inch by 1.4-inch cross section designed specifically for half-wavelength stacking in an antenna array. Several new techniques of antisymmetric dielectric loading are reviewed that convert microwave energy from a TEM mode in strip-line transmission to a TE-type mode propagating in a dielectrically loaded rectangular waveguide. The advantages of greatly reduced phase shifter cross section derived using these techniques are emphasized.

Effects of Wall Pinning on Bias Susceptibility Measurements, *A. C. Sharp, C. S. Comstock, A. V. Pohm*—A technique was devised to obtain a quantitative measure of some of the internal magnetostatic fields in a thin Ni-Fe film that are present when the film is broken up into strip domains whose angular orientations are parallel to the average easy axis. The process involved the experimental-numerical evaluation of the average angle that the magnetization makes with the easy direction as a function of a transverse dc bias field. These angles were found for all bias field values from zero to saturation. It was found that one of the internal fields, a demagnetizing-type field brought about by wall and ripple boundary pinning, was very instrumental in effecting an explanation of the

experimentally observed bias susceptibility measurements.

Interactions Between Regions Within a Magnetic Film, *T. F. Brukiewa, R. L. Coren*—Calculations are made on a model of a ferromagnetic film in which interactions between regions enter as a perturbation of the configuration without interactions. Nine regions are assumed with a uniform dispersion of uniaxial anisotropy axes through 0.16 radian and with no magnitude dispersion. The energy of interaction between any two regions is taken to be $-\lambda M_1 \cdot M_2$ and values of the relative interaction field, $h_i = 2\lambda M/H_k$, which are studied, are 0.0, 0.05, 0.1, and 0.3. Calculations are made corresponding to torque and magnetoresistance measurements. The field variation is a rotation in the film plane with constant magnitude. Values chosen for $h = H/H_k$ range from 0.1 through 1.1. The representation of magnetoresistance values as Cartesian coordinates is shown to be very revealing of the effects of interactions. In the presence of interactions it is found that irreversible, rotational switching of the local magnetization is through smaller angles than with no interactions; this causes the appearance of locked regions.

A Technique for Determining Magnetization and Field Distributions in Magnetic Films, *R. B. Roe, T. C. Pilkington, W. F. Chambers*—A method for computing the equilibrium magnetization and internal field distributions for magnetic thin films with nonplanar surfaces is presented. The iterative calculation is based on a three-dimensional model in which the surface topology of the film is assumed to be periodic along one of the film-plane coordinates and uniform along the other. Each period of the film structure is subdivided into regions in which the magnetization and internal field are assumed to be uniform. The magnitude of the magnetization is taken as M_0 throughout the film. A procedure is then established for computing the equilibrium direction of the magnetization and the magnitude and direction of the internal field within these regions. The results of computer calculations for several simple configurations are presented.

Magnetoresistance of Stray-Field Coupled Films, *A. A. Hirsch, N. Friedman*—The magnetoresistance effect is used as an experimental tool in the investigation of the mechanism of magnetic coupling in multilayer films with intermediate laminations of electric insulating materials. The analysis of the shape of the hysteresis loops of the magnetoresistance can provide information about the inhomogeneous magnetization of such films. The films consisted of a soft layer of NiFe and a hard layer of Co, separated by approximately 1000 Å of SiO. Shifted hysteresis loops, indicating the presence of a unidirectional anisotropy, were observed when the driving field had a small amplitude. However, with increasing drive amplitude these loops became regular, and the existence of a field-dependent uniaxial anisotropy was demonstrated. Both kinds of anisotropies are discussed in terms of stray field effects introduced by the initially polarized hard layer. With films whose ferromagnetic layers have nearly perpendicular easy axes, one obtains asymmetric magnetoresistance loops for some orientations of the driving field. These loops were attributed to the inhomogeneous distribution of the magnetization vectors within the laminations of the coupled films. This new method of investigation of the magnetic behavior of coupled films seems to be preferable to other methods when the ferromagnetic layers of the films are very thin.

Magnetic Films and Optics in Computer Memories, *D. O. Smith*—The thermal cycle time and read bandwidth are calculated for a magnetic film memory that is written by heating from focused light and read by the same beam at reduced power. The heat flow model approximates the memory bit as a planar disc source and the cycle time T is determined by the condition that for repetitive writing the ratio of transient to dc temperature must be >1. Then it is found that for $T < 1$ μs the bit radius a must be $< \sqrt{\kappa T}$ = thermal diffusion length in time T (κ = thermal diffusivity of substrate); for an Ag substrate this gives a ~ 5 μ. For a magnetooptical reflection coefficient $k \sim 10^{-3}$ the shot-noise-limited bandwidth is then found to be ~ 100 MHz for a temperature rise of 10 degrees in the memory bit. Surface noise due to imperfections will limit the bandwidth to less than the shot noise limit unless some form of signal processing can be used to extract the magnetic information. For incident light polarized at say 45° to the plane of incidence, phase modulation of one of the components will generate a magnetooptical signal with a phase of 0 or π relative to the modulation, depending on the magnetic state of the memory bit. Additional topics considered include a review of magnetooptical enhancement using multilayer dielectric films, a discussion of possible memory materials, and a proposal for a content-addressed memory that is interrogated magnetooptically.

Preparation and Properties of EuO Films, *K. Y. Ahn, J. C. Suits*—Films of EuO have been vacuum deposited by three techniques: electron beam heating of bulk EuO, simultaneous deposition of Eu and Eu_2O_3, and evaporation of Eu in a partial pressure of oxygen X-ray measurements show the structure of these films to be essentially the same as bulk EuO. The Faraday rotation of EuO films was measured at 5°K for wavelengths between 0.5 micrometer and 1.2 micrometers. The largest specific Faraday rotation occurs at a wavelength of 660 nm and is 5×10^5 degrees per cm, which is one of the highest values yet reported for any material. From magnetooptical measurements and force balance measurements, various magnetic properties of these films have been determined and compared with bulk EuO. Magnetic moment, susceptibility, and squareness of EuO films do not differ greatly from bulk. The coercive force, however, is several times bulk value, and appears to be related to stress in the films.

Wide-Band Magnetooptic Readout, *D. Treves*—In the system described, digital magnetic information is recorded on a rotating disc thin film by a conventional tape recorder head. The information is read out using the longitudinal magnetic Kerr effect, and a 1.5-MHz bandwidth electronic system. The use of spatial filtering a differential scheme yields a ratio of peak-to-peak signal to rms noise of 32 dB, which is very close to the shot-noise-limited case.

An Analytic Model for the Flux-Gate Magnetometer, *S. V. Marshall*—The output voltages from various flux-gate probe types are found to have the same general form, and an analytic model has been developed with which the output may be calculated. In the saturation region where the output pulse is developed, the differential permeability can be closely approximated by an exponentials, $dB/dH = k_1 H^{k_2}$, where k_1 and k_2 are of the order of 100 and -2.0, respectively, for cores of Supermalloy or Permalloy 80. Using this model, the effect of the nature of the excitation function on output pulse amplitude and width and the effect of the squareness of the core characteristic can be clearly demonstrated, and good agreement with experimental results has been obtained.

A Magnetic-Core Analog Memory, *F. J. Friedlaender, J. C. McMillen*—The stored flux level in a 50 percent Ni-Fe tape core is read nondestructively to provide an analog memory. The stored flux level is set by means of a low-field ($H < 2H_c$) pulse. This flux level can be read out nondestructively by applying a short high-field pulse ($H < 4H_c$) which produces a peak rate of change of flux proportional to the stored flux level relative to saturation remanence. A subcoercive bias field applied to the core restores it to the original low-field flux state. Experimental data and the model leading to the conception of the memory are presented; the circuit details of a typical core analog memory are described.

DC Reset Analog Memory with Negative Feedback, *K. Harada, T. Kawano*—Previously proposed analog memory devices of the second harmonic type have two defects: that resetting the memory cores by ac demagnetization requires considerable time, and that the input–output characteristic of the memory device is nonlinear. A device is discussed in which these defects are overcome. Two cores are used in which the zero memory state corresponds to saturation magnetization states of the cores. Consequently, quick reset to the zero state is possible. The output voltage has both fundamental and second harmonic components of the ac bias used for readout. Linearity is improved by negative feedback. The rectified and filtered output of the two-core circuit is fed back and compared with the memory write-in signal. The error signal is used to set the memory.

The Magnetic Analog Memory Element of a Single Core, *T. Urabe, Y. Sakurai*—The behavior of an analog memory element ring a single toroidal magnetic core with rectangular hysteresis loop is presented. In this element, flux levels stored in the core as analog information can be nondestructively and continuously read out. With the application of a slight, amplitude-modulated, radio-frequency field, the modulation frequency component of the induced voltage waveform is detected as an analog output signal. The principle of operation requires only one core per memory element, so that problems of mismatching of two cores, which appear in a second-harmonic-type element, are completely eliminated. Experimental results show that this is suitable as an analog memory element, and that the eddy-current effect enhances the output signals.

A 20-MHz NDRO Thin Film Memory, *E. E. Bittmann, L. J. Arndt, J. W. Hart*—The 256-word, 200-bit NDRO memory described utilizes magnetic films deposited in arrays of discrete spots on thin glass substrates. Sandwiching of conductors between two substrates provides partial coupling to film pairs. The magnetic films exhibit both uniaxial and biaxial anisotropy and are interrogated by word fields of less than H_k amplitude. Word currents of 15-ns duration and 5-ns rise time produce sense signals in excess of 1 m V with a 7- to 10-ns duration. A single compact assembly houses the stack and its associated circuitry. Circuits are packaged employing hybrid techniques where electroless plating produces resistors from a nickel-phosphide solution onto copper-clad glass-epoxy laminates.

A 0.25×10^6 Bit, High-Density, Low-Power NDRO Film Memory, *A. V. Pohm,, T. A. Smay, W, N. Mayer*—A number of partially populated NDRO film arrays employing 2-layer films were constructed and tested to demonstrate that high-performance low-power NDRO film memories can be made with read and write requirements that are compatible with integrated circuits. The results are described. Test arrays were made in which two or four turns of fine wire were used for word lines spaced on 0.010-inch centers. The read

word current for the arrays with two-turn word lines was nominally 75 mA and the write word current was 180 mA. Digit current for all arrays was approximately 35 mA. The read word current for the array with four-turn word lines was nominally 30 mA and the write word current was 85 mA.

Device Applications of Multilayer Films, *W. T. Siegle, B. L. Flur*—A study has been made of the device applications of multilayer films of Permalloy–SiO–Permalloy. Of particular interest is the application to film memory, where domain wall creep is an important factor. A variety of samples of a $T_p/T_d/T_p$ configuration was investigated. Under the conditions of this study, optimum results were obtained with a structure employing two 300 Å nonmagnetostrictive films separated by 10 kÅ of SiO. For this geometry, both writing and disturb characteristics are significantly improved relative to a conventional 600 Å film. An absence of wall creep is found in this structure, accounting for the improved disturb characteristics. Unexpected interactions are also found that influence the wall motion switching characteristics, but have no significant influence on memory characteristics.

Inductively Coupled Bit Memories, *J. L. Anderson, H. O. Leilich, T. R. Scott*—The application of inductively coupled magnetic films to memory organization is described. Experimental work resulted in bilateral flux transfer between magnetic film elements of equal size. The influence of the device and coupling loop parameters, as well as the rise time of the drive pulse, on the maximum number of identical elements for a generalized model is shown. The parts used experimentally to demonstrate bilateral flux transfer were chain-store elements electrolessly plated with 20 000 Å of nickel-iron film. Continual flux transfer back and forth on a tight flat coupling loop was obtained. Structures required effectively to use inductively coupled magnetic films in memory organizations were investigated. Application of inductively coupled magnetic films implies the possibilities of large memories, nondestructive readout memories, or 3D-like organization for magnetic film device memories.

Common Mode Capacitive Coupling in Memory Arrays, *H. O. Leilich, T. R. Scott*—Capacitance between intersecting word and bit lines of a memory array causes a special type of line-to-line interaction. Signal waveforms may be seriously distorted if a large number of common polarity signals occur simultaneously and the word and bit line delay times are comparable to the width of the signal. A two-dimensional linear array model with distributed parameters was used, and a mathematical process for the determination of the wave coefficients according to the partial differential equation of the array and its boundary conditions is described. Typical cases were computed, interpreted, and compared with simple approximations that are useful as rules of thumb for the memory designer.

Flexible Ferrite Keepers and Their Application in Thin-Film Memories, *A. H. Agajanian, C. G. Raci*—The results of an investigation of flexible keepers are reported. The parameters studied include the composition, preparation, and particle size of the ferrite and the thickness and binder content of the sheet. The optimization of these parameters improved the performance of the keeper by ten percent. The use of the improved keeper in thin-film memory arrays results in reducing the increase of bit drive current due to worst-case effects by a substantial amount.

Intrinsic Coercive Force of Rare Earth Iron Garnets Near the Compensation Temperature, *J. P. Hanton*—The intrinsic coercive force of single crystals of those rare earth iron garnets having magnetization compensation temperatures greater than 77°K has been measured as a function of temperature and orientation with particular emphasis given to the temperature range near the magnetization compensation temperature. A single peak in the intrinsic coercive force was observed at the magnetization compensation temperature for almost all of the samples and for all principal orientations. Typically, the peak value of the coercive force was 50 Oe independent of material and orientation with a temperature difference between half-maximum points of less than 3°K. A single-domain model is proposed that concludes that the iron sublattice is primarily responsible for the coercive force near the magnetization compensation temperature and that complete magnetization compensation temperature and that complete magnetization compensation cannot occur due to the susceptibility of the rare earth sublattice. This leads to a finite coercive force at the magnetization compensation temperature.

Effect of Heat Treatment on the Magnetic Properties of Substituted YIG, *F. Euler, B. R. Capone, E. R. Czerlinsky*—Heating and subsequent quenching of aluminum and gallium substituted YIG changes the distribution of the cations among the *d*- and *a*-sites in the garnet lattice and, consequently, the magnetization of the material. This effect can be utilized to adjust the magnetization to a particular desired value and to obtain matching samples for microwave devices. This ion redistribution process was studied in detail on single-crystal specimens with different amounts of substitution for two purposes: (1) to determine the influence of the heat treatment on the magnetocrystalline anisotropy and (2) to establish the relation that describes the cation migration between the two sites. Therefore, the saturation magnetization and the magnetic anisotropy between 4.2 and 300°K was measured on samples that experienced a variety of heat treatments with subsequent quenching or slow cooling from temperatures between 800 and 1200°C. The results are as follows: (1) Although the saturation magnetization may change rather drastically with different previous heat treatments, the anisotropy constant K_1 is practically unaffected. (2) With samples of dominating tetrahedral sublattice magnetization, slow cooling produces the lowest saturation magnetization M_s, whereas quenching from temperatures T_q increases M_s with increasing T_q. This increase involves the exponential factor $\exp(-E/kT_q)$ with E being of the order of 1 eV. (3) Heating above 1250°C creates a high concentration of crystal defects. The consequences upon M_s, K_1 and E are discussed.

Temperature Dependence of the Hysteresis Properties of Polycrystalline Spinel Ferrite and Garnet Materials, *T. Collins*—The hysteresis properties of polycrystalline spinel ferrite and garnet compositions with $4\pi M_s$ in the 380- to 5000-gauss range were investigated to determine their temperature stability over the range from −55 to +85°C. Magnesium, nickel, and garnet-type compositions, which possess low microwave dielectric losses (tan δ <0.001), were chosen for investigation. Many of the materials exhibited suitable room temperature characteristics for microwave latching applications. The remanent magnetic flux density, coercive force, and squareness of the hysteresis loop for these compositions were found to be quite temperature-dependent, thus placing a limitation on their usefulness. Lithium ferrites, which normally possess high Curie temperatures and high microwave dielectric losses, were also investigated. It was found that in these materials the dielectric losses can be reduced to tan δ <0.001 while providing superior temperature stable hysteresis characteristics. The merits of the lithium ferrites are discussed; they indicate promise for microwave latching applications requiring temperature stability.

A New Approach to Experimental Investigation of Coercivity Temperature Dependence, *O. Benda, V. Ac*—It is shown that, if some conditions are fulfilled, it is possible to use Preisach's model for the investigation of the distribution function that has a character and temperature dependence similar to the distribution function of local critical fields. At the critical fields an irreversible movement of the Bloch walls appears. This distribution function $K(h_c)$ is not affected by the internal interaction fields. Using its first moment the first approximation of the macroscopic coercive force H_c may be obtained. As an example, the temperature dependence of the function $K(h_c)$, which was obtained for a square-loop MnMg-ferrite in the temperature interval from −194°C up to 200°C, is presented. The results are compared with the directly measured macroscopic coercive force temperature dependence.

Measurement of the Line Width of Single-Crystal Ferrites by Monitoring the Reflected Wave in a Short-Circulated Transmission Line, *I. Bady*—A method is described for measuring the line width of single-crystal ferrite spheres, based on monitoring the reflected wave in a short-circuited transmission line. The ferrite sample is at the short circuit, or a half-wavelength from it. An equation is given for the normalized equivalent resistance of a ferrite sphere at resonance, and a comparison is made between theory and experiment. At C band, resonance curves of undercoupled spheres are relatively free of distortion. However, at frequencies of 2 GHz and lower, resonance curves are often distorted. Moreover, it is frequently possible to obtain a discrete number of different resonant curves at a given frequency. Data are given on errors due to nonideal microwave components. A method of displaying a resonance curve on an oscilloscope is given.

Low-Drive, Temperature Stable Ferrite for Laminated Memory Arrays, *R. L. Harvey, I. Gordon, A. D. Robbi*—Research on thermally stable ferrite materials tailored to laminated memory arrays operated at low current levels is described. For this application, a ferrite combining low coercive force, fast switching, good squareness, small grain size, high Curie temperature, and high resistivity is necessary. The manganese-ferrous ferrite, manganese-lithium ferrite, and manganese-magnesium-ferrite systems (including, in some cases, small amounts of other metal ions) are studied. A manganese-magnesium-zinc ferrite ($Zn_{0.11}Mn_{0.41}Mg_{0.83}Fe_{1.65}O_4$) has the best combination of properties for laminated memory arrays. Arrays containing 256 × 100 conductors were successfully operated, without thermal or current compensation, over a temperature range of 0° to 50°C. The memory arrays described have operating characteristics that are compatible with integrated semiconductor drive currents.

Electrophoretic Deposition of Ferrite for Computer Stores, *M. Barraclough, N. E. Bolton, A. H. Collins, J. Andrews*—A method for the batch fabrication of storage elements by the electrophoretic deposition of ferrite onto platinum wires is described. Two types of experimental arrays of storage elements and their operating characteristics are given. One consists of an array of orthogonal wires coated with ferrite, the storage elements being formed at the intersection points of the wires. The second uses the rotational switching properties of very thin ferrite coatings on single wires with external strip conductors acting as word lines. The potential of this method of fabrication is shown to be considerable in reducing costs of both storage arrays and associated electronics.

Batch-Fabricated Integrated All-Magnetic Logic, *M. Carbonel, V. Chaptal*—All-magnetic logic is known for its very high reliability, but this logic has serious drawbacks: wiring cost, high power dissipation, etc. The use of very thin laminated magnetic sheets and an integrated fabrication process solves all these problems. Very low cost, power, size, and weight and a high reliability can be obtained by this technique. An experimental integrated two-bit shift register has been fabricated.

A Magnetic Double-Balanced Monolithic Frequency Converter, *H. J. Wierzba*—Some results pertinent to the monolithic magnetic double-balanced modulator are presented and discussed. The patterns taken experimentally for a working sample are compared with the theoretical as predicted by the formula for conversion gain. The advantages of monolithic construction are outlined.

Time-of-Day Clock, *R. H. Braasch*—A time-of-day clock system employing digital magnetic logic is described. The system design is directed toward the problem of minimizing the number of drivers commonly associated with large-scale magnetic logic systems. The clock system derives its basic count rate from a time-base generator that is realized through truncation of a maximal length linear pseudorandom sequence generated by a feedback shift register. The basic count rate is accumulated in a set of accumulators having semibidirectional properties derived from prime control logic to minimize the number of driver sections required. The design of a clock system based on a 0.01-hour time base derived from the 60-Hz power-line frequency and accumulator capacity sufficient for 365 days is given.

Magnetic Field Distributions and Energy Losses Resulting from Metal Tape Motion, *S. Ohteru, H. Kobayashi, I. Nashiyama*—The eddy current losses and magnetic field distributions in the alternatively magnetized metal tape moving with constant velocity V are analyzed for the case of constant permeability. As a result of the analysis, the effect of additional eddy current losses for velocity V is estimated as approximately proportional to V^2 and the reciprocal of coil length. Furthermore, an interesting result is obtained in that the magnetic fields between tape and coil have leading phase on both time and space with respect to the exciting current. It is thus concluded that there is no effect due to deformed field distributions and additional eddy current losses caused by running velocity of the tape when detected by applying a symmetrically wound coil at center of the exciting coil.

IEEE Transactions on Microwave Theory and Techniques

Vol. MTT-15, no. 8, August 1967

The Amplitude Response of a Coupled Transmission Line, All-Pass Network Having Loss, *R. A. Kolker*—The voltage transfer function of a first- and second-order coupled transmission line, all-pass network having loss is derived. The amplitude response is calculated from the transfer function. It is shown that the amplitude response is completely determined when α, the real part of propagation function, is known. A method for calculating α is presented and an example is given. The results show that the losses (dielectric and conductor) cause periodic dips in the amplitude response of the all-pass networks. However, for practical materials and configurations, the peak amplitude loss is less than 0.4 dB for the first two periodicities. The results show that, for most applications, it is possible to cascade many first-order or second-order lines before the amplitude response must be equalized.

Propagation Through a Twisted Medium, *G. C. McCormick*—An explicit solution is obtained for propagation through a uniform twisted anisotropic medium subject to the conditions that propagation is along the twist axis, and that the structure is fine. The propagation constants are altered and coupling exists between the propagation modes. A parameter is defined that indicates the tendency of the radiation to adhere to the structure of the medium. The effects at boundary discontinuities are discussed, and tapers to an isotropic medium are dealt with. The particular application of the theory to cases of polarization conversion is discussed.

The Numerical Solution of Rectangular Waveguide Junctions and Discontinuities of Arbitrary Cross Section, *C. A. Muilwyk, J. B. Davis*—A method is described of calculating automatically the performance of junctions of rectangular waveguides including conducting cylinders of arbitrary shape. The only restriction is that the overall problem should be effectively two-dimensional, i.e., the structure be uniform in some cross section. The one basic approximation made (which could be removed) is shown to give useful results for the devices tested, viz., for various shaped irises and the four-port H-plane junction.

The Green's Dyadic for Radiation in a Bounded Simple Moving Medium, *Y. J. Seto*—It is shown that the wave equation for electromagnetic wave propagation in an isotropic and uniformly moving medium is solvable by the separation method in four coordinate systems. Solutions in the form of complete sets of eigenfunctions are possible for problems where boundary surfaces are presented. A Green's dyadic for finite or semi-infinite domain problems involving sources in the moving medium has been formulated through vector operation on the eigenfunction solutions of the homogeneous wave equation. The case of electromagnetic waves excited by a current loop, immersed in a moving medium, and confined by a circular cylindrical waveguide, was examined. The electric and magnetic field intensities in such a waveguide were compared with those obtained through a different approach. The Green's dyadic for electromagnetic waves in an infinite domain moving medium was shown to be obtainable from the finite domain Green's dyadic through limiting.

Coupler-Type Bend for Pillbox Antennas, *V. Mazzola, J. E. Becker*—A new type of 180° H-plane bend has been developed for use in double-layer pillbox antennas. This bend, called a coupler-type bend, permits complete coupling between two pillbox layers with a minimum of reflection, cross-polarization, and defocusing. It can be used with short-focus antennas where large feed angles are involved. The coupler-type bend utilizes a metal plate between the pillbox layers; the plate contains a pattern of holes that achieves the desired coupling. Analytical and experimental programs have been implemented to determine the optimum hole size and distribution. Simulation techniques in rectangular waveguide were employed for convenience in measurements. The bend design was measured to have a reflection less than 2 dB SWR over a ten percent frequency band; this is computed to contribute less than 0.2 dB SWR to the reflection seen by the feed-horn of a double-layer pillbox. The bend introduces less than −22 dB of cross-polarization in the antenna radiation.

A Parallel-Plate Waveguide Approach to Microminiaturized, Planar Transmission Lines for Integrated Circuits, *H. Guckel, P. A. Brennan, I. Palocz*—The parallel-plate waveguide with a two-layer loading medium, a conducting semiconductor substrate, and a relatively thin dielectric layer approximates the interconnections in many integrated systems if the fringing fields are ignored. The fundamental mode of this structure is an E mode which is a surface wave. Its propagation behavior is analyzed and the equations are evaluated by highly accurate numerical methods.

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Analysis and Calibration of a Reflection Coefficient Bridge for Use with Any Waveguide Mode, *K. S. Champlin, J. D. Holm, D. B. Armstrong*

Magnetodynamic Modes in Axially Magnetized Ferrite Rods Between Two Parallel Conducting Sheets, *H. D. Godtmann, W. Haas*

Relative Humidity Effects in Microwave Resonators, *D. M. Smith*

Optimum Elliptic-Function Filters for Distributed Constant Systems, *L. Fraiture, J. Neirynck*

Higher-Order Modes in Rectangular Coaxial Waveguides, *L. Gruner*

Numerical Solution of TEM-Line Problems Involving Inhomogeneous Media, *H. E. Brenner*

Characteristic Impedance of Multifin Transmission Lines, *C. R. Boyd*

Realizations of a Duo-Pole Branch of an Elliptic-Function Bandstop Filter, *B. M. Schiffman*

Comment on "Cylindrical Waveguides Containing Inhomogeneous Dielectric," *S. L. Richter, Y. Klinger, E. AhSam*

IEEE Transactions on Microwave Theory and Techniques

Vol. MTT-15, no. 9, September 1967

Least-Weighted-Square Methods for Analysis and Synthesis of Transmission Lines, *N. Seshagiri*—Analysis and synthesis of transmission lines of arbitrary geometry are not easy to realize with currently available methods. It is shown that by introducing a new principle, to be called the "least-weighted-square invariance deformation," it is possible to solve transmission-line problems to desired orders of accuracy. A procedure based on this principle is given for deforming a given transmission line geometry keeping the characteristic impedance an invariant, or for synthesizing a transmission-line cross-sectional geometry corresponding to the given constant parameters of the structure. The method is applied to the analysis of transmission lines having a regular polygonal outer conductor and a circular inner conductor. An application to a representative situation in synthesis is also described.

An Analysis of the Quarter-Wave Technique of Reducing the Errors in UHF and Microwave Impedance Measurement, *W. E. Little, D. A. Ellerbruch, G. F. Engen*—An analysis is given of the quarter-wave impedance measurement technique. This technique, which finds its widest potential application in conjunction with standing-wave machines, permits the approximate elimination of the error due to residual reflection or VSWR. If the other sources of error are small, the potential reduction in error is in the ratio $|t_{11}|/2|S_{11}|$, where S_{11} and t_{11} are the residual reflection coefficients of the standing-wave machine and quarter-wavelength section respectively.

Solution of Waveguide Discontinuities by Modal Analysis, *A. Wexler*—A general method is presented for analysis of waveguide junctions and diaphragms by summing normal modes of propagation, giving solutions for the resulting scattered modes. Because interaction effects of dominant and higher-order modes between discontinuities are allowed, finite-length obstructions can be studied. Solutions are found without any prior assumption about the total fields existing at the

discontinuities and, as a result, the formulation is applicable to a wide range of problems. The technique proves to be simple and is ideally suited to computers, involving mainly the solution of sets of simultaneous linear equations. Thick and thin symmetrical bifurcations of a rectangular guide are studied. Forward-scattered mode amplitudes and input admittances are calculated, the computed admittance of the thin bifurcation is compared with well-known results, and transverse field patterns on both sides of the junction are plotted, thus showing the accuracy of the match. The results of a finite-length bifurcation by a thick vane are presented for a range of lengths.

A One-Gigahertz Ferroelectric Limiter, *J. Horton, M. Donaldson*—The design and analysis of a one-gigahertz limiter that uses voltage variation of the dielectric constant of a ferroelectric material to achieve limiting is described. An RF electric field derived from the input power is used to change the relative dielectric constant of the material; the resulting nonlinear change of capacitance of a small element of the material is used to change the condition of a tuned circuit. The tuned circuit terminates a quarter-wavelength stub that shunts the main transmission line, thereby providing a power-dependent mismatch at the junction of the two transmission lines. The degree of this mismatch is controlled by the condition of the tuned circuit and, therefore, the magnitude of the input power. Theoretical analysis and experimental results for small-signal and large-signal operation are presented. Limiter analysis is based on the measured change of ferroelectric (nonlinear) capacitance as a function of dc electric field. The ferroelectric element is 0.011 by 0.013 by 0.020 (inches) machined from polycrystalline $(Pb_{0.315}\text{-}Sr_{0.685})\,TiO_3$ material.

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Two Partially Filled Cavity-Resonator Techniques for the Evaluation of Scalar Permittivity and Permeability of Ferrites, *J. K. Sinha*

Design of TEM Equal Stub Admittance Filters, *H. J. Hindin, J. J. Taub*

On the Design of Stepped Transmission-Line Transformers, *M. A. Hamid, M. M. Yunik*

Nonsymmetrical Coupled Lines of Reentrant Cross Section, *E. G. Cristal*

Circulator Action at 140 GHz in a Semiconductor Loaded Waveguide Junction, *M. Brodwin, S. Kahn*

IEEE Transactions on Power Apparatus and Systems

Vol. PAS-86, no. 7, July 1967

Power System Stability Studies by the Method of Liapunov: I—State-Space Approach to Synchronous Machine Modeling, *J. M. Undrill*—The development of a synchronous machine model in the mathematical form required by most modern automatic control theorems is recorded. The model is based on a new expression for the constraint imposed on the machine by a general balanced 3-phase T-form transmission system consisting of a step-up transformer, a shunt load, and a transmission line terminating at a bus of known voltage. A simple time constant representation of the voltage regulator is included in the model but the equations for the simulation of hydro or steam turbine governor action are omitted. A typical use of the model is demonstrated by a simple simulation of synchronous generator performance with and without amortisseur windings.

Power System Stability Studies by the Method of Liapunov: II—The Interconnection of Hydro Generating Sets, *J. M. Undrill*—The second method of Liapunov is used to investigate the optimum settings of certain governor and voltage regulator parameters of interconnected hydroelectric generating sets. A two-machine system with a simplified tie-line representation, and a one-machine system including a detailed model of the generator and its interconnection to an infinite bus are considered. The Liapunov method is shown to produce a useful form of information and to allow flexibility in the selection of the aspect of system performance for study. The results obtained provide one possible basis for coordinating the settings of governor gains, dashpot time constants, voltage regulator gain, and governor derivative gain on interconnected hydro systems.

A High-Power-Density Electric Machine Element, *F. L. Zeisler*—A dc homopolar machine with liquid metal contacts can achieve high power density and efficiency. The analysis of a simple model of such a machine shows that a power density of several horsepower per pound at 90 percent efficiency is possible. The results of a design study of an experimental 280-pound 250-hp homopolar automotive transmission showed a 90 percent efficiency over a useful operating range. Problems arising during test limited the efficiency to 75 percent.

Motor Transient Analysis on a Small Digital Computer, *L. F. Wiederholt, A. F. Fath, H. J. Wertz*—Results are presented of a study the objective of which was the high-speed solution of the differential equations characterizing induction motors. It was found to be possible to reduce the time required for the solution by a factor of about ten with no loss of accuracy. Details of two sample problems and the techniques used are presented.

Stability Analysis of a Reluctance-Synchronous Machine, *T. A. Lipo, P. C. Krause*—A stability study of a reluctance-synchronous machine (synchronous-induction machine) is performed by applying the Nyquist stability criterion to the equations that describe the behavior of the machine during small displacements about a steady-state operating point. This investigation reveals that machine instability can occur at low speeds (low frequencies) even though balanced, constant-amplitude, sinusoidal voltages are applied to the stator terminals. Regions of machine instability are established from the results of a digital computer study. The results of an analog computer study are included to illustrate the modes of operation that occur within these regions. Also, regions of instability for different values of system parameters are given and discussed.

Polyphase Induction Machine with a Slitted Ferromagnetic Rotor: I—Experimental Investigations and a Novel Slipmeter, *K. R. Dorairaj, M. R. Krishnamurthy*—The performance of polyphase induction motor with slitted ferromagnetic rotor is presented. Experimental studies cover the influence of physical dimensions of slits and their number on the rotor performance, the effects of inserting a conducting nonmagnetic material like copper in the slits, and the performance of these rotors terminated with and without copper end rings. The conclusions drawn are amply supported by the results of a careful measurement of flux penetration at different depths beneath the rotor surface. In addition, a slipmeter, a unique device with a high sensitivity at low slip regions, used for a quick and direct measurement of slip, is described. It is believed that the slipmeter will find extensive use in induction machine testing.

Polyphase Induction Machine with a Slitted Ferromagnetic Rotor: II—Analysis, *K. R. Dorairaj, M. R. Krishnamurthy*—An analysis of the polyphase induction machine with a slitted ferromagnetic rotor, using Maxwell's field equations and concepts of equivalent permeabilities and resistivities, satisfactorily accounts for the physical dimensions of the slits and their number, the provision of a nonmagnetic conductor like copper in the slits, and the nature of rotor end terminations. The linear theory presented extends to the nonlinear region and results in a new treatment. Comparison with test results shows good agreement. Field problems of this nature can be successfully programmed on an IBM 1620 computer.

Capability Curves and Excitation Requirements of Saturated Cylindrical Rotor Synchronous Machines, *J. P. Hunt*—Generator capability curves, used by operating personnel in the loading of generators, are usually based upon a generator synchronous reactance equal to 1/SCR. Use of this reactance partially corrects for the effects of saturation and, although resulting in a reactive capability in error by less than 1.3 percent, produces a field excitation requirement as much as 3.8 percent lower than actual requirements. The effect of saturation, expressed by the saturation factor K, and Kingsley's equation for saturated synchronous reactance, results in capability curves and excitation requirements that agree with test data.

Digital Methods Applied to Power Flow Studies, *A. M. Sasson, F. J. Jaimes*—The theoretical foundations of different methods of solution developed for load-flow problems in a didactical form are presented. The load-flow problem is first defined, then a classification of different methods of solution is proposed. This consists of three groups: nodal admittance, variational, and nodal impedance matrix methods. Convergence characteristics of several methods are presented, using the example system given by Ward and Hale. Finally, criteria for comparison of different methods are discussed and a look at the future is presented.

A Digital Computer for the Automatic Determination of Dynamic Stability Limits, *D. W. Ewart, F. P. deMello*—The ability to calculate the dynamic stability limits of synchronous machines is of increasing importance today as generation and transmission equipment is being applied with higher reactances and correspondingly lower stability margins. A digital computer program that enables the rapid computation of dynamic stability limits for a single machine connected to an infinite receiving system through a transmission line is described. Effects of excitation and prime mover power controls are included, making the program a valuable tool for the equipment designer. Typical results illustrate the effect of terminal voltage, transmission-line reactance, and machine inertia on the stability limits. The concept of damping ratio as an index to relative stability is discussed and illustrated. Also shown are the effects of neglecting saturation and other second-order effects on the calculation of dynamic stability.

Insulated Sodium Conductors, *L. E. Humphrey, R. C. Hess, G. I. Addis*—The development and characterization of a new polyethylene-insulated sodium conductor are described. The resistivity, specific gravity, and cost of sodium are compared with corresponding properties of copper and aluminum. Although the alkali and alkaline earth metals have relatively good electrical conductivity, sodium was chosen because of its light weight, low cost, and availability. Physical properties of the polyethylene-insulated sodium conductor were determined. Potential areas of question, such as service life, reaction of water with damaged cables, and combustion characteristics, are covered in detail.

The Development of Connectors for Insulated Sodium Conductor, *I. F. Matthysse, E. M. Scoran*—The characteristics of insulated

sodium conductor required the development of a new type of connector and a new installation technique. The problems involved making stable electrical contact to the sodium, sealing against chemical attack, installation with a minimum exposure of sodium, securely gripping the insulation, effects of the melting point of sodium, and temperature limitations of the insulation. The connector contact element penetrates the sodium from the end of the conductor, and an external sleeve is compressed by a standard compression tool to seal the joint and provide a secure grip to the insulation. The simple installation technique is rapid and safe. Satisfactory performance is shown in the mechanical, electrical, thermal, and environmental tests conducted.

Field Trials on 15-kV and 600-Volt Sodium Cable, *E. J. Steeve, J. A. Schneider*—The use of sodium conductor cable presents an opportunity for a reduction in the cost of cable for underground residential distribution systems. In order to evaluate its usage a direct buried test installation was made involving both 15-kV and 600-volt sodium cable. Testing of the 15-kV cables consisted of load cycling, short-circuit faulting, and fault location tests. After the completion of the tests on the 15-kV sodium cable, a service installation was made in a rural area west of Chicago. Load-cycle tests were also made on the 600-volt sodium cable. This included an overload that resulted in the failure of the cable at the terminal. Insulation damage tests were made to determine the corrosive properties of the conductor. Fault-locating tests made on the 600-volt cable, as on the 15-kV cable, showed that presently available equipment should be adequate.

Drawing of Insulated Sodium Conductor, *L. E. Humphrey, G. I. Addis, R. C. Hess*—The preparation of high-strength, small-diameter sodium wire is discussed. A new production method consisting of simultaneous extrusion of conductor and insulation followed by high-speed drawing and annealing of the composite is described. The influence of polyethylene properties and process conditions on the characteristics of the wire is shown. Resistance to damage through crushing is of particular note because the soft conductor does not act as an anvil to cut the insulation. The wire has high tensile strength, especially in the smaller sizes. Permeability to water vapor is a problem but practical means of combating it already are in use in other services. Development of reliable long-life connectors is required for future applications.

Methods for Reducing Induced Voltages in Secondary Circuits, *D. A. Gillies, H. C. Ramberg*—The protection of control and instrumentation cables in a high-voltage switchyard is becoming more essential as higher magnitudes of system voltage, load and fault currents, or overall power levels are handled. Concurrently, with these increases in transient severity in the switchyard, there is developing a greater need for more sophisticated control involving components more easily damaged by induced voltages. When the problem is recognized early enough so that proper circuit configurations and metallic sheaths are incorporated in the initial installation, it can be solved quite effectively. Two criteria developed for control circuit protection are the use of radial circuits where all conductors are contained within one cable (no large loops formed), and the use of conductive sheaths of low resistance that are connected to the grounding grid at both ends.

Design of the Celilo Sylmar 800-kV DC Line—BPA Section, *R. F. Stevens*—The capacity of this line is many times that of previous dc lines, and its length far exceeds that of any line, dc or ac, now existing. Lacking operating data on overhead dc lines, criteria were based largely on tests at the BPA dc test center. Conductor size was established by thermal limits, based on possible need to carry double normal full load for occasional short periods. Clearance, conductor to tower, was approached in three ways and 93 inches was selected. Suspension towers are either guyed aluminum or self-supporting steel. Dead-end and angle towers are of self-supporting steel. An advantage of the bipolar dc line over ac is that the usual negative lightning stroke should involve the positive conductor only, leaving the other free to transmit up to half of full-load rating.

IEEE Transactions on Solid-State Circuits

Vol. SC-2, no. 2, June 1967

Noise Characterization of Linear Two Ports in Terms of Invariant Parameters, *J. Lange*—A new representation of noisy two ports in terms of parameters invariant under lossless transformation is proposed. This representation is especially advantageous when the terminals of the intrinsic device are not directly accessible. A method of determining noise parameters in a transmission-line system using a calibrated slide-screw tuner is discussed. Experimental results are presented.

Worst-Case Gain Sensitivity with Zero Phase Sensitivity in Active RC Network Synthesis, *H. E. Jones, B. A. Shenoi*—The change in only the magnitude of a network function or the pole vectors due to an infinitely small change in the control parameter K has been usually considered in studying the sensitivity of an active network. K is assumed to increase or decrease from its nominal value by finite amounts. A worst-case synthesis procedure, based on a new polynomial decomposition, is presented for designing an active RC network, such that the maximum and minimum modulus of the gain function at a prescribed frequency lies within specified limits and also the phase remains unchanged. An example of a transistor amplifier is worked out.

Realization of a Magnetoresistive Gyrator Circuit, *V. A. Marsocci*—The realization of a gyrator network with the use of magnetoresistive devices is analyzed from the viewpoint of minimizing the required number of negative-resistance devices. It is demonstrated that the special nature of these devices, which permits their output polarities to be easily reversed, enables the gyrator network to be realized using only one negative-resistance element. The devices investigated are the cryotron operating in a linear mode and the conventional magnetoresistive device. The various methods of connecting the devices are compared, and considerations are given to the advantages and the disadvantages involved in the practical implementation of the various circuit arrangements.

Radiation Impedance Approach to the Analysis of a Thin-Film Inductor in a Microwave Integrated Circuit, *E. Yamashita, R. Mittra*—The radiation resistance and reactance of a thin-film inductor in a microwave integrated circuit are evaluated by a Fourier transform technique. The results are useful in designing circuits with reduced radiation coupling of the inductor with adjacent elements. Numerical results are presented for various ranges of parameters.

Long-Term Storage Circuit Using a Sampling Technique, *R. L. Nelson, Jr., C. O. Harbourt*—A circuit is presented that exhibits stable long-term memory analogous to that provided by Coulomb friction in mechanical systems. The circuit stabilizes the voltage across a capacitor. The capacitor voltage controls the length of a delay whose beginning is synchronized with a stable oscillator. At the end of the delay, the oscillator output is sampled and fed as a current to the capacitor. Periodic repetition of this procedure produces an average capacitor current that is a periodic function of capacitor voltage. Over the voltage range where the peak value of this current exceeds the intrinsic leakage current, every other one of those voltages at which the net average current is zero is a stable voltage. The principles used in this circuit may be applied to cancel the drift of any viscous-type analog memory element. The stored values are discrete but may be made so numerous as to approximate true analog memory to virtually any desired degree.

IEEE Journal of Quantum Electronics

Vol. QE-3, no. 8, August 1967

Observations on a Concentric Spherical Cavity Laser Oscillator, *J. W. Strozyk*—Experimental results on a number of ruby rods in concentric spherical cavities are presented and discussed. The observations include intensity variations (spiking) as a function of input energy, longitudinal and transverse mode structure, and output energy distribution. The characteristics of flat and concentric cavities are compared using the data presented. The spiking frequencies and decay times are compared with simple rate equation predictions during the quasi-continuous-wave time of operation with reasonable agreement. Results indicate that the cavity effects will be similar regardless of the type of laser material used.

Solutions of the Damped Oscillator Fokker–Planck Equation, *W. H. Louisell, J. H. Marburger*—The quantum theory of damping is presented and illustrated by means of a driven damped harmonic oscillator. The theory is formulated in the coherent state representation, which illustrates very vividly the nearly classical nature of the problem. In this representation the reduced system density operator equation becomes a Fokker–Planck equation. Green's function solutions are found for the damped oscillator in closed form and as an eigenfunction expansion. In addition, a quantum regression theorem due to Lax is derived in the coherent state representation. The theorem allows two-time averages to be computed from one-time averages.

Nonlinear Absorption of Light: Optical Saturation of Electronic Transitions in Organic Molecules with High-Intensity Laser Radiation, *C. R. Giuliano, L. D. Hess*—A review of spectroscopic properties of complex molecules is presented and used to show that a simple two-level scheme is inadequate to describe the optical bleaching of dye molecules. Experimental data are reported for the transmission of intense ruby laser radiation by several types of dyes. Rate equation analyses are carried out using steady-state solutions and iterative computer solutions; calculated bleaching curves are compared with data for cryptocyanine. On these bases, it is shown that, in general, the optical bleaching process involves the removal of ground-state molecules to other states having smaller absorption cross sections at the exciting frequency, and that recovery of absorption at this frequency is characterized by a complex relaxation mechanism.

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Near-Infrared Laser Transitions in Pure Helium, *R. L. Abrams, G. J. Wolga*

Observed Laser Lines in Freon-Helium Mixtures, *G. Trusty, P. Yin, S. H. Koozekanani*

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New CW Laser Wavelength in KrII, *A. M. Johnson, C. E. Webb*

Translated journals

Translated issues of four Russian and two Japanese publications are published, under National Science Foundation grants, by the IEEE with the assistance of Scripta Electronica, Inc. Advance tables of contents of forthcoming translated issues and available reviews of selected papers from recent translated issues appear below. Subscription rates and further information are available from IEEE Special Subscription Department,* 275 Madison Ave., New York, N.Y. 10016.

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Reviews

Electrical Engineering in Japan

Vol. 86, no. 8, August 1966

Plasma Diagnostics by Means of Hall Current, *M. Nagata*—The conductivity of a plasma may be inferred from measurements of the Hall voltage and Hall current between electrodes oriented transverse to the plasma stream, subject to corrections due to the plasma current and to the sheath at the electrodes. The author presents a method for designing a circuit and a program of measurements that minimize these errors.

It is the reviewer's belief that Eq. (1) of the paper contains an erroneous factor $(1 + \mu_e^2 B^2)^{-1}$, since no transverse current flows in the open-circuited condition described by that equation. Since, however, measurements are made with small magnetic field, results of this error are negligible.—*R. P. Kenschaft*

Vol. 86, no. 9, September 1966

Transient Performance of Induction Motor Connected to the System with Fluctuating Load, *S. Yamada*—The problem being considered in this paper is the effect of bus line voltage fluctuations on an induction motor's speed and torque. The bus line voltage variations are considered to be produced by a fluctuating load connected to the same bus as the motor. Three different kinds of load fluctuations are considered, namely, sinusoidal, rectangular, and triangular variations with time.

The performance of the induction motor is studied by solving the system's nonlinear differential equations on both an analog and a digital computer. On the digital computer, the Runge–Kutta integration method was used in the solution. The speed and torque fluctuations produced by the three types of load variations are displayed in curve form as a function of frequency. The calculated results are compared with model test results.

The paper will be of interest primarily to those people concerned with power systems studies and the application of large induction motors on systems that are subject to voltage variations.—*H. E. Jordan*

Quality of High-Speed Data Transmission in Telephone Channels of the Electric Power Company, *S. Imaide, K. Takikawa*—With the advent of computers, digital telemetering, and supervisory control systems, code security and message structure for data transmission is an important factor in the design and application of this equipment. Most often the basis for such decisions is a theoretical analysis of the problem without evidence of actual data transmission tests.

The authors have conducted extensive voice channel data transmission tests at speeds up to 1200 bands and documented their results in a very commendable manner. These results will provide useful information in the application of data transmission systems.—*H. J. Fiedler*

Electronics and Communications in Japan

Vol. 49, no. 3, March 1966

A Location-Invariant Method for Measuring Dielectric Constants at Microwave Frequencies, *O. Fukumitsu*—Papers on dielectric measurements, in particular, papers describing new or different procedures, are welcome in this rapidly growing field. In general, it is desirable to employ thin samples and the method described requires it. The method makes use of sliding-short-circuit techniques popularly employed to characterize low-loss two-ports, extended and simplified to include the simple case of a short section of dielectric-filled waveguide. It has merit, not necessarily as the author states, that accurate absolute distance measurements are avoided, but because it serves the need for more techniques to cover the many special cases encountered in dielectric measurements. Although the author does not so state, it would appear that the method can be employed in TEM waveguides, such as coaxial lines.—*John Zorzy*

Engineering Cybernetics

Vol. 4, no. 3, May–June 1966

Statistical Analysis of Systems with Ambiguous Nonlinearities, *Ye. Kazakov*—This paper is concerned with the problem of analyzing nonlinear systems containing random disturbance signals, where the nonlinearity is a multivalued function, e.g., hysteresis nonlinearity. The basic contribution of the paper is the conversion of a multivalued function of one variable into a single-valued function of many variables. Thus, for example, a single hysteresis curve is viewed as a single-valued function of the variables representing position and velocity. This single-valued nonlinear function is then approximated by statistical linearization. Finally, nonlinear algebraic equations are derived for the variances of the system variables.

No analysis is made of the errors introduced by the above approximation. However, the method does provide an extension of statistical linearization techniques to multivalued nonlinearities.—*Peter Dorato*

Random Search in the Presence of Noise, *L. S. Gurin*—This paper discusses the convergence of a random search for the global extreme of a multiextremal function in n variables. The search is carried out in an n-dimensional region Ω. The case is considered where the random element in the search is introduced in the form of noise impressed on the function. The noise is represented by k, n-dimensional vectors ξ, whose components are random variables which are independent, normally distributed with zero mean and variance σ^2.

The function to be investigated has in the region Ω an arbitrary number of local minima and at a point X_{opt} a global minimum. By evaluating the function at test coordinates consisting of a test point perturbed by the set of random variables at the point a series of coordinates is obtained. The process of selection of the coordinates is according to the relation $X_{k+1} = X_{k+\mu}\xi_k$ where ξ_k is an n-dimensional random vector (the noise) and γ_k is either zero or unity depending on the outcome X_{k+1} (an n-dimensional position vector).

The author states that this process of selection will cause convergence of X_k to X_{opt}. Theorems are given for convergence to a δ region of X_{opt} with probabilities dependent on the number of tests made.—*Robert Levin*

Reliability of Systems with Majorital Elements, *V. M. Ozernov*—This paper presents a method of calculating the probability of failure of redundant systems or devices connected by majorital elements (for determining correct operations by best two out of three, three out of five, and so forth). The system uses random failure and repair times with exponential distributions.

The calculation of probability of failure is based upon Markov chain transitions with absorbing states. The absorbing state is a failure of system operation, in that one of the system elements or the majorital element fails. That is, repair prior to total system failure cannot be accomplished. As an example this paper uses three parallel logic systems connected by a majorital element. The state diagram is derived and the transition states, failure rates, and the repair rates are indicated. A Markov chain transition matrix is then generated from this diagram. The transition matrix and the Chapman–Kolmogorov equation are used to determine a stochastic matrix or transition probability in a given interval of time, thereby forming an absorbing Markov chain. The probability of system failure considers the transitions from nonabsorbing states to the absorbing state, and can be directly determined additively.

The probabilities are also found in an alternate way based on the probability of transition from a nonabsorbing state to the absorbing states directly.

Although the use of a Markov chain with absorbing states for determining the probability of failure is a convenient method for exhaustive determination of the probability of failures to different states in the system, it is by no means new. This case simply extends the application of these methods for the use of the particular condition where a majorital element is included which is treated as a different class of device.—*W. D. Rowe*

Telecommunications and Radio Engineering Part I—Telecommunications

Vol. 20, no. 10, October 1966

Method of Increasing Discrete Data Transmission Rates, *L. I. Yaroslavskiy, S. P. Vol'fbein, I. S. Usov*—This paper is concerned with the duobinary method of data transmission. It goes into a short review of this method and the two well-known schemes for precoding. The review also includes the equally well-known spectral density characteristics, which show that, with respect to the binary wave, the duobinary wave has a characteristic one half the bandwidth except for a tail of low-amplitude components extending beyond.

The authors contend that the 2:1 increase in bit speed of duobinary transmission over straight binary transmission cannot be explained by the 2:1 reduction in the main body of the spectral density characteristic of the duobinary wave. The tail cannot be ignored. The contention is theoretical and the proof is dependent on an assumed time-domain response of a baseband channel. This is a straight-line ramp in an interval of one bit (at the binary rate) starting with a horizontal "0" line and ending with a horizontal "1" line. The result of the proof is that duobinary transmission can only operate at 1.5 times the speed of binary transmission.

The result is due to an assumption that the highest bit rate, in either the binary or the

duobinary case, is obtained when the applied input bit is only long enough to allow the response of the assumed channel just to exceed the slicing threshold for a correct determination. The result is, therefore, trivial since the partial response characteristics thus obtained would be completely intolerant of channel impairments. If this constraint is removed and the normal Nyquist rates are applied, channel impairments can be tolerated and duobinary transmission rate would indeed be twice that of a binary channel but with 3-dB signal-to-noise penalty.—*S. T. Meyers*

The Effect of the Channel Phase-Frequency Characteristic on Data Transmission Reliability, *A. V. Mikhailov*—This paper presents an analysis of binary transmission on a channel that is ideal except for phase distortion. Curves of error probability are given as a function of signal-to-noise ratio, for several values of two parameters related to the degree and rapidity of phase variation.

The channel is assumed to have a narrow rectangular passband having a sinusoidal phase characteristic that passes through zero at exactly mid-band. The signal pulse is a full-period sinusoid whose frequency is exactly centered in the band. By these assumptions of bandpass symmetry the problem is reduced to one of baseband analysis. To account for the effects of phase distortion, the well-known method of paired echoes is applied, with the implicit assumption that only two echoes are sufficient. Because of the assumptions of highly idealized characteristics for the channel and the signal, the results are of little interest.

The treatment of intersymbol interference is superficial. Error probability is calculated under the assumption that only the two nearest neighboring pulses on either side contribute to the interference. Actually, pulses that are more distant in time will cause a residual interference which is quasi-Gaussian, and this residue may set a lower limit for error probability, regardless of signal-to-noise ratio. The theoretical point is whether or not the distribution of intersymbol interference is peak-limited to a value that is less than the decision threshold. Because the author does not indicate that he has considered such matters, one may question if his calculations are valid for the lower values of error probability.

Evidently, data communications engineering in Russia is many years behind the development of this field in the United States. By current American standards, Mikhailov's paper, for example, is naive, and a book reviewer in the same journal points out that a new book by Ye. V. Basilevich is the first in Russian literature to deal with the whole field of data transmission.—*Richard Gardner*

Log Normal Impulsive Noise Power at the Narrow-Band Filter Output of a Receiver with an AM or FM Detector, *B. P. Kalinichev*—The author presents results of the calculation of the output noise power in a narrow band when impulsive noise having a log normal distribution is applied to the input. The receiver model in the AM case consists of an IF amplifier, an ideal limiter, and an envelope detector followed by a bank of narrow-band filters. The FM model is the same but the detector is a discriminator. The calculation is carried out by evaluating the second moments of the input noise distribution and finding the noise power at the narrow-band filter output by considering the energy spectrum at the output of a filter with known input pulse shapes at the input. The author gives no details on the derivations and relies heavily on references. The paper is supported with calculated curves for various input signal and system parameters (bandwidth ratio, impulse noise median level, etc.). There are also presented some experimental results that seem to support the trend of the calculations. It is possible that these results will be of interest to radio engineers having to deal with impulsive interference.—*R. L. Pickholtz*

Special publications

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Publication		Prices M	Prices N
S-135	Power Cable Ampacities, Volumes I and II (Sold in sets only)—1962	15.00	15.00
	Radio Spectrum Utilization (book)	10.00	10.00
3 C 38	International Symposium on Antennas & Propagation—Dec. 5–7, 1966	4.00	6.00
6 C 64	Vehicular Communications Conference Record—Dec. 1–2, 1966	2.50	5.00
7 C 50	1967 Symposium on Reliability—Jan. 10–12	8.00	8.00
10 C 22	1966 Aerospace Systems Conference—July 11–15 (Transactions Supplement)	7.50	15.00
10 C 34	1966 Aerospace & Electronic Systems Convention Record (Supplement to AES-2, no. 6, Nov. 1966)—Sept. 26–27	7.50	15.00
13 C 65	IECI Special Symposium for Integrated Circuit Manufacturing—June 5, 1967	4.00	6.00
15 C 41	Thermionic Conversion Specialists Conference—Nov. 3–4, 1966	10.00	15.00
15 C 63	8th Conference on Tube Techniques—Sept. 20–22, 1966 (Record)	6.00	9.00
	(Digest)	1.00	2.00
15/17 C 48	Conference on Laser Engineering & Applications—June 6–9, 1967	2.00	4.00
17 C 66	G-MTT 1967 International Microwave Symposium—May 8–10	3.00	6.00
19 C 30	1966 International Communications Conference—June 15–17 (Digest)	10.00	15.00
26 C 68	Conference on Improving the Strategy of Oral Presentations—Feb. 6, 1967	2.00	4.00
	INTERMAG, International Conference on Magnetics—April 5–7, 1967 (Digest)	2.50	2.50
28 C 72	8th Annual IEEE Symposium on Human Factors in Electronics—May 3–5, 1967	3.00	5.00
31 C 35	1966 Special Technical Conference on Underground Distribution—Sept. 26–29	8.00	12.00
31 S 60	An Annotated Bibliography of High-Voltage Direct-Current Transmission 1963–1965	3.00	6.00
31 C 69	PICA, Power Industry Computer Application—May 15–17, 1967	10.00	10.00
34 C 36	Industry & General Applications Group Annual Meeting—Oct. 3–6, 1966	10.00	16.00
34 C 55	Industrial and Commercial Power Systems Technical Conference—May 22–25, 1967	5.00	7.50
F 63	7th Annual New York Electronic Reliability Conference—May 20, 1966	8.00	12.00
F 67	5th Annual Symposium on Microelectronics—July 18–20, 1966	8.00	22.00
F 70	Northeast Electronics Research and Engineering Meeting (NEREM)—Nov. 2–4, 1966	7.50	7.50
F 71	Region 3 Meeting—April 17–19, 1967 (Record)	5.00	10.00
	IEEE-G-AES 2nd International Congress on Instrumentation in Aerospace Simulation Facilities—Aug. 29–31, 1966 (Order from P. L. Clemens, VKF/AP, Arnold Air Force Station, Tenn. 37389)	11.00	11.00
	13th Annual Petroleum Industry Conference—Sept. 12–14, 1966	8.00	12.00
	19th Conference on Engineering in Medicine and Biology—Nov. 14–16, 1966 (Hardbound)	12.00	18.00
	International Solid-State Circuits Conference—Feb. 15–17, 1967	6.00	6.00
F 72	Southwestern IEEE Conference (SWIEEECO)—April 19–21, 1967	6.00	9.00
	1966 Electron Devices Meeting—Oct. 26–28 (Abstracts)	2.00	2.00
F 76	10th Midwest Symposium on Circuit Theory—May 18–19, 1967	6.00	9.00
	13th Annual Pulp & Paper Industry Technical Conference—May 3–5, 1967	**5.00**	**7.50**
	1967 IEEE International Communications Conference—June 12–14	**5.00**	**5.00**
34 C 61	**1967 IEEE Cement Industry Technical Conference—May 16–19**	**10.00**	**15.00**

tically, in orbit, devices and techniques being developed for possible use in satellite communications systems. LES-5, which is the first all-solid-state UHF-band communication satellite, will be used in experiments to aid development of a tactical communication system for the U.S. Department of Defense.

The LES-5 satellite is cylindrical in shape, approximately 1.68 meters long and 1.2 meters in diameter, and weighs about 102 kg. It is the first communications satellite to operate entirely at assigned frequencies in the ultrahigh communications band, which extends from 225 to 400 MHz. It is also the first communication satellite to have an all-solid-state UHF-band communication transmitter, which is potentially more durable and reliable than transmitters that were previously used in this frequency range. In addition, it is the first UHF-band communication satellite to transmit circularly polarized radio signals, which permits ground terminals to use much smaller, simpler receiving antennas than would otherwise be required.

The major components of LES-5 include a radio receiver–transmitter system, or transponder, to pick up radio messages from ground terminals and rebroadcast them to other ground terminals; and a telemetry system to monitor the status and performance of equipment and circuits aboard the satellite and transmit this information back to earth. LES-5 also carries a radio-frequency interference experiment, to survey radio signals from other sources that might interfere with satellite communications in this frequency range.

The LES-5 satellite is designed to operate in an equatorial orbit at an altitude of about 33 670 km. In this orbit, called "quasi-synchronous," it drifts slowly but steadily around the earth, from west to east, at a rate of about 30 degrees longitude per day, taking about 12 days to make a complete circuit. Thus it stays in sight of a fixed ground station for several days before disappearing over the horizon and staying out of sight for a somewhat longer period. The visibility period varies with the latitude of the site, ranging from more than five days in the tropics to slightly over three days in the arctic regions.

For experimental purposes, a quasi-synchronous orbit permits relatively extended operational tests to be carried out in different parts of the world without the necessity for multiple satellites.

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Technical correspondence

Wired broadcasting

You published in the April 1967 issue of SPECTRUM a most informative article concerning wired broadcasting in Great Britain by R. P. Gabriel, of Rediffusion International Ltd.

Those of us who are involved in the design of CATV equipment in the United States have followed with great interest the development of wired systems in Great Britain. I have been particularly impressed with one aspect of this development which has no parallel in our own CATV engineering progress. Approximately ten years ago the British engineers involved in this kind of work formed a society, the "Society of Relay Engineers," with regularly published Proceedings. These Proceedings present technical papers describing in considerable detail the development of cable, equipment, and techniques; to one associated with this kind of engineering, they make fascinating reading.

There has been no similar development of a professional group concerned with CATV engineering in the United States. Although there have been a few papers published in ELECTRICAL ENGINEERING and most recently in some of the IEEE TRANSACTIONS, there has been no effort to form a coherent organization within one of the existing professional groups or as a new organization. It would be difficult to discover all the reasons why we have not achieved such an organization. In any case, we in the United States have great respect for the work the British are doing and the professional way they present the results of their efforts, a practice we would do well to imitate.

It was somewhat disturbing to read Mr. Gabriel's comments on community television systems, specifically his flat statement that "They do not represent a sound engineering solution to the problem posed in this article" (that is, the problem of providing television service by wire in metropolitan areas).

I do not feel that the engineering approach to this problem employed by Mr. Gabriel and his associates is "unsound." However, as it applies to the engineering of cable systems in this country, it appears to me that it fails to take into account certain physical and social realities. A reading of Mr. Gabriel's article will show that the primary economic advantage he claims rests on the considerable reduction in the cost of television and sound receivers obtained by designing a unit specifically for the cable system that is rented to the householder.

Cable television engineering in the United States starts with a premise based not on engineering principles but on social behavior. This principle recognizes that the American householder is accustomed to—and we assume prefers—a wide variety of choice in purchasing household appliances with literally hundreds of models to choose from. The American purchaser of a television receiver would feel greatly restricted if his selection of receivers were limited to a few models available on lease from the cable company. In addition, U.S. cable systems have been, in most cases, established in towns where widespread use of television receivers already existed and the duplication of these receivers would represent an unwarranted and unnecessary expense.

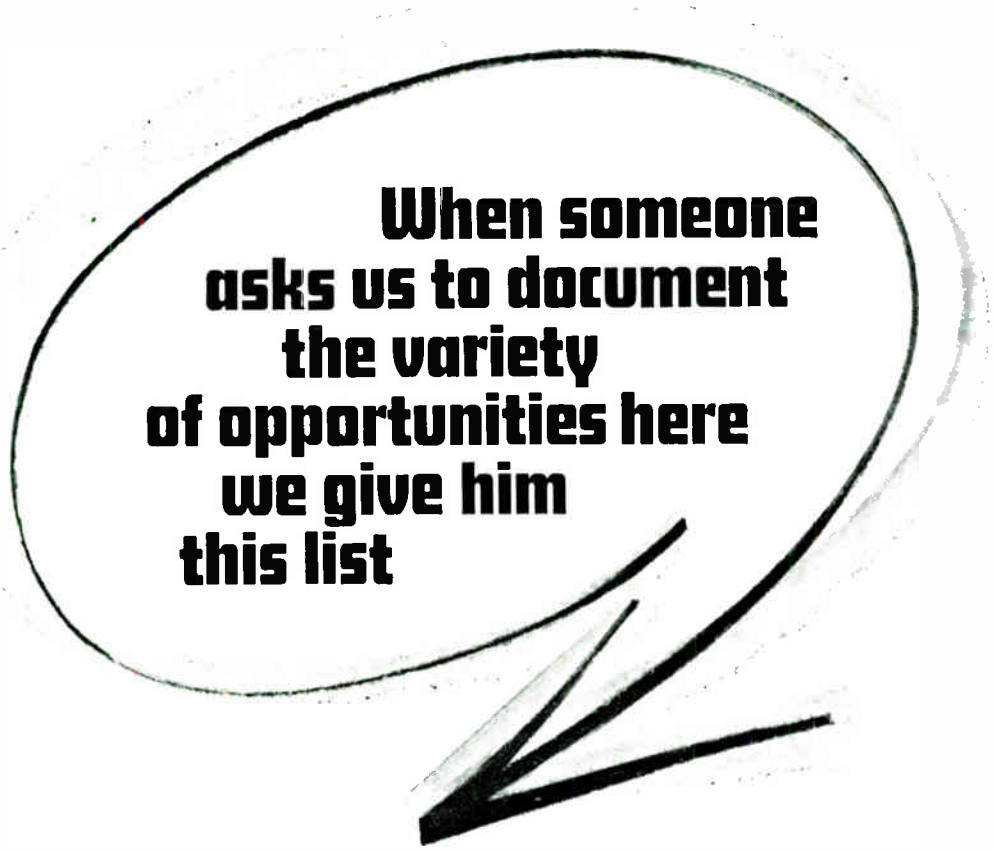
In view of this philosophy, our CATV engineering has, from the outset, adopted the principle of constructing a distribution system capable of supplying signals usable by a normal American television receiver. In retrospect this was not the great economic disadvantage it might at first appear. Because of the high sensitivity of these receivers, they function adequately with input signals of 1 mV across 75 ohms, whereas the receivers in Mr. Gabriel's systems require 15 mV. It is an elementary principle of multiple-outlet systems that the cost of the system is increased in proportion to the required signal level at each outlet. Certainly, the optimum is not necessarily reached by using the most sensitive receiver possible, since this implies an increased receiver cost. However, it can be found by balancing all the economic factors involved, including such tenuous ones as the number of channels in the system and the buying preferences of the ultimate consumer.

Mr. Gabriel is horrified by the idea of using "two tuners in series." Before this practice is condemned out of hand, the reasons behind it, as well as its future implications, must be explored. When commercial television receivers were first developed in the United States, the input circuit was designed to accommodate a balanced transmission line having a characteristic impedance of 300 ohms. I believe this was done with the idea that such a line, when connected to a simple dipole cut for channel 2, would provide approximately equal response for the television channels then in use (channels 2-6 inclusive). Although this justification was quickly eliminated by the use of folded dipoles, the 300-ohm twin lead was found inexpensive and easy to install and its use has unfortunately continued to the present day—unfortunately, that is, in view of the technical requirements of a cable system.

Present-day cable distribution systems use cables with solid metallic sheaths and amplifier equipment in well-shielded enclosures. As a result of these design factors, our systems are capable of operating satisfactorily in strong ambient fields involving frequencies identical to those being distributed.

This statement is true up to but not including the point at which the home receiver is connected. At this point a transformer must be introduced converting from the commonly used 75-ohm distribution cable to the 300-ohm balanced input. This connection and the receiver itself are far more susceptible to interferences from the ambient field than is the entire distribution system. In practice this fact often prevents the direct use of those channels on which programs are broadcast in a given metropolitan area.

The situation could be tremendously improved were the tuner input to be equipped with a truly coaxial connection for the cable. Unfortunately, this technique requires either a modification to the consumer's instrument or a receiver specifically designed for CATV. The former operation is highly undesirable as a routine operating procedure; the latter will only be justified when the market for these receivers is considerably larger than it is now. A reasonable interim solution to this problem is to supply, in those cases where direct pickup of radiated signals makes it necessary, a converter (the "second tuner") which is extremely well shielded and provided with a coaxial input terminal, and which may be tuned to convert any one of the incoming signals to a channel for the receiver on which no



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broadcasting is done in that area.

Although this may appear to be an unattractive solution to the original problem, it does have several attractive features. It not only eliminates direct pickup, but also provides for unambiguous channel identification. Most cable systems today, for various reasons, carry signals at frequencies differing from those on which they were originally broadcast. This means that the signal loses a property of great value to its originator, namely, its channel identification. The requirement that a householder must set his receiver to channel 7, for example, in order to receive channel 48 leads to confusion and reduces the value of advertising and published programs. The external converter provides a convenient way in which each channel can be clearly identified by number.

Another factor that has a strong bearing on the engineering soundness of the coaxial cable system as contrasted with the multiple-pair approach used in Great Britain concerns the number of channels to be made available at the home receiver. When one is dealing with six channels or less, it is possible, by rigorous care in the design of the distribution cables and by the use of engineering tricks like the *tête-bêche* principle employed in the British system, to control "crossview" between channels. When we are asked to supply 12 channels or, as seems quite possible in the future, many more than 12, the problems of cable design as well as the complexity of program selection become outrageous and the principles of "sound engineering" point to other solutions.

A single coaxial cable has the capability of bringing into the home a variety of programs and services limited only by the engineering and social imagination of the system designer. It is simply installed and economically manufactured and can provide technical performance satisfying the most critical user in systems as large as the largest metropolitan areas in the world. By progressing in this direction, we in the U.S. CATV industry are convinced we are leaving the door open for future developments in areas which have not yet been considered. We feel that we have a technique capable of tremendous expansion in channel capacity without replacing substantial portions of the tremendous investment represented by a distribution system, and we feel that—considering our technical and social environment and the future needs of our public—the engineering we have done is at least as "sound" as that of our esteemed colleagues on the other side of the water.

Keneth A. Simons
Jerrold Electronics Corp.
Hatboro, Pa.

In reply to Mr. Simons, I should first like to put right a very common misconception on which part of his comments are based. The public's choice is not restricted to a few models of receivers available on lease from the cable company. The householder can use any type of television receiver he likes and when he buys a new one he can, if he wishes, choose from many different models of the cheaper wired receiver, which are designed for use with the system and which are manufactured by many different firms and marketed through their usual dealers.

The cable company is only one of many suppliers for these receivers. It is true that the renting of television receivers is very popular in the U.K. and the wired receivers for the system may be leased from an even wider range of suppliers; but this factor of leasing is really quite irrelevant in the present context. Of course, I agree that when the market for these receivers is small, manufacturers and retailers are not likely to be interested. However, when it reaches substantial proportions, as it has in Great Britain, particularly in Community Service areas where every home is wired under a bulk contract with the estate developer, then this becomes a commercial necessity if the manufacturers and retailers are to remain competitive in these areas.

In our own case also, networks are established in towns where the population is already equipped with conventional television receivers, but these do not last forever: the public on average replaces them every eight to ten years and in the present replacement cycle we are witnessing a wide-scale re-equipment for color.

We believe that both distribution system and receiver should be taken into account and designed as parts of one single whole; and the point that Mr. Simons makes about the input level is a good illustration of our differing philosophies. The choice of the high figure, 15 mV in our case, results from considerations of the overall costs of the system plus the receiver and, in this broader field, his elementary principle does not hold. By using a high level we save money in the receiver, which is important for us but not for him; in addition, we save in the distribution cable since no screen is required.

Mr. Simons thinks that distribution of 12 channels is likely to cause difficulty on a multipair system but this is not so because the problem of crossview is concerned, first, with the crossview between one pair and its neighbors on either side—the adjacent pairs; and, second, with the pairs beyond these two—the alternate pairs. Once the crossview problem has been solved for this group, the number of pairs can be extended without limit. The point has been proved in practice by the installation of an 11-channel system in the BBC television studio complex at Shepherd's Bush—the BBC being well known for the exceptionally high standard of performance it demands from all its equipment. When the number of channels exceeds 12, then the idea of remote program exchanges, to which I referred in the article, is likely to show the lowest overall cost.

I did not wish to imply that VHF coaxial distribution systems are in themselves unsound. We have a high regard for the work of our U.S. colleagues in the field of coaxial distribution. Our quarrel with them is that they have selected, for social and commercial reasons, which we fully understand, only one part of the complete system necessary to provide the public with pictures and sound in their homes.

Although we understand those reasons, we do not accept that they need be any more inhibiting in the United States than they have been here. Householders are not concerned with the technical details of how the delivery is made nor, in the long term, are they committed by the type of television set that they at present own. They have a right to expect of communication engineers as a body that the complete system shall be as simple, reliable, and cheap as we can make it; anything less than this is "unsound" in the sense in which I used the word.

R. P. Gabriel
London, England

It seems possible that the differences between Mr. Gabriel's viewpoint and mine are semantic. How can a given engineering job be labeled "sound" or "unsound?" Shall we do it on the basis of the "number of customers" or how well we "outpace all rivals?" I am afraid that if these are the ground rules, my company can also claim "sound engineering," since the users of our equipment number several times the

quantities he mentions, and we too have outpaced most of our rivals.

I would prefer to think that *any* engineering solution to a problem that squarely meets a real problem with an economic solution (not necessarily the most economical solution), and which provides a service satisfactory to the customer and profitable to the investor, may, in all justice, be called "sound." Shall we say that a Volkswagen has sounder engineering than a Rolls Royce because it uses less fuel? Or is not each soundly engineered for the market for which it was intended?

Keneth A. Simons
Jerrold Electronics Corp.
Hatboro, Pa.

Cooperative education?

Regarding the article entitled "Practical Experience and Engineering Education" (SPECTRUM, pp. 60-66, May 1967), in spite of the rather learned dissertations given by eminently qualified writers, it is my humble opinion that from both an academic and a working standpoint an undergraduate student benefits most rapidly by the cooperative education method originated at the University of Cincinnati.

I believe that this system is now in use at approximately 50 accredited colleges throughout the United States and I was sorry that this point was not brought out specifically by more of the educators.

C. J. Sheridan
Cincinnati, Ohio

Patterns of education

I wish to convey my congratulations to you and the author for the article, "New Patterns of Industry-Government Partnership," appearing in the May issue of IEEE SPECTRUM.

It is indeed timely to draw attention to the matters referred to by Dr. Hollomon and I would hope that his comments will reach further than the IEEE membership alone, which after all is rather a select readership.

There is one aspect of the article that I feel might be expanded somewhat. The author lays considerable stress upon the longer period of training, shorter working period, and earlier retirement to be anticipated in the future. He also mentions the need for preparing people for this new mode of life. I would like to suggest that more emphasis should be given to preparing

people for a constructive and useful life during the greater leisure time they can look forward to in the future. After all, the most satisfying experience in life is in accomplishment. It would seem to me that society should be giving attention to means whereby those who retire from their first round of work should have the opportunity of taking up some part-time activity other than simply spending their time amusing themselves. Today professional people have this opportunity and generally can keep themselves suitably occupied, but it is not the case for many others. Industry may eventually find it profitable to make use of this talent and experience, which has been so carefully developed and which apparently can be expected to be productive for a constantly decreasing period of time in the future.

I would also like to comment upon the author's remarks about educational institutions and the idea of operating the educational system at a profit. I submit that this is really an old idea in new shape. Private schools today are operated at a profit, and generations ago schools in many parts of the world were private or were profit-making enterprises. The idea that education should be free is a relatively modern cry and, I quite agree, can be carried too far. In fact, the need for a college education for all sorts of jobs in the United States has already been carried to extremes and has almost become a fetish. In many cases the needs of the student and society would be met far better if vocational training in a trade were given instead of a college degree. I have often been shocked to hear graduates saying that, even after receiving their first degree, they do not know what they really want to do.

May I once again express my appreciation of Dr. Hollomon's article.

R. Vaughan Sear
McLean, Va.

Communicating on nerves

This letter is in regard to "Suggestions for Nerve Theory." (See IEEE SPECTRUM, *Technical Correspondence*, pp. 192–194, March 1967.) From our point of view in biotechnic engineering, the two correspondents, Professors Max Valentinuzzi, Jr., and Fing Y. Wei, are discussing each other's point of view rather than talking to each other. In the interest of bringing about better communication between the engineers and life science professionals, we offer the following technical commentary.

Transistor theory is a quantum mechanical theory developed to explain an observed phenomenon in crystalline solid-state materials. The developers used Bloch's[1] concept of the application of quantum mechanics to crystalline solids in their derivations.

The engineering approach is to inquire first into the properties of the materials. The membrane is then found to be a phospholipid–water alloy in the liquid crystal state. Phospholipids are paraffin-like materials whose theory has been developed by Daniel.[2] X-ray diffraction studies and electron microscope studies reveal that the material is in a lamellar or ribbon-like configuration approximately 75 Å thick in the resting membrane.[3] From Gubanov[4] we see that quantum mechanics is still applicable to the behavior of amorphous solids in the liquid crystal state.

In the pure state at body temperature the phospholipids are clear, or transparent, which identifies them immediately as insulators according to the band theory of solids; the experimental evidence also verifies this.

One then sees that Professor Valentinuzzi's question, "What are the majority carriers in the membrane?" was not completely answered by Professor Wei.

The reason is that, from the band theory of solids, the energy gap in an insulator is so large (three to six eV) compared with the thermal energy of electrons at room temperature ($\backsimeq$0.025 eV) that there are a negligible amount of majority carriers to be modulated by minority carriers in insulators. Semiconductors, with energy gaps of the order of 0.5 to 1.5 electronvolts, do have majority carriers available at room temperature for modulation; hence, we have transistor theory, which would only be directly applicable if the membrane material were a liquid crystal semiconductor.

Since we have established the nature of the membrane material in its pure state as an insulator, it is now possible to consider its behavior with various ionic and organic impurities in it. This phrase describes a category of photodetectors[5] and application of the continuity equations and Einstein's relationship becomes straightforward.[6]

Since the mobility of the electrons in paraffin-like materials is very small (their electron shells are completely filled like the noble gases), it is necessary to examine the behavior of the impurity ions to account for any conduction.

As the material is not a solid, but rather a liquid crystal, one finds that these ionic impurities have a small mobility, of the order of 1×10^{-8} cm/s in the host material at the temperatures of living systems. In the absence of an external field, however, the drift term in the continuity equation is zero, leaving only the nonequilibrium conductivity terms, which, for "unipolar" nonequilibrium carriers of one sign only, are:

$$\Delta\sigma_{nl} = e\mu\tau\beta kI$$

where

- $\Delta\sigma_{nl}$ = conductivity change due to nonequilibrium carrier densities
- e = charge on the electron
- μ = mobility of electron or hole
- τ = average lifetime of carriers
- β = number of electron–hole pairs liberated by a quantum of incident radiation
- k = optical absorption coefficient
- I = light intensity

Recall that the thickness of the membrane is approximately 75 Å or only about 15 times the interatomic spacing of most solids. One sees that the diffusion length of a minority carrier l_D needs only to be increased to 40 Å for a negative charge to appear on the surface of the membrane. The diffusion length l_D is defined as:

$$l_D = \sqrt{D\tau}$$

where

$$D = \frac{\mu kT}{e}$$

the Einstein relationship and

$$l_D = \sqrt{\frac{kT}{e}\mu\tau}$$

- k = the Boltzmann constant
- T = the absolute temperature

Since, at room temperature, the Boltzmann factor, $kT \approx 0.025$ eV, it is easy to see that the capture of a photon by an impurity ion, where the photon is in the near-infrared range typical of the internal environment of biological organisms, would raise kT transiently from 0.025 eV to approximately 2.5 eV, for a particular electron, a factor of 100. Then

$$\frac{l_{D\text{excited}}}{l_{D\text{unexcited}}} \approx \sqrt{\frac{2.5}{0.025}} \approx 10$$

Hence, a negative electron[7] from an impurity ion within the membrane would suddenly appear at the membrane surface due only to the capture of a near-infrared photon, as the negative electron's diffusion length would be raised from 5 Å to 50 Å; and we see a source

for the membrane potential from a physical background. Also, in keeping with Professor Wei's observation, the excess of electrons appearing on the membrane surface will make it look like an η-type material. If these "hot" electrons are captured by a material at the surface of the membrane, the inside of the membrane becomes populated with positive ions, which then drift slowly to the surface, and one sees the observed "active" carriers of the current.

The membrane then becomes electrostatically polarized due to the variation in capture probability across the membrane of photons released from within the cell by metabolic activity in agreement with the observations of Davson and Danielli.[8] At this point, we refer to Edwards and Lyman[9] for a possible internal control mechanism of this type in the visual sense.

The thermodynamic theory in quantum mechanics, first explored by Leo Szilard,[10] indicates that the foregoing means for generating an electrostatic potential from radiant energy in a liquid crystal-fluid system could approach 100 percent efficiency; hence, it is of technological interest to engineers. Attention is drawn to the two-step process for creating solvated electrons. The first step is the capture of a photon, while the second one is a thermodynamic step in which negative entropy is generated, just as predicted by Leo Szilard in 1929.

N. Bohr introduced the correspondence principle in 1923 when microscopic theoretical models of this type were first finding acceptance in physics. The correspondence principle states that in the limit of large quantum numbers, the microscopic theory should agree with the macroscopic observations and theory of classical physics, specifically, spectroscopic observations.

Applying the correspondence principle to the microscopic biological control phenomena described above, we would expect control to be initiated by and macroscopically observed at specific wavelengths of the electromagnetic spectrum. This principle was called the psychophysical parallel by Bohr.[11]

Turning to the literature, we find a paper by H. Mohr[12] describing the extensive work at long visible and near-infrared wavelengths on the regulation of the metabolism of cells and organisms by relatively small quantities of photomorphogenically effective radiation.

Similar investigations on nerve membranes at the longer infrared wavelengths characteristic of the metabolic activity of animal cells appear to be awaiting the technological development of improved monochromatic energy sources (lasers) and more sensitive detectors at these wavelengths.

Robert F. Edwards
University of California
Los Angeles, Calif.

(This investigation is supported in part by Public Health Service Special Research Fellowship 1-F3-GM-36.)

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I would like to make a few remarks on Dr. Edwards' letter. First, my correspondence to the IEEE SPECTRUM as published in March 1967 was not only to answer some of Dr. Valentinuzzi's questions but, also, to answer those sent to me by other people from various disciplines and various places. Actually, I had only picked up the ones that I considered to be important from the standpoint of "principles." In this way I intended to cover a wider range of questions and perhaps to answer some of those that might still be in the reader's mind.

Second, Dr. Edwards seems to have made a little too much of the comparison between a nerve membrane and an "electronic semiconductor." This is where one must exercise the greatest caution. What we need is 222: 2 types of charged particles, 2 junction barriers, and 2 basic equations. The other requirements for an electronic semiconductor such as a band structure, band gap, high mobility of electrons, etc., are not necessary for a nerve membrane as far as the "ion transport" is concerned. If one considers "electron transport" in the nerve, then some of Dr. Edwards' comments may be helpful.

Third, although Dr. Edwards feels that Dr. Valentinuzzi's second and fourth questions were not answered in a "direct" way, the questions were, I feel, answered in "essence." Both from the Danielli–Davson model of cell membrane and from a great deal of experimental evidence it is clear that a nerve membrane is very likely to have excess negative ions. The questions of what these negative ions are and of whether they are mobile or immobile are not pertinent to my theory, as long as they are assumed to have recombining probabilities with positive ions. The question on the labeling of "bias" is also unimportant, for the charge particles only see the barrier height in front of them and do not care at all about how the barrier is created (internally or externally). There could be many questions like this if one compares a transistor and a nerve axon *too literally*. As I emphasized in my previous correspondence, the important thing is the "physics," not the "device aspects."

I might mention in passing that I have been seriously considering the possibility of electron transport in the nerve, and a part of this work will be published elsewhere.[1]

L. Y. Wei
University of Waterloo
Waterloo, Ont., Canada

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Book reviews

Electromagnetics, Robert S. Elliott—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1966; 511 pages, illus., $15.50.* This is a refreshing scholarly text that is recommended to all readers seriously interested in the subject of electricity and magnetism.

There are two unusual features in the book. First, there is a historical development of the subject along with the technical development. Second, electromagnetic theory is developed from Coulomb's law and the special theory of relativity alone. Postulating the Biot-Savart law and Faraday's law is not necessary. Incidentally, the author points out that this was first done by Prof. Leigh Page in 1912.

The material is arranged in eight chapters, and contains over 100 pages of appendixes and a mathematical supplement.

The first chapter is concerned with the phenomenon of light, and the second one with the special theory of relativity. Here, as throughout the book, after the introductory historical survey, discussions of many of the classic experiments are blended into the development of the subject. Thus, the principles of special relativity are developed in a framework of simple mechanics and optics and are not obscured by involved mathematical detail.

Chapter 3, the longest, is devoted to the subject of electrostatics in free space. This is followed by a chapter on magnetostatics. Here, a Lorentz coordinate transformation is used to convert a static system of charges to a rigidly translating system having the features of a steady current. Application of the relativistic force transformation, derived in chapter 2, yields the Lorentz force law that permits the definition of a magnetic field. From this, the Biot-Savart and Ampere laws follow along with the subject of magnetostatics.

Chapter 5 employs a second Lorentz transformation to convert the steady electric and magnetic fields to time-varying fields as seen by a moving observer. These fields, which are defined to conform to the Lorentz force law, are shown to satisfy Maxwell's equations. The remainder of the chapter discusses the solutions to these celebrated equations and some applications, such as the waveguide problem.

In chapters 3, 4, and 5, the subject matter is restricted to fields in free space. The last three chapters are devoted to the constitutive parameters, ϵ, μ, and σ. Included is a development of the theory of the physical phenomena that give rise to these parameters. For instance, in the chapter on dielectric materials, there is a discussion of ionic polarization and ferroelectrics. Chapter 7 includes some material on the modern theory of magnetism and ferrites. Chapter 8 has a section on the conductivity of semiconductors as well as one on metals. Characteristics and constants for typical materials that are now available are given.

In summary, this text is a welcome addition to the literature of electromagnetic theory. Practicing engineers should find the historical surveys interesting reading. For those whose background includes only classical electricity and magnetism, this is an excellent place to begin the study of special relativity or modern solid-state materials. For university students, this fresh approach should provide motivation and give them some perspective. Furthermore, they will be introduced to important areas of study usually neglected in most electrical engineering curricula.

The author has a lucid, informed style, and the text is free of typographical errors.

Bernard Silverman
Syracuse University
Syracuse, N.Y.

Magnetoelectric Devices: Transducers, Transformers, and Machines, Gordon R. Slemon—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 530 pages, illus., $11.50.* The author states very clearly the motivation behind the preparation of this book. According to him, the essence of engineering is design, and the route to this objective has four distinct but interrelated aspects: an understanding of the physical processes, the derivation of approximate models, techniques of analysis, and, finally, design. This pattern of development is faithfully executed in the writing of this book.

The volume consists of five chapters: (1) electric energy conversion processes (105 pages), (2) analysis of magnetic systems (60 pages), (3) transformation of electric energy (66 pages), (4) commutator machines (102 pages), and (5) polyphase machines (197 pages). The book is primarily written for students who already have had an introductory course in electricity and magnetism. No advanced mathematics beyond calculus is needed.

There is very little review of the foundation of electromagnetism. Coulomb's law, Faraday's law, Lorentz' force law, and the energy principle are the main tools used in the analysis.

The book shows evidence of having been carefully written by an experienced man in this field. The greatest value of the book lies in the problems, about 40 of which are contained in each chapter. Most of the problems have a touch of engineering design. The book as a whole is a valuable contribution to electric power engineering in an era dominated by electronics.

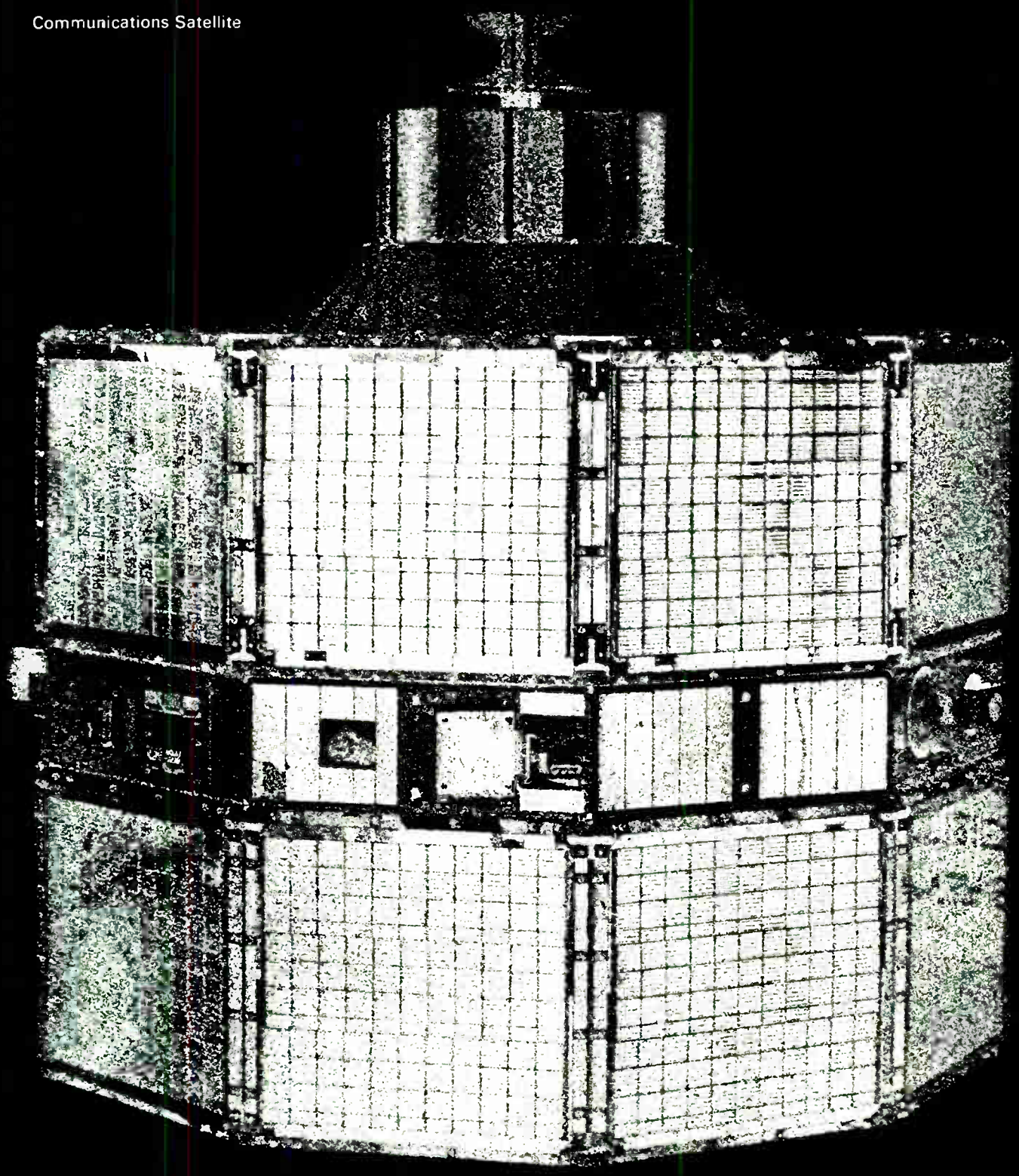
Chen-To Tai
The University of Michigan
Ann Arbor, Mich.

Proceedings of the International Conference on The Physics of Semiconductors (Supplement to the *Journal of the Physical Society of Japan*, vol. 21, 1966), Toshinosuke Muto—*The Physical Society of Japan, 21, Shiba-Koen, Minato-Ku, Tokyo, Japan, 1966; 774 pages, illus., $32.00.* This collection of papers is grouped into 19 sections representing both conventional and advanced areas in the field. As with the proceedings of any conference, the technical and literary quality of the individual papers shows variation. On the whole, however, the papers are excellent on both counts.

Some of the topics covered exhibit a high degree of completeness in the treatment of the subject matter, which is a result of the paper selection, and areas that are generally not readily available are discussed here. Examples of this are the papers on magnetoplasma and magnetoacoustic phenomena, magnetic semiconductors, and semimetals. Even in more familiar areas, such as impurity state and current instability, the papers are timely and stimulating.

The other topics covered are band theory, optical properties—lattice, optical properties—electronic, exciton, magnetooptics, recombination, transport phenomena, quantum transport, hot

Communications Satellite



The Lincoln Laboratory, a research center of the Massachusetts Institute of Technology, is engaged in theoretical and experimental investigations in advanced electronics, with emphasis on technological applications to national defense and space exploration. The program in *Space Communications* is directed toward the discovery and development of methods for long distance communication resistant to disruption by natural or man-made disturbances. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 41, Lexington, Mass., 02173.

Solid State Physics
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A description of the Laboratory's work will be sent upon request.

electrons, electron–phonon interaction, impurity conduction, tunneling, superconductivity, and plasma instability.

The work represents a complete record of the meeting since the discussions that took place at the meeting follow each paper. This adds dimension to the work and creates a rather exciting identification with the subject.

As with any such collection, the book in itself is not directed at any particular group of workers, but most people in the field should find items of interest. The book provides an above-average record of a conference proceedings.

G. Strull
Westinghouse Electric Corporation
Baltimore, Md.

Psychiatric Case History Event System—Transcription Procedures with Lexicons, Bernice T. Eiduson—*Reiss-Davis Child Study Center, 9760 West Pico Blvd., Los Angeles, Calif., 1966; 259 pages.* This report describes a first step for the storage in a machine of descriptions of events from psychiatric case histories. The machine provides the opportunity for rapid logical manipulation of information and for subsequent retrieval. In the design of the machine lexicon and in the delineation of doctors' procedures for transcribing case histories into machine format, a good balance between accuracy, precision, relevance, and purpose has been achieved.

The effort to build the lexicon in terms of events (in the patient's life), whether actual or inferred, and the discrimination between them while allowing them to coexist in the lexicon framework, is particularly valuable; it coincides with the way in which members of the profession use the information in decision making. Also, the immense amount of data available on multitudes of hospital and clinic admissions and on frequently revalidated case histories has not previously been gathered together in a single, accessible storehouse.

The utilization of computer-based intelligence for the measurement of human behavior and the simulation of this formally defined behavior promises to provide an interesting avenue for progress in the next few years.

Warren M. Brodey
M.I.T. Science Camp
Cambridge, Mass.

Russian English Dictionary and Reader in the Cybernetical Sciences, Samuel Kotz—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 196 pages, $11.00.* This rather short dictionary is an attempt to collect specialized terms from the areas of automatic control, communication theory, digital and analog computation, probability and statistics, and other disciplines included among the "cybernetical" sciences, in the Russian usage of the word. The dictionary is not intended to stand alone, but only to supplement some larger, more general, Russian–English scientific dictionary, such as the well-known work of Emin (*Russian-English Physics Dictionary*, John Wiley and Sons, Inc., New York, 1963).

Only 144 pages of the book are devoted to the dictionary itself. The rest of the volume contains an irrelevant foreword (by Arthur Porter) devoted to a philosophical discussion of "cybernetics," an introduction briefly describing Soviet publishing efforts in the area, a section of 46 pages of excerpts from appropriate Russian papers with interlinear English translation (the *reader* of the title), and a 16-page bibliography of books and articles on a wide range of topics. The bibliography is of some use in calling attention to available journals, but the *reader* seems not to be worth the space devoted to it. The structure of technical Russian, in contrast to that of German, for example, seems simple enough so that suitable practice material would be available throughout the unsimplified working literature.

As to the dictionary itself, there are three audiences that one might postulate. First, for the professional translator, working in a broad range of areas without necessarily having a deep technical knowledge in the area of any given paper, the dictionary will be of value since it pinpoints the particular meaning of a term which is appropriate for cybernetics. Second, for the practiced translator in a particular technical area, the book is probably not useful. None of the entries examined by this reviewer were such that their correct meaning would not have been clear from a more general dictionary, such as that of Emin.

Finally, there is the casual translator, who does not necessarily have a deep grasp of the language but stays within his own technical area. (This is the group, incidentally, to which this reviewer belongs, and toward whom the author states that the book is in fact aimed.) Here the usefulness, or lack of it, of the dictionary is less clear. With a good knowledge of the subject of the paper, even a casual translator should be able to infer the correct meanings of most terms, working only from a book such as Emin. This reviewer found, in general, that if Emin was of no help in a particular case, neither was Kotz.

In short, the objective of a cybernetically oriented dictionary is laudable, but this one is too brief to be of serious use. However, for someone who is seeking short-term aid in the process of learning the language, the combination of *reader*, brief dictionary, and guide to the literature may well be worth the price of the book.

Robert N. McDonough
Morris Plains, N.J.

Modern Optical Engineering—The Design of Optical Systems, Warren J. Smith—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1966; 449 pages, illus., $15.00.* The stated purpose of this book is to provide effective practical technical information on optical systems and their design for the practicing engineer or scientist. It is designed to assist those who, while well trained in electronics, mathematics, mechanics, etc., have only a remote familiarity with the optics material covered in a first-year physics course, and who are required to develop a relatively advanced competence in optical engineering. Within the space available, the author has done a remarkable job.

The reviewer regards the chapters on image formation, prisms and mirrors, stops and apertures, optical computations, image evaluation, design of optical systems and, particularly, optics in practice, as having considerable utility.

Each chapter is followed by a number of problems of varying degrees of complexity. These problems are well chosen to illustrate the topics under discussion and enhance the book's utility.

There are several minor criticisms. For example, the identification of aberrations by means of the adjectives only, such as spherical for spherical aberration, etc., causes some confusion in places. The definition of resolving power of an optical fiber bundle is true only for certain locations of the test object. In the opinion of the reviewer, the discussion of optical path difference would have been enhanced by a discussion of the approximations involved in Fig. 11.1.

This book is recommended to the attention not only of those engineers desiring to improve their competence but, also, to teachers seeking a textbook for a course in optical design.

W. A. Miller
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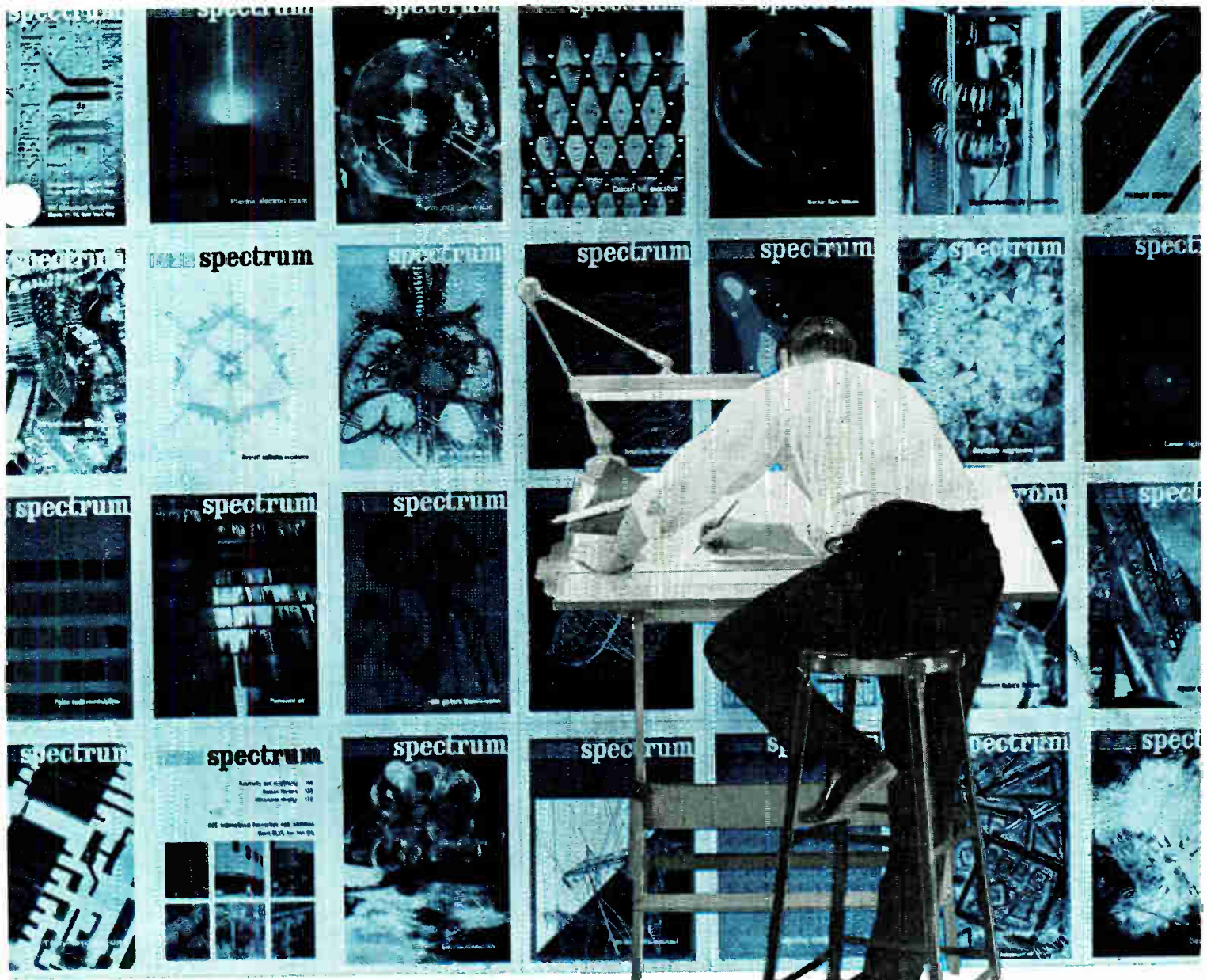

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New Library Books

The books described below were recently acquired by the Engineering Societies Library. Members of the IEEE in Canada and the continental United States may borrow books from the library by mail. The books may be kept up to two weeks; a charge of fifty cents for a week or a fraction thereof is made for each volume, exclusive of transit time. Requests for books and for information on literature searches, translation services, and photocopying and microfilming of library materials should be addressed to the Engineering Societies Library, 345 East 47 Street, New York, N.Y. 10017.

Basic Automatic Control Theory, Gordon J. Murphy—*D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N.J., 1966; 832 pages, $16.64.* The purpose of this book is to present many of the more modern concepts in the analysis and design of automatic control systems, in conjunction with older concepts, in order to provide the student with a broad foundation for more advanced work. To stress the fact that automatic control is concerned with physical systems and is not merely a mathematical pastime, characteristics of the physical components of typical systems are presented and transfer functions are derived in an early chapter. An attempt has been made to include most of the topics of continuing importance in the field of automatic control, so that the book can be used effectively both as a reference book and as a textbook. It is suitable for undergraduate courses at the junior or senior level, and also for first-year graduate courses.

Biological Control Systems Analysis, John H. Milsum—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1966; 466 pages, $17.50.* Bridging engineering, biology, and medicine, this book demonstrates that many biological systems can be mathematically modeled and analyzed, utilizing techniques developed in control engineering. Much of the book is devoted to developing the basic tools of linear dynamic analysis and control theory. The author draws freely upon a wide selection of models from the biological research literature, and incorporates these throughout the book in order to motivate each new necessary theoretical development. The use of computers is emphasized.

Communication System Engineering Handbook, Donald H. Hamsher, ed.—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; various pagings, $28.50.* This is a comprehensive digest of communication system engineering based on the experience and practice of the 33 specialists who are contributors. The handbook begins with information needed prior to system design, continues through the development of the communication system plan for all basic types, describes the variety of transmission and switching components of the systems, and treats the essential auxiliary and supplementary topics of power, facility layout, operation, and costing. Particular consideration is given to data transmission, closed-circuit television, potential address systems, and radio-frequency assignment procedures. The book also points out important divergences from U.S. practice.

Communication Systems and Techniques, Mischa Schwartz, William R. Bennett, and Seymour Stein—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1966; 618 pages, $16.50.* In the rapidly expanding field of communications, too often theoreticians and practitioners have been unaware of each other's activities. This book attempts to bridge the gap between theory and practice not only by emphasizing theory and basic principles, but also by describing applications to current technology. It is hoped that the book will serve both as a graduate text and as a reference book for experienced communications engineers. Part I describes the fundamental aspects of communications in the presence of noise, directing its attention to the two major classes of signal representation—digital and continuous wave. In Part II, continuous wave and pulse modulation are again considered, but with a somewhat different approach. The discussion here reviews the art of modulation as practiced in modern communication systems. The material of Part III covers digital communications theory and principles, with particular emphasis on the applications to problems of transmission and reception over fading radio channels.

Electronic and Magnetic Behavior of Materials, Allen Nussbaum—*Prentice-Hall, Inc., Englewood Cliffs, N.J., 1967; 155 pages, $5.95.* An understanding of dielectric and magnetic materials, and of solids used in devices such as diodes and lasers, requires a knowledge of electromagnetic theory and of quantum physics. In this concise little book, a review of the nature of fields inside materials is provided in chapter 1; and a simple treatment of quantum theory is given in the first part of chapters 2 and 5. These topics then form the basis for the study of semiconductor materials and devices, dielectrics, magnetic materials, and quantum electronics. It is assumed that the reader has a background that includes some modern physics and has a familiarity with the vector differential operators.

Handbook of the Engineering Sciences, Vol. I: The Basic Sciences, James H. Potter, ed.—*D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N.J., 1967; 1347 pages, $37.50.* Prepared by 33 specialists in science and engineering, this first of two volumes concisely presents the enduring fundamental considerations of the basic sciences—mathematics, physics, chemistry, graphics, statistics, mechanics, and the theory of experiments—as background for the applied engineering sciences, which will be presented in volume II. The coverage includes up-to-date material on matrices and tensors, condensed states of matter, transport properties, Mössbauer effect, structure of matter, metal corrosion, fluid-film lubrication, and elasticity and plasticity theory. The explanation of each topic is followed by clearly defined derivations used to make essential engineering calculations, with examples of their use. In addition to a complete index, an extensive bibliography follows each chapter. The book is written at a level approximating that of the first-year graduate student in engineering.

Microwave Breakdown in Gases, A. D. MacDonald—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 201 pages, $7.95.* A text for senior undergraduates or first-year graduates in electrical engineering and physics, this book begins with experimental and theoretical principles and stresses the interrelationships of the two. It describes basic atomic properties and their relation to analysis based on the Boltzmann equation. Because of current interest in break-down in the atmosphere and in the ionized shock region in the neighborhood of missiles, there is a chapter covering microwave breakdown in air and atmospheric gases. Much previously scattered data have been incorporated, and theory is used to present extensive sets of data economically.

Modern Analytical Design of Instrument Servomechanisms, Bruce A. Chubb—*Addison Wesley Publishing Co., Reading, Mass., 1967; 228 pages, $11.95.* The purpose of this book is to provide engineering personnel with the latest analytical techniques developed for instrument servomechanism design. Its goal is to help the reader to develop an extensive ability to design optimized instrument servomechanisms with an assuredness that they will perform as predicted. Close attention is paid to bridging the gap between theory and practice. All component tolerance effects are considered, specification techniques are discussed, and emphasis is placed on obtaining design data from component specifications. The design and analysis techniques presented lend themselves directly to programming on the digital computer. This computerized approach leads directly to computer-aided design concepts and, finally, to completely automated design.

Networks and Systems, Peter H. O'N. Roe—*Addison-Wesley Publishing Co., Reading Mass., 1966; 336 pages, $12.50.* Since the author is mainly concerned with the analysis of physical systems that can be described by linear algebraic and differential equations, this book, although designed for a second course in electric circuit theory, is also suitable as a supplementary text in a first graduate course in system theory. In the first three chapters the basic concepts of network theory are discussed, and several methods of formulating suitable mathematical models of linear systems are introduced. In chapter 4 the analysis of large systems by treating subsystems as components is introduced. Chapter 5 is concerned with time domain techniques in the analysis of linear systems. Finally, chapter 6 introduces the wider framework of system theory. Here the author abandons the exclusive use of the electrical example and indicates the direct applicability of all the concepts and methods of the previous chapters to mechanical, hydraulic, and mixed systems.

Principles of Coherent Communication, Andrew J. Viterbi—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1966; 321 pages, $13.50.* This book is a presentation of the theory of phase-coherent communication systems operating in a thermal-noise environment. This theory has found widespread application in space, satellite, and military communications systems.

The book consists of a unified treatment of three distinct but related topics of statistical communication theory: (1) the theory of operation of the phase-coherent receiver or phase-locked loop; (2) the optimization of coherent demodulators for both analog and digital modulation systems; and (3) the comparative performance analysis of coherent and noncoherent or conventional demodulators. The material is intended for graduate students and practicing engineers.

Quantum Theory of Molecules and Solids, vol. 3: Insulators, Semiconductors and Metals, John C. Slater—*McGraw-Hill Book Co., 330 West 42 St., New York, N.Y., 1967; 549 pages, $15.50.* This is volume 3 of a comprehensive four-volume series on modern solid-state theory. It applies the information on electronic structure of molecules and the theoretical calculations of energy bands in crystals, covered in volumes one and two, to the study of the actual properties of solids. A bibliography of some 6000 items is appended, including many experimental as well as theoretical papers. The final volume will deal principally with basic magnetic properties, paramagnetism, ferromagnetism, diamagnetism, and superconductivity, with some attention to the many-body problem and various types of excitations in crystals.

Solid-State Electronics, Shyh Wang—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1966; 778 pages, $15.50.* The invention of transistors and lasers has opened new territories for technological exploitation and has encouraged electrical engineers and physicists to work closely together. The purpose of this book is to provide a text which treats the properties of solid-state materials from a device standpoint. It is written for electrical engineers and applied physicists who will have to translate basic knowledge in the sciences and new discoveries of physical phenomena into technological advances. The book deals with solid-state electronic devices that utilize the conductive, dielectric, magnetic, and optical properties of materials. Its main objective is to introduce the student to the modern theory of solid-state devices, starting with a discussion of material properties. The book attempts to bridge the gap between physics and electrical engineering, and is wirtten as an introductory text at the advanced senior and graduate level.

Recent Books

An Analysis of Time-Shared Computer Systems (M.I.T. Research Monograph no. 36), Allan L. Scherr—*The M.I.T. Press, 50 Ames St., Bldg. E-19, Rm. 765, Cambridge, Mass.,* $5.00

Computer Design, Ivan Flores—*Prentice-Hall, Inc., Englewood Cliffs, N.J.,* $14.00

Crystal Physics of Interaction Processes, (Pure and Applied Physics, vol. 22), Warren P. Mason—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.,* $14.95

Electrical Machine Theory, Morris Jevons—*American Elsevier Publishing Co., Inc., 52 Vanderbilt Ave., New York, N.Y.,* $15.75

Experimental Methods of Materials Research, vol. 1. Advances in Materials Research, Herbert Herman, ed.—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $14.95

Gallium Arsenide (Proc. of International Symposium organized by The Institute of Physics and The Physical Society in cooperation with the Avionics Laboratory of the U.S. Air Force)—*The Institute of Physics and The Physical Society, 47 Belgrave Sq., London, S.W.1, England,* $12.00

Guide to Gathering Information in Face - to - Face Interviews, Morris Bolsky—*Ramsey-Wallace Corporation, 88 West Main St., Ramsey, N.J.,* $3.50 pprbk.

Handbook of Basic Transistor Circuits and Measurements, Semiconductor Electronics Education Committee (Thornton, Linvill, Chenette, Ablin, Harris, Boothroyd, Willis, Searle)—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $4.50; $2.65 pprbk.

Introduction to Numerical Methods and FORTRAN Programming, Thomas Richard McCalla—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $7.95

Les Machines Electriques en Automatique Appliquee, J. Henry-Baudot—*Dunod, Editeur, 92, rue Bonaparte, Paris, 6eme, France,* 68 F (approx. $13.74)

Linear Multiport Synthesis, Robert W. Newcomb—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y.,* $14.50

Memoirs of the American Mathematical Society, no. 65. On the Enumeration of Non-Planar Maps, William G. Brown—*American Mathematical Society, Box 6248, Providence, R.I.,* $1.30 pprbk.

Physical Acoustics (Principles and Methods, vol. 2, part A), Warren P. Mason, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.,* $15.50

Project Nero—Near-Earth Rescue and Operations, M.I.T. Report no. 10—*The M.I.T. Press, 50 Ames St., Room 765, Cambridge, Mass.,* $7.50 pprbk.

Properties of Electrical Engineering Materials, G. C. Jain—*Harper and Row, 49 East 33 St., New York, N.Y.,* $12.95

Secrets of Electronic Espionage, John M. Carroll—*E. P. Dutton and Co., Inc., 201 Park Ave. So., New York, N.Y.,* $3.95

Standard Industrial Hydraulics Questions and Answers, Steve Elonka and Orville H. Johnson—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y.,* $10.95

Tables of Folded Sin x/x Interpolation Coefficients, Leslie F. Bailey—*Supt. of Documents, U.S. Government Printing Office, Washington, D.C.,* $2.75

Ten-Minute Test Techniques for Electronic Servicing, Elmer C. Carlson—*TAB Books, Drawer D, 18 Federick Rd., Thurmont, Md.,* $6.95

The Engineer and His Profession, John Dustin Kemper—*Holt, Rinehart and Winston, Inc., 383 Madison Ave., New York, N.Y.,* $4.95 pprbk.

The Four-Color Problem, Oystein Ore—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.,* $12.00

The Physics of Modern Electronics, W. A. Gunther—*Dover Publications Inc., 180 Varick St., New York, N.Y.,* $2.25

The Slide Rule—A Complete Manual, Alfred L. Slater—*Holt, Rinehart and Winston, Inc.,* $5.50 pprbk.

Your Career in Computer Programming, I. J. Seligsohn—*Julian Messner, 1 West 39 St., New York, N.Y.,* $3.95