VOLUME 4 □ NUMBER 5 MAY 1967

IEEE spectrum

features

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

A beam of light (red) traverses a beam of ultrasound (green). Photons intercept some of the phonons, absorb their energy and momentum, continue in a new direction after collision. For a more conventional, nonquantized discussion of light–sound interaction, see the article beginning on page 43.

Transients and trends

Privacy in a computer society was the topic of the keynote session at last month's Spring Joint Computer Conference. The risks inherent in the proposed U.S National Data Center—a giant computer system of the U.S. Federal Government that would collect and collate information now in the files of some 20 agencies of the government—were outlined by Representative C. E. Gallagher, Democrat from New Jersey. Among other risks he cited were: errors in reporting, recording, and correlating; distortion of information caused by machine malfunction; misuse of information by persons working with the data; misuse by people who are at a distance from the data but who have acess to the data through remote consoles; and violation of an individual's understanding that information furnished a particular Federal agency or official would not be disclosed.

Prof. A. F. Westin of Columbia University, in speaking at the same keynote session, said: "What is called for is a new legal approach to the processing of personal information by authorities in a free society and a new set of legal, administrative, and systems protections to accomplish this objective. The fact is that American society wants both better information analysis *and* privacy."

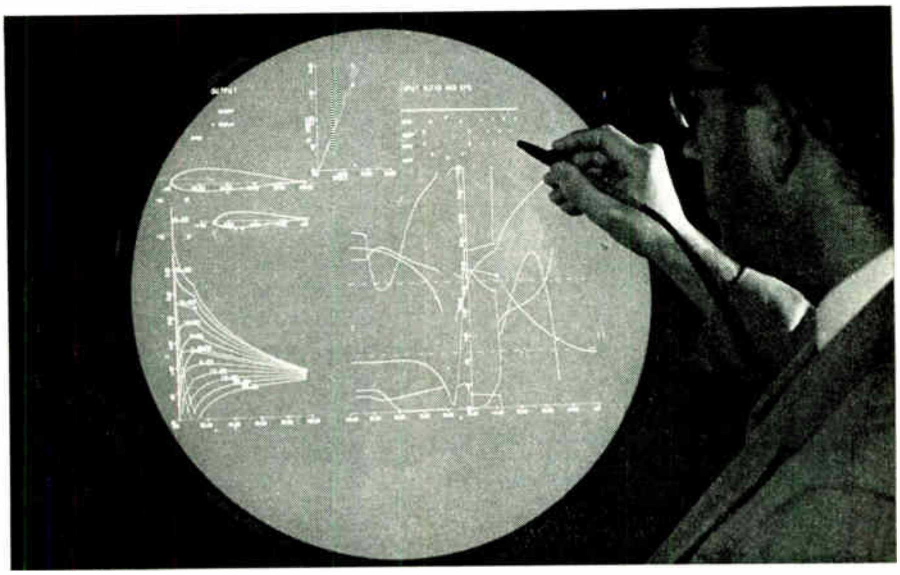
The world's largest and fastest computer, ILLIAC IV, was introduced in Atlantic City at the Spring Joint Computer Conference. The brainchild of University of Illinois Prof. Daniel Slotnick, the new computer—when completed in 1969—will perform one billion calculations every second, making it 500 to 700 times faster than any computer in use today. The computer uses the technique of parallel processing. Destined to become part of the U.S. Weather Bureau's forecasting system when built by The Burroughs Corporation, the new computer actually consists of 256 individual computers in one large system that occupies 40 cabinets approximately the size of a home refrigerator.

An artificially created aurora borealis is scheduled as the first phase of a series of high-altitude experiments probing the earth's atmosphere. The experiment calls for rocketing an electron accelerator aloft in a 320-km-high ballistic trajectory. At high altitude and at about 10-second intervals, the accelerator will shoot a stream of electrons down toward the earth. As the accelerator is fired, electrons are exhausted at a rapid rate, leaving the space vehicle with a positive charge. To neutralize this charge, an expandable disk-shaped screen, some 26 meters in diameter, deploys to collect free electrons in the vehicle's path. Recharged with these electrons, the accelerator is enabled to fire its pulsed electron beam again and again.

Scientists expect that when the electrons collide with gas molecules high in the earth's atmosphere, they will create an aurora effect about 104 km above the earth. The brilliant spot of light, they believe, will be somewhere between 0.6 km and 8 km in diameter, and probably at least as bright as a full moon. The initial space shot is scheduled for June of this year. Prime contractor to NASA for the program is Fairchild Hiller Corporation. G. T. Schjeldahl Company is actively participating in the program.

An electronic wind tunnel has been developed at the Lockheed-Georgia Company by making use of the synthesis capabilities of a computer. Airfoils, or wing cross sections, for any type of aircraft can be designed, analyzed, and tested under various flight conditions by the computer and an aeronatutical engineer working as a team. A television-type screen displays computer-developed data and design information. The engineer uses a hand-held light pen to activate the computer and to communicate with the memory bank of the electronic wind tunnel. The memory stores thousands of bits of data relating to aircraft wing shapes and characteristics and performance. Initially, the engineer signals the computer to provide a basic wing design in accordance with his instructions. The computer-derived design is then displayed on the screen and the computer literally asks the engineer if he likes the design. When the basic design is agreed upon, the computer proceeds to display all the performance data needed to complete the design.

DISPLAY SCREEN for the electronic wind tunnel. Any displayed data or information can be changed or modified with a hand-held light pen.



IEEE forum

Correspondence relating to activities and policies of the IEEE

Licensing and status

Having read C. C. Cutler's "Spectral lines" in the January issue and E. N. Dingley's comments on that article in the March SPECTRUM, I must conclude that Mr. Dingley is misrepresenting the purpose of professional licensing. He appears to be promoting legal registration as a means of gaining recognition and increased status.

To be sure, Mr. Cutler's discussion concerns professional stature, the need of such, and how it might be obtained. Only in part did he refer to licensing as related to status, yet Mr. Dingley seized on this section in order strenuously to advocate the necessity of professional *registration* to secure professional *status*. Unfortunately, this seems to be the notion of all too many Registered Engineers whom I have met—viz., registration is some sort of badge that will, to quote Mr. Dingley, "separate the sheep from the goats," and that "differentiates between those who are solely interested in earning a buck and those who wish to uphold and improve the professional status of the engineering profession." One wonders whether Mr. Dingley has a license for membership in some select engineering club.

Nowhere in the Rules and Regulations for registration in my state did I read that I would be enhancing my professional stature by being granted a license. On the contrary, it is emphasized that "to safeguard life, health, and property, and to promote the public welfare," the Board of Examiners by granting a license has agreed that I am qualified to practice professional engineering *in that state*. Therefore, licensing is nothing more than legal authorization for me to perform my work—assuring the public that I meet the state's requirements and am, consequently, no "quack" who will endanger their safety. Registration is not an award, or honorary title, or merit badge, to distinguish me from my unlicensed (but equally competent) colleagues who, incidentally, may be performing the same tasks, for the same pay, for another employer.

My answer to Mr. Dingley, then, is that professional licensing should be divorced from the concept of professional stature. By implying that the one is a means to gain the other, we only offend our unlicensed brethren who far outnumber us.

Preston E. Law, P.E.
Bowie, Md.

Range of IEEE responsibility

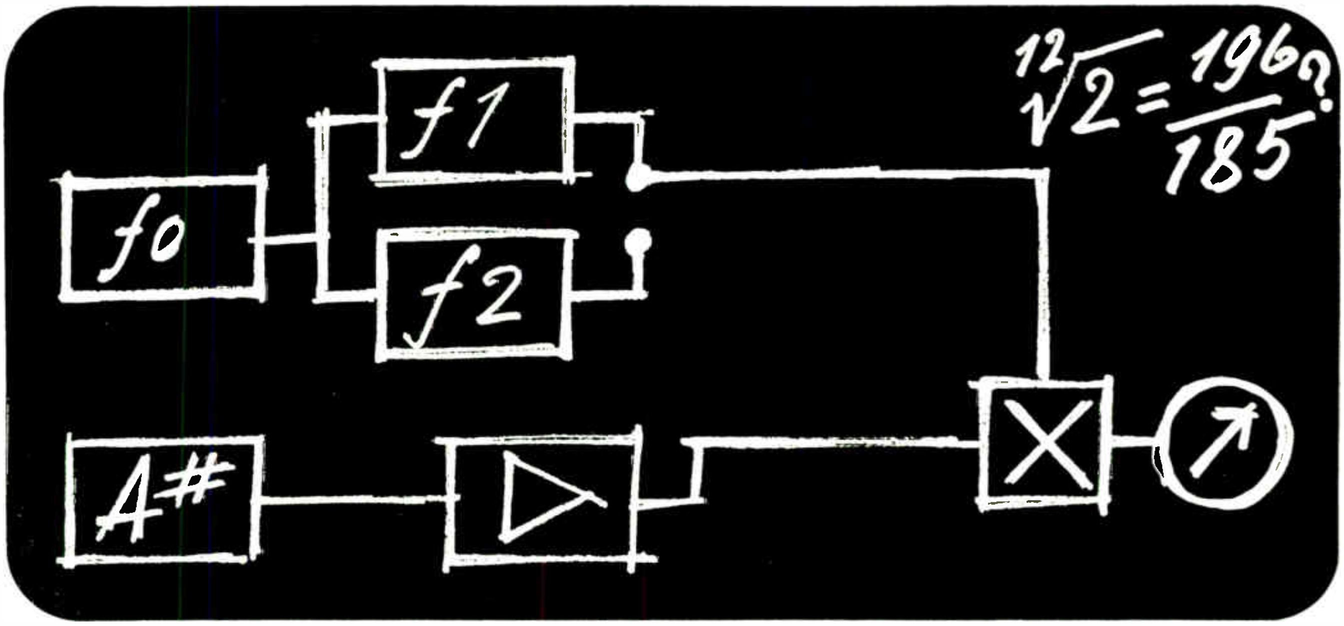
Comments by G. B. Jordan on "Philosophy and Engineering" (SPECTRUM "Technical correspondence," Jan. 1967) express many of the professional problems faced by the practicing engineer in our industry.

Where problems exist, an organization can either recognize them and make attempts to apply corrective action, or wait until someone else does the job. This is an area in which the IEEE is failing! In the past six–eight years as a member of the IRE and now IEEE, I have observed little, if any, editorial comment on the professional problems facing electronic and electrical engineers employed by corporations or government agencies.

Trade magazines have occasionally published editorials relating to employment problems (*Electronics*, July 26, 1965, and Mar. 7, 1966). The report published in *Engineer* (vol. VII, no. 4) on the Engineering Foundation–EJC Conference, "Industry and the Young Engineer," also examines causes of mounting frustration within the profession. The last two paragraphs are especially revealing:

"Why do engineers almost universally prefer management? Greater salary and a feeling of greater participation in the company's goals and decisions were given as two primary reasons.

"To make technical careers more attractive, management was urged to recognize an individual's contribution by paying him appropriately, by providing technical and clerical support, by giving him a choice of projects wherever feasible, and by implementing the dual ladder concept—the latter being a pay scale whereby technical people receive the same advances as do management personnel of similar experience and educational level."



$\sqrt[12]{2} = \frac{196}{185}$: *true or false?* *Our ears say true*

Over the past few thousand years, the problem of tuning musical instruments has attracted the attention of several distinguished people. Pythagoras was one of them and, as one might expect, he tried to solve the problem mathemetically. Though his solution was applied for nearly two thousand years, it did not enjoy the lasting success of his theorems. He based the scale on a tone and its octave (a 1 : 2 frequency ratio) and a tone and its fifths (a 2 : 3 ratio). However, it was found to have serious limitations when harmonies came into vogue.

So towards the end of the 14th century, the mean tone scale became fashionable, based on octaves and thirds (a 4 : 5 ratio). But there were still problems: chords which harmonised perfectly in most keys were ear-splitting, false chords in others. Avoiding these chords - the so called "wolves" - was a source of constant anxiety to early keyboard instrumentalists.

Then in the 15th century, a scientist called Ramis de Pareja devised a means of muzzling the "wolves"... though it wasn't until the early part of the 18th century that his ideas were put into general use. Pareja's solution was to divide the octave into twelve successive intervals, each with the equal frequency ratio of $\sqrt[12]{2}$. Although the perfect harmony of the tones with simple frequency ratios was lost (with the exception of the octave), the system, known as the equally tempered scale, had a striking advantage: a musician had complete freedom for modulating into any key without being bitten by the dreaded "wolves".

The tuning of a keyboard in successive intervals of $\sqrt[12]{2}$ calls for a high degree of skill. And the increasing rareness of skilled tuners presents a threat to the future of the keyboard instrument ... serious enough for Mr. Gossel of our Hamburg Research Laboratories, an electronic engineer and amateur musician, to suggest an electronic solution. One of his colleagues started playing around with a slide rule and found that $\sqrt[12]{2}$ is almost exactly equal to the ratio 196 : 185, to within a tolerance of 4×10^{-5} (a mathematician would have deduced this by applying continued fractions). Starting from this, Mr. Gossel and his colleagues built a square wave generator with a frequency which can be varied between 50-90 kc/s. They then added a circuit which could divide any set frequency of the generator by 196 or 185. So at the output side, one of two audio frequencies can be obtained (f_1 and f_2) which are almost exactly an "equally tempered" half-tone apart.

Let us now show you how this instrument is used for tuning. The generator is set at 81,400c/s so f_1 is exactly 440c/s - the standard middle A - and f_2 is half a tone lower (A flat). The middle A of the keyboard is picked up (and made to sound continuously) and compared in a frequency comparison circuit with f_1. The beat frequency is read on a simple ammeter. The tuner then adjusts the middle A until the beat frequency is zero (easily accomplished to within 0.01c/s) and the note is tuned. Without changing the generator, A flat can then be tuned to f_2. Now what about the rest of the notes? The generator frequency is lowered until f_1 equals the newly found A flat and then f_2 becomes a tempered G. The tuner continues in this fashion until he has tuned a whole octave. He then makes an overall check. The frequency ratio between the octave will now be 1 : 2 - apart from the slight systematic error and possible personal error. But since the systematic error is only 5×10^{-5} and the most sensitive ear can hardly discriminate frequency differences which are at least ten times greater, it's of no consequence. As far as our ears are concerned, the tone interval $\sqrt[12]{2}$ is equal to 196/185.

This is an interesting example of how a scientist with an interest in music can point to the solution of a centuries' old problem; and of how modern electronics can make the solution a reality.

The Philips Research Laboratories carry out research in many fields of fundamental science. Among these: Acoustics, Chemistry, Cryogenics, Perception, Plasma, Material testing, Nuclear physics, Solid state physics, Telecommunications, Television.

A professional organization has a moral obligation to the dues-paying membership to speak out when problems exist. As a first step, I would suggest that IEEE SPECTRUM, perhaps with the cooperation of the National Society of Professional Engineers, discuss professional objectives with comment on chronic unresolved problems such as mass layoffs of professional personnel. Where appropriate, local Section meetings might also contribute to such discussion.

In the long run, an ineffective organization will eventually be relegated to a secondary role in society; a professional organization that succeeds in solving crucial problems of its membership will prosper. As a member of IEEE, I hope that the Institute will follow the latter course.

John P. Densler
Cambridge, Mass.

IEEE is a scientific, literary, and educational organization, organized and operated exclusively in the public interest for the advancement of electrical and electronics engineering and the related arts and sciences. It is a "professional organization" only in the sense that it is an organization composed primarily of professionals. For this reason, IEEE does not engage in the kind of activities suggested in Mr. Densler's letter, which are more properly within the scope of organizations that are organized and operated for such purposes, such as The National Society of Professional Engineers.—Ed.

Spectral lines

Spin-off. Technology grows like a plant, with roots twining into the fine soil made up of science, mathematics, and older technology. The plant grows, branch upon branch, each new branch making place for dozens more, and pulling sustenance from its environment for an ever-stronger root system. The whole is impelled by the drive and ambition of youth, trained by the wisdom of experience, and fertilized by position, fame, and a certain amount of greenery called money; but perhaps most of all by the satisfaction of accomplishment. Like the mangrove, the technology "plant" often drops new trunks, bypassing early growth to obtain direct nourishment from new areas of science, and forming an almost impenetrable mass of intertwining growth. I suppose the simile could be completed by reference to the leaves (publications), which end up forming a mulch that protects and sustains the soil.

The simile is not new, but it illustrates well the difficulty of tracing any technological development to its beginnings, and the trouble people get into when they attempt to credit a new development to a particular source.

Very rarely do big advances come in definable steps. Even when they appear to do so, one should not forget the contributions of the developer's technical environment, laboratory, teachers, and colleagues, as well as the literature, without which there would be little chance for innovation. We decry extravagant claims that ignore the efforts of collaborators, and we black-list the man who claims more than his worth. Thus we see more multiple authorships, longer lists of acknowledgments, and more voluminous bibliographies. Ought we not to expect a similar standard of behavior from our corporations and our government, and their representatives?

Federal governments have become big contributors to the advancement of science and technology. Billions of tax dollars are spent on research and development. No one can reasonably doubt that the massive efforts of the space program, military research, and supplementary research grants stimulate civilian science and technology and result in great technological advances. Many supporters of such work tout the accomplishments by citing "spin-off," or contributions that reach beyond the immediate intended goal. They like to speak of technological breakthroughs. The trouble is that clearly defined examples of technological spin-off are hard to find, and in great enthusiasm and with desire to justify budgets, extravagant claims are made. In citing contributions of the space program to the development of the solar cell and the transistor, a U.S. Congressman recently wronged a large industry-supported research effort and three Nobel Prize winners. Although not many claims are so blatant, few are without offense, because the roots of almost any development twine through the laboratories of many organizations, with and without federal support.

To claim due credit for the development of tantalum capacitors without acknowledging the man or the organization responsible for their invention, or the concern that provided the skills even though supported by government funds, is not admirable—nor is claiming credit for the digital computer, whose inception and development owes much to private enterprise as well as to government support. Yet, this is what we find in recent publications. It is in the class of the late-coming manufacturer who asserts in his advertisements that he has "perfected" color television by finding a new phosphor. Worse still is the recent editorial in an electronics magazine that attributed the first use of the transistor in the telephone system *two* years ago to government-supported development. In fact, the transistor was used commercially in the system as part of direct distance dialing in 1952, and in other parts of the system since 1953.[1]

That large-scale spin-off from government-supported research and development is a fact of life is witnessed by the report[2] that the Clearing House for Federal Scientific and Technical Information, a principal avenue for spin-off, has an annual income of more than one million dollars from the sale of technical reports. Altogether, the several government agencies active in promoting spin-offs are reported to operate at an annual cost of $200 million. Few areas of technology have not benefited from this activity; however, it has been well expressed[3] that by far the greatest part of spin-off is intangible.

The term "spin-off" is applied almost exclusively to federally supported activities, but the phenomenon is obviously neither new nor unique. The flow of technical information through the open literature, technical libraries, trade magazines, technical advertising, and patents dwarfs government-supported publication, and supplies a major source of technical information input to most industries. This great volume of data, which is only partly due to federal funds, is a most significant characteristic of our age, and is a major cause for the burgeoning of science and technology.

Didacus Stella (A.D. 39–65) has said: "A dwarf standing on the shoulders of a giant may see farther than the giant himself." That statement has special significance for us—but today we build upon the achievements of a multitude of giants.

C. C. Cutler

1. *Bell Lab. Record*, July 1953, June 1955, June 1958.
2. Olkan, H., "Spin-offs: a business pay-off," *Calif. Management Rev.*, pp. 17–24, Winter 1966.
3. Welles, J. G., and Waterman, R. H., Jr., "Space technology: pay-off from spin-off," *Harvard Business Rev.*, pp. 106–118, July–Aug. 1964.

Authors

Interaction between light and sound (page 42)

Robert Adler (F), vice president and director of research for the Zenith Radio Corporation, Chicago, Ill., received the Ph.D. degree in physics from the University of Vienna in 1937 and, in the following year, became assistant to a patent attorney in that city. From 1939 to 1940 he worked in the laboratory of Scientific Acoustics, Ltd., London, England. He next served Associated Research, Inc., Chicago, for one year. He joined the Research Group at Zenith in 1941, becoming associate director of research in 1952 and, eleven years later, director of research.

His work in the vacuum-tube field includes the phasitron modulator used in early FM transmitters, receiving tubes for FM detection and color demodulation, transverse-field traveling-wave tubes, and the electron-beam parametric amplifier. His work in ultrasonics includes an electromechanical IF filter (1943) and, later, the development of ultrasonic remote control devices for television receivers. In recent years, Dr. Adler has been active in the field of acoustooptical interaction.

Limitations in solid-state technology (page 55)

E. G. Fubini (F), IBM vice president and group executive, is responsible for the company's Research Division, Advanced Systems Development Division, Science Research Associates, Inc., the Production Systems Department, and the Instructional Systems Development Department. He joined IBM in 1965 as vice president.

Between 1942 and 1945, he was a research associate at the Harvard University Radio Research Laboratory; during this time he also was a scientific consultant to the Armed Forces. In 1945 he joined Airborne Instruments Laboratory, becoming vice president in 1960. He joined the Office of Defense Research and Engineering of the Office of the Secretary of Defense in 1961. He served as Deputy Director of Defense Research and Engineering and, in 1963, was appointed Assistant Secretary of Defense. Presently, he is a member of the Scientific Advisory Board of the Air Force, the Defense Science Board, the National Academy of Engineering, and is chairman of the Scientific Advisory Committee of the Defense Intelligence Agency. He has received the Presidential Certificate of Merit and the Defense Medal for Distinguished Public Service.

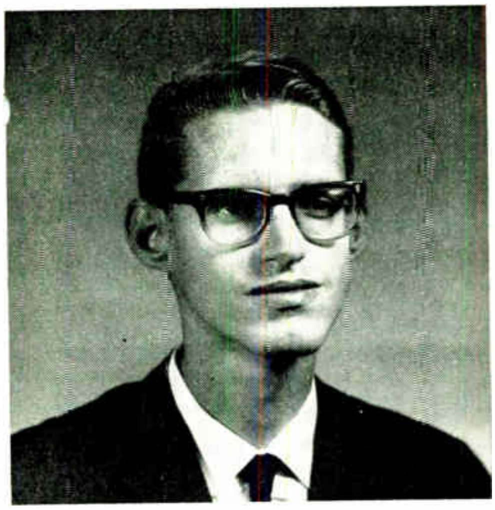
M. G. Smith (SM) is presently serving as assistant manager of the Solid State Electronics Department at the International Business Machines Corporation's Thomas J. Watson Research Center, Yorktown Heights, N.Y. Since 1963 he has been responsible for engineering projects in a large-scale integration program.

During 1951 and 1952, while serving in the United States Army, Mr. Smith was a member of the Facsimile Group at the Signal Corps Engineering Laboratory, Fort Monmouth, N.J. Subsequent to his discharge from the Army in 1952, he joined IBM, where he became engaged in work on the Naval Ordnance Research Calculator (NORC).

Since that time, he has been responsible for efforts in microwave-frequency division, microwave computing techniques, varactor logic, tunnel diodes, high-speed transistor logic, electronic packaging, and large-scale integration logic and memory.

Mr. Smith received the bachelor's degree in engineering from the University of Cincinnati in 1950 and the master of science degree in electrical engineering from Columbia University in 1956.

Bulk negative-resistance semiconductor devices (page 71)



John A. Copeland (M), presently serving as a member of the technical staff of Bell Telephone Laboratories, Inc., Murray Hill, N.J., has been engaged, since joining BTL in 1965, in research on bulk negative-resistance semiconductors. This includes theoretical studies of space-charge dynamics, thermal noise generation, and interactions of bulk devices with external circuits, as well as experimental studies of devices for high-speed logic and millimeter-wave power generation.

Dr. Copeland attended the Georgia Institute of Technology from 1958 to 1965, there receiving the bachelor of science, master of science, and doctoral degrees in physics. His doctoral thesis, on the quantum theory of ferromagnetism, was entitled "First Order Green's Function Theory of the Heisenberg Ferromagnet." From 1959 to 1965, he worked at the G.I.T. Engineering Experiment Station doing theoretical and experimental research on thin magnetic films. During the summer of 1962 he did research at the Jet Propulsion Laboratory.

Dr. Copeland is the author or coauthor of 13 published papers.

New patterns of industry–government partnership (page 78)

J. Herbert Hollomon, Acting Under Secretary of Commerce and Assistant Secretary for Science and Technology, supervises the U.S. Patent Office, National Bureau of Standards, Environmental Science Services Administration, and Office of State Technical Services. He is also a member of the Federal Council for Science and Technology, consultant to the President's Science Advisory Committee, and chairman of the Interdepartmental Committee for Atmospheric Sciences.

He received the B.S. and D.Sc. degrees, in 1940 and 1946, respectively, from the Massachusetts Institute of Technology. He served as an instructor at the Harvard University School of Engineering and Applied Science and as adjunct professor at Rensselaer Polytechnic Institute; he has been an advisor to Harvard, M.I.T., Cornell, and George Washington University. The veteran of 18 years of service with the General Electric Company, Dr. Hollomon was general manager of the General Engineering Laboratory immediately prior to joining the Government.

Communications, the police, and the Crime Commission (page 83)

Peter M. Kelly (M) is the president and chief scientist of Kelly Scientific Corporation, a firm of analytical scientists located in the Washington, D.C., area. Prior to the time he founded the Kelly Scientific Corporation, Dr. Kelly was associated for a decade with the Aeronutronic and Philco activities of the Ford Motor Company. He served successively in the capacities of research engineer, radar department head, principal scientist, associate research director, and manager of advanced technology in the Ford Divisions. The technological areas in which he has made direct contributions include radar. computer, and communications technology, and operations and systems analysis.

Dr. Kelly received the doctoral degree in physics and electrical engineering from the California Institute of Technology, Pasadena, Calif. He has written numerous articles and papers, which have been published in various technical journals, both in the United States and in Europe.

Interaction between light and sound

Because of the development of the laser and new acoustic techniques, the interaction between light and sound, first observed more than 30 years ago; has led to applications of great promise and practical utility

Robert Adler *Zenith Radio Corporation*

Sound waves can modulate light in amplitude and phase, deflect it, focus it, or shift its frequency. Light can render acoustic images visible or provide detailed information on the thermal vibrations in solids and liquids. Diffraction of light waves by sound waves takes several different forms, depending on the two wavelengths and the dimensions of the interaction region. An analysis and description of these different forms is given, followed by a detailed discussion of a wide variety of applications, including signal processing devices, spectrum analyzers, television displays, image translators, memories, and the conversion of light into sound.

If we look at a lighted object through a glass of water and then generate an ultrasonic wave of a few megahertz in the water, the lighted object appears to break up into a number of closely spaced images. Increasing the intensity of the sound makes the effect more conspicuous and causes additional images to appear on both sides; increasing its frequency moves the images farther apart. Diffraction of light by high-frequency sound waves, often called Brillouin scattering after the man who predicted it,[1] was first observed in 1932, and a great deal of experimental and theoretical work was done in the years that followed. Recently, the development of the laser and advances in high-frequency acoustic techniques have combined to make possible a wide range of light–sound interaction experiments that could not have been done before, and many new applications have been shown.

In this article, we will review some of these acousto-optical devices—starting with the ultrasonic light modulator developed in the 1930s, which operates quite well with incoherent light, and going on to the light modulators, optical frequency shifters, and light deflectors of recent years, which use lasers as light sources. Coherent light permits us to observe acoustic waves in solids up to frequencies in the microwave range, and we will show how this is used to read out acoustic delay lines and to measure acoustic radiation patterns. We shall describe an imaging process in which ultrasonic waves scattered by a small object interact with laser light to form a visible image of the object. Finally, we shall take a brief look at experiments in which physical properties of liquids and solids are studied by means of acoustooptical interaction processes.

The review of applications is preceded by a discussion of the two most important forms of sound–light interaction, the Debye–Sears effect and Bragg reflection. (Ray bending, a low-frequency effect, is briefly treated in a separate section.) The discussion is qualitative and leans heavily on the electrical engineering concept of phase modulation. The reader whose time is too short to worry about any theory may wish to skip this discussion and look at just three illustrations—Fig. 5, which illustrates the Debye–Sears effect, and Figs. 8 and 9, which show the main features of Bragg reflection—before going on to the applications.

There are three ways in which light–sound interaction may be understood. Each approach stresses a different aspect of the process; all three are useful. Let us merely name the three interpretations at this point and develop them more fully later.

1. We may use classical optics and think of the sound wave as a moving three-dimensional phase grating that scatters the incident light wave.

2. We may borrow from electrical engineering and interpret the process as a distributed parametric interaction in a nonlinear reactive medium, making use of concepts such as up and down conversion and of the equations governing parametric devices.

3. We may employ the ideas of quantum mechanics and think of the process in terms of collisions between photons and phonons, in which energy and momentum are conserved.

In the following discussion we shall use all three interpretations, giving preference to electrical engineering concepts where it seems practical to do so.

The Debye–Sears effect

Let us visualize a plane wave of light, of angular frequency ω, which travels from left to right in a slab of length l (Fig. 1). The slab is made of a material with a refractive index n; this means that the velocity of light in the slab is reduced from its vacuum value c to c/n. The wavelength in the slab is $\lambda = 2\pi c/n\omega$, and the propagation constant β (the number of waves per 2π units of length) is $\beta = \omega n/c$. The slab can be considered an optical delay line with time delay $\tau = ln/c$, and phase shift $\phi = l\beta$ radians.

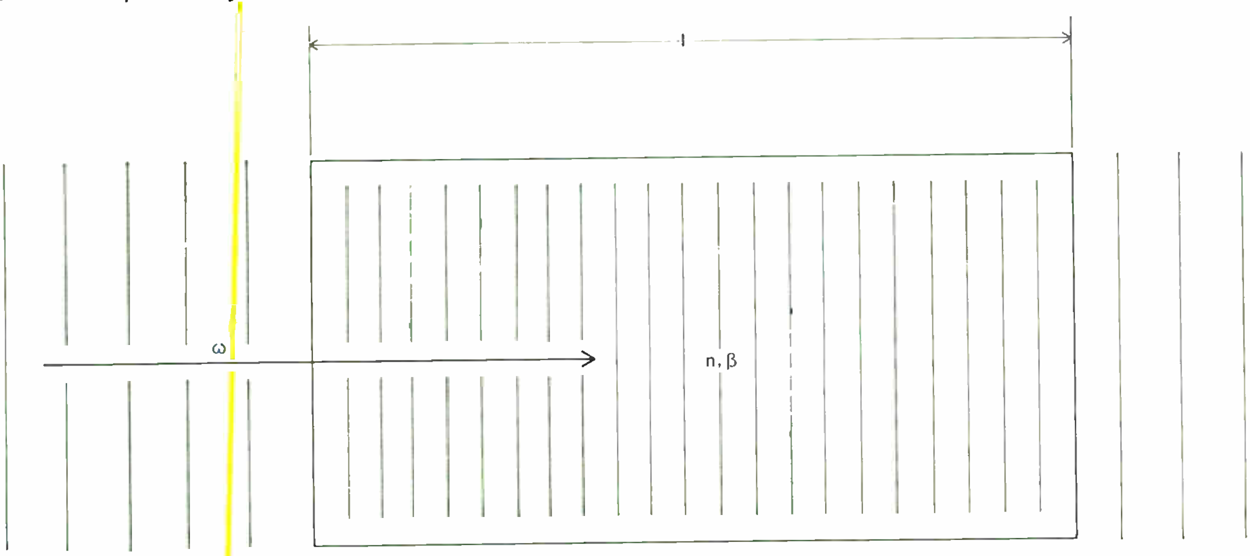
Let us now assume that we can vary the index n by a small amount, Δn. In so doing, we vary the time delay. The resulting phase excursion at the output is

$$\Delta\phi = l\Delta\beta = l\beta \frac{\Delta n}{n} = 2\pi \frac{l}{\lambda_0} \Delta n$$

where λ_0 is the vacuum wavelength of the light. The factor l/λ_0, for a slab 2.5 cm long and assuming red light, equals about 4×10^4; thus a change in refractive index of only $\Delta n = 10^{-6}$ causes one-quarter radian of phase excursion. By electrical engineering standards a delay line 40 000 wavelengths long is unusual, and it is hardly surprising that a small change in phase velocity would produce a large phase shift at the receiving end.

Let us vary Δn sinusoidally at a modulation frequency ω_m. The output signal—the light emerging from the right end of the slab—is now phase modulated at ω_m, with the phase excursion $\Delta\phi$ as calculated in the preceding paragraph. Phase-modulated waves are familiar to many electronics engineers and are treated in standard texts on FM systems. These texts tell us that a phase-modulated wave is composed of a carrier and of sidebands spaced by ω_m from the carrier and from each other (Fig. 2). The carrier and sideband amplitudes are functions of the maximum phase excursion, often called modulation index (Fig. 3). Up to $\Delta\phi \approx 1/2$ rad, only the first pair of sidebands has significant amplitude; as $\Delta\phi$ increases, more and more sideband pairs come into play. At $\Delta\phi = 2.4$ rad, the carrier amplitude goes through zero. At the right end of the slab, light at the sideband frequencies $\omega \pm \omega_m$, $\omega \pm 2\omega_m$, etc., is present in amounts determined by Δn, in accordance with the curves of Fig. 3. Light at the original carrier frequency ω is also present, unless we have adjusted Δn to one of the specific values

FIGURE 1. Optical delay line. Variation of refractive index n produces phase modulation.



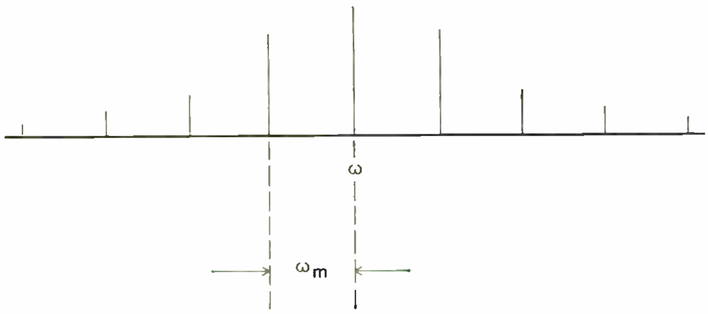


FIGURE 2. Carrier (ω) and sideband spectrum of a typical phase-modulated wave.

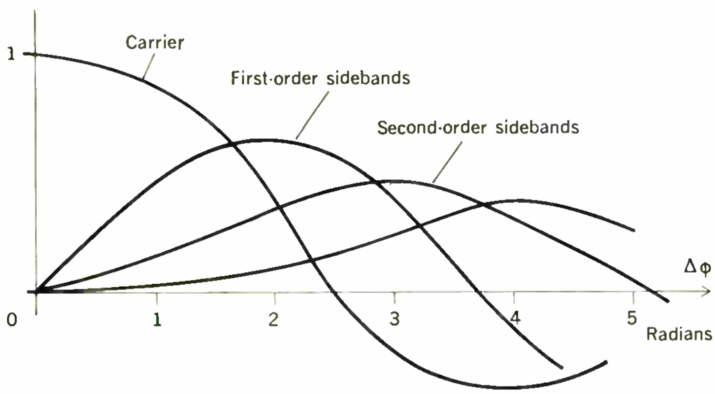
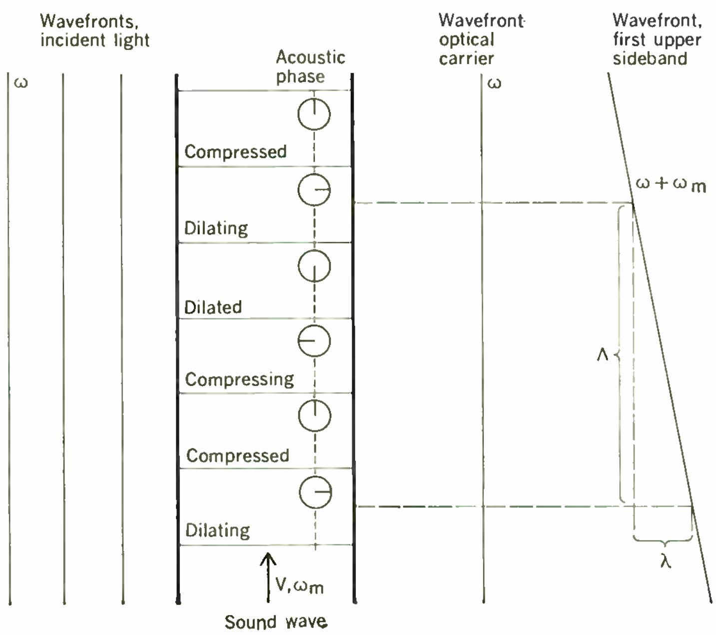


FIGURE 3. Carrier and sideband amplitudes of a phase-modulated wave vs. phase excursion $\Delta\phi$. These curves are Bessel functions J_0, J_1, J_2, etc.

FIGURE 4. Sound wave traveling upward generates optical phase shifts, which combine to tilt wavefront of first-order upper sideband. Carrier wavefront remains unaltered.



that render its amplitude zero. In interpreting Fig. 3 we must remember that the intensity or power of each component is proportional to the square of its amplitude.

In Fig. 4 we have stacked a large number of slabs upon each other to form a vertical column through which we can send a compressional wave of frequency ω_m traveling upward. Each slab now represents an incremental portion (as shown, a quarter-wavelength portion) of an acoustic transmission line. At a given instant, a specific slab is compressed and its refractive index increases. One-half cycle later, it is dilated and its index decreases. The compressional wave is thus accompanied by a wave of refractive index variation; both waves travel upward together at the sound velocity v.

A plane wave of light of frequency ω, traveling horizontally from left to right, impinges upon the left boundary of the column. Each slab modulates the light as before and we find carrier and sideband components everywhere along the right boundary of the column. The carrier components, although changed in amplitude and perhaps reversed in polarity (if the phase excursion $\Delta\phi$ exceeds 2.4 rad), have the same phase for all slabs; hence, what remains of the light at the original frequency ω proceeds as optical carrier wave toward the right in the original direction. The situation is different for the first upper sideband $\omega + \omega_m$; in each slab, the phase of this sideband corresponds to the phase of the acoustic modulation that generated it, and that varies linearly from slab to slab as a function of vertical position, going through one complete cycle between the two slabs marked by the dashed lines, which are one acoustic wavelength apart. The first upper-sideband components that emerge from the right-hand boundary of the column exhibit the same linear variation of phase with vertical position.

To find the direction in which sideband light of frequency $\omega + \omega_m$ is radiated, we construct a wavefront by connecting points of equal phase together. Near the lower portions of the column, where the sound wave passed earlier and the phase is further advanced, such points move further to the right, one wavelength λ of light horizontally for each wavelength Λ of sound vertically. The wavefront is therefore tilted by an angle λ/Λ, as shown. The direction of propagation—which, in isotropic substances, must always be perpendicular to the wavefront—is deflected upward by the same angle. Wavelengths Λ and λ must be measured within the medium that carries the sound wave; but if we observe the diffracted light outside, in air or vacuum, and if the optical boundary of the medium is approximately parallel to the direction of sound travel (vertical in Fig. 4), the angle between the directions of carrier and sideband light is increased by refraction at the boundary to λ_0/Λ, where λ_0 is the vacuum wavelength of the light.

Similar reasoning shows that higher-order sidebands emerge with correspondingly larger tilts and that the lower sidebands are deflected downward, as shown in Fig. 5. For a sideband of frequency $\omega \pm N\omega_m$, the deflection from the original direction is $\pm N\lambda/\Lambda$. Here, then, is the origin of those multiple images seen in a glass of water through which a wave of ultrasound passes. The phenomenon was first described by Debye and Sears[2] and by Lucas and Biquard[3] in 1932. Three years later, Ali[4] confirmed experimentally that the diffracted light is shifted in frequency by approximately the expected amount. Precise confirmation (Cummins–Knable, 1963) had to wait for the laser.[5]

To show how easy it is to observe the Debye–Sears effect, arrange a square transducer to radiate a 5-MHz wave into water. In water, v = 1500 m/s, hence Λ = 300 μm. For red light, with $\lambda_0 = 0.6$ μm, the images are 0.002 rad or about 1/8 degree apart and appear clearly separated to the unaided eye. For a sound power of 0.5 watt, the light intensity of the carrier is down to 5 percent of the original intensity of the undiffracted light; 33 percent appears in each of the first-order sidebands, and 12.5 percent in each of the second-order bands; the rest goes into higher orders.

The critical length

Up to this point in our analysis, we have used a peculiar mixture of geometrical and wave optics. To determine the frequency, intensity, and direction of each component of the diffracted light, we used our knowledge of its wavelike character. Yet, in assuming that each slab or incremental portion of the acoustic column propagates its own little slice of light in accordance with its own value of Δn, regardless of what happens in adjacent slabs, we fell back on geometrical optics. A narrow light beam, however, no matter how well collimated, eventually spreads through diffraction: far away from a source with uniform phase and amplitude across an aperture D, radiation of wavelength λ (in the medium) spreads out over an angle $\pm\lambda/D$. Let us now apply this knowledge.

Figure 6 shows, greatly enlarged, adjacent portions of the acoustic column, which are alternately compressed and dilated. Each of these portions is $\Lambda/2$ high. Consider light that enters the compressed portion, where Δn is positive. This slice of light suffers increased delay. But how far can it travel before, through diffraction, it spreads into the adjacent dilated portions, where Δn is negative? The height $\Lambda/2$ of the compressed layer constitutes aperture D; hence the angle of spread is $\pm 2\lambda/\Lambda$. Diffracted light will spread across the two adjacent layers, corresponding to a vertical spread of $\pm\Lambda/2$, if we let it travel a horizontal distance $l_{max} = \Lambda^2/4\lambda$. This reasoning is qualitative, but it clearly shows that our method of calculating the sidebands may be used only if l is sufficiently small. This condition is often expressed as $2\pi\lambda l_{max} \ll \Lambda^2$ or $K^2 l_{max}/\beta \ll 1$, where K is the propagation constant ω_m/v of the sound and β the propagation constant $n_0\omega/c$ of the light within the acoustic medium. Experiments for which this condition holds are said to lie within the Debye–Sears or Raman–Nath[6] regime.

Checking our previous 5-MHz example, we find l_{max} = 3 cm, so that a transducer of, say, 1 cm square would be well within limits. Because l_{max} depends on Λ^2, the condition is almost invariably violated at higher sound frequencies. For 50 MHz in water or for 300 MHz in rutile (crystalline TiO_2, a material with low acoustic attenuation even at microwave frequencies), with red light, l_{max} is only 0.03 cm. Clearly, we need to know what happens when l is much larger than the limit of the Raman–Nath regime.

We may proceed as follows: The interaction length l is split into a large number of short elements dl. The first of these elements is a thin, platelike section along the left edge of the column. The phase shift $d\phi$ produced by it is so small that only two sidebands are generated—that is, plane waves at angles $\pm\lambda/\Lambda$ to the original wave. The three waves now enter the next section where they again split, generating two new sidebands and modifying the amplitude and phase of the first two and of the carrier. This procedure is carried on through to the right edge.

The multiple sidebands so produced appear at the same frequencies and angles as before, but to calculate their amplitudes hardly seems worthwhile, since we can show that these amplitudes do not continue to grow, but return to zero as l increases. The incident light wave (Fig. 7) travels parallel to the acoustic wavefronts. Consider the first-order upper sideband. Everywhere along a given acoustic wavefront, sideband radiation is generated (dashed lines) and goes off under an angle λ/Λ; because of this tilt, the wavefronts of sideband light produced on the left (solid tilted lines) do not stay in step with the incident light (vertical lines) or with the additional sideband light (dashed) generated further to the right. If l is long enough, destructive interference is unavoidable. The cosine of the angle of tilt (assuming $\lambda/\Lambda \ll 1$) is equal to $1 - (\lambda^2/2\Lambda^2)$.

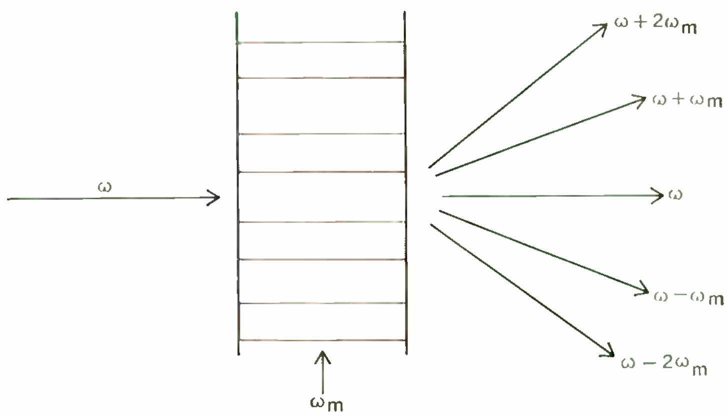
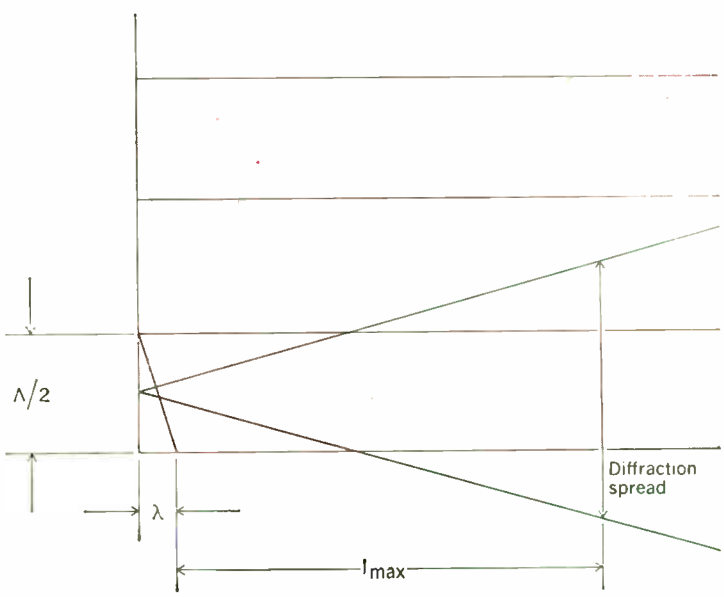


FIGURE 5. The Debye–Sears effect.

FIGURE 6. The critical length. Light starting in compressed portions of the sound wave spreads by diffraction into dilated portions. The value l_{max} is the upper limit of the Debye–Sears regime.



Thus, after traveling a distance of $2\Lambda^2/\lambda^2$ wavelengths of light, the deflected wave has skipped one whole wavelength of incident light and cancellation is complete. This number of wavelengths corresponds to $l = 2\Lambda^2/\lambda$. (Note that we have neglected the difference in wavelength between carrier and sideband caused by their differing frequencies. This is permissible so long as $\lambda/\Lambda \gg v/c$, a condition always met in practice.) For the higher sidebands with their larger angles of tilt, cancellation occurs over even shorter distances. If we want to diffract a large percentage of the incident light, it would seem that increasing l is not of much help.

Yet there is a way to turn destructive into constructive interference. A very simple change permits us to take full advantage of an arbitrarily long interaction length l, no matter how high the acoustic frequency. This change and its surprising consequences will now be described.

Bragg reflection

Let us rotate the direction of the incident light until that direction forms an angle $\alpha \approx \lambda/2\Lambda$ (both wavelengths measured in the medium) with the acoustic wavefronts, as shown in Fig. 8. The upper first-order sideband,

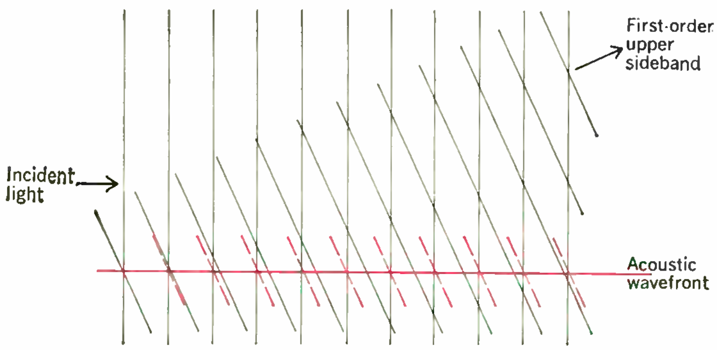
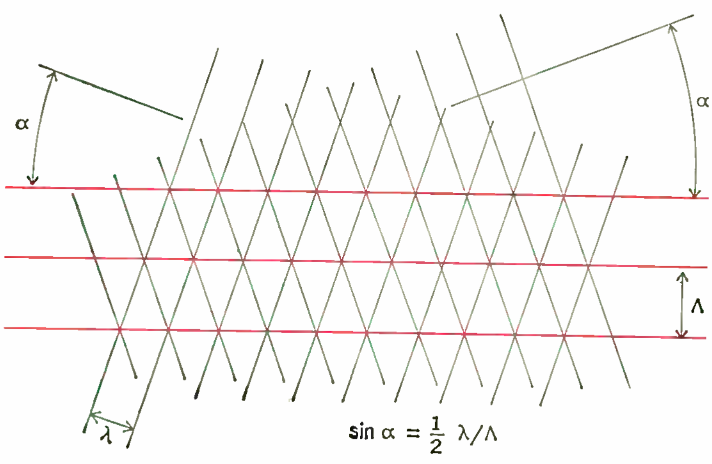


FIGURE 7. Destructive interference. Contributions to the sideband generated at different points along the acoustic wavefront (dashed lines) do not add up in phase.

FIGURE 8. Bragg reflection. Constructive interference leads to buildup of one selected first-order sideband. Horizontal lines are acoustic wavefronts; tilted lines, wavefronts of incident and diffracted light.



still going off at an angle $\approx \lambda/\Lambda$ with respect to the incident light, now appears to be reflected from the acoustic wavefronts as if they were mirrors. No matter how long we make l, incident light and upper first-order sideband light remain in phase along each acoustic wavefront. Note that this cumulative interaction occurs only for one first-order sideband; the other one and all the higher-order sidebands are still subject to destructive interference.

This striking phenomenon, which permits the unlimited growth of one first-order sideband, is called acoustic Bragg reflection, in analogy to the selective reflection of X rays by the lattice planes of crystals first observed by Bragg. The angle $\alpha \approx \lambda/2\Lambda$—more precisely, $\sin \alpha = \lambda/2\Lambda$—is called the Bragg angle. Experiments for which the condition $2\pi\lambda l \gg \Lambda^2$ or $K^2 l/\beta \gg 1$ holds (it usually does when the sound is at VHF or higher frequencies) are said to lie within the Bragg regime.

Again, just as in the case of the Debye–Sears effect, optical refraction at the external boundaries of the device in which Bragg reflection occurs will increase the angles we observe externally, in vacuum or air. Provided that these boundaries are approximately parallel to the direction of sound propagation (vertical in Fig. 8), the externally observed Bragg angle α_0 is obtained by substituting the vacuum wavelength λ_0 of the light for its wavelength λ in the medium: $\sin \alpha_0 = \lambda_0/2\Lambda$.

We can now take full advantage of the procedure previously outlined to determine the amplitude reached by the selected sideband. The phase excursion over an incremental length dl is

$$d\phi = \beta_0 \frac{\Delta n}{n} dl$$

Two sidebands are generated, each with an amplitude $dS = d\phi\, C_0/2$, where C_0 is the amplitude of the incident optical carrier. One of the sidebands, selected by positioning, builds up; its amplitude would increase linearly with l if the carrier amplitude remained constant. The other sideband and all the higher-order bands never grow beyond a certain amplitude and if Δn is small enough their power content can be neglected. In the presence of a carrier amplitude C, the selected sideband grows at the rate

$$\frac{dS}{dl} = \frac{1}{2} C \frac{d\phi}{dl}$$

Once the sideband is present it causes the carrier to decrease at a corresponding rate:

$$\frac{dC}{dl} = -\frac{1}{2} S \frac{d\phi}{dl}$$

These two equations have the simple solutions:

$$S = C_0 \sin(\Delta\phi/2) \quad \text{and} \quad C = C_0 \cos(\Delta\phi/2)$$

where $\Delta\phi = l\beta\Delta n/n$ as before. The amplitude of the sideband or diffracted wave first increases linearly with $\Delta\phi$, becoming equal to the full carrier amplitude when $\Delta\phi = \pi$, and at that point the incident light is completely suppressed. The sum of the powers carried by the incident and diffracted wave remains constant.

The behavior of the amplitudes of incident and diffracted light resembles that of the voltages on two symmetrical, loosely coupled transmission lines. We may think of the two plane waves of light, traveling under the positive and negative Bragg angle with respect to the acoustic wavefronts, as two modes coupled together by the acoustic wave. The frequency shift from one to the other does not fit the transmission-line analogy; it can be interpreted as a Doppler shift. It is positive or negative, depending on whether the incident light wave is directed to meet the sound wave or to catch up with it (Fig. 9). In the first case, the upper first-order sideband is produced; in the second case, the lower one. The option of selecting a single sideband by merely changing orientation is a valuable feature of Bragg reflection.

Note how simple and efficient acoustic Bragg reflection is. Light enters under the Bragg angle. A single mode of diffracted light is produced, whose frequency is upshifted or downshifted as desired and whose amplitude is a sinusoidal function of sound amplitude and interaction length. Complete conversion occurs when the cumulative phase excursion $\Delta\phi$ equals π.

It is interesting to compare a Bragg diffraction cell with the parametric devices that are used in microwave circuits. In a parametric up-converter, we have the relationship

$$\omega_{out} = \omega_{pump} \pm \omega_{signal}$$

the sign depending on whether it is an upper or lower sideband up-converter. Similarly, in a Bragg device,

$$\omega_{out} = \omega_{incident} \pm \omega_{sound}$$

A parametric amplifier often uses lumped circuits or cavities whose resonant frequencies enable us to choose between sidebands. In the case of a traveling-wave parametric amplifier, resonance is not needed; here, Tien's relation[7]

$$\beta_{out} = \beta_{pump} \pm \beta_{signal}$$

must hold for the propagation constants of output, pump, and signal wave, the sign again depending on the type of operation selected. To avoid producing both sidebands at once, Tien's relation should hold only for the desired set of frequencies; to insure this, the transmission line must be made dispersive.

In the Bragg diffraction cell, the three propagation constants are vectors lying in a plane. They must satisfy Tien's relation in two dimensions (see Fig. 10):

$$\boldsymbol{\beta}_{out} = \boldsymbol{\beta}_{incident} \pm \mathbf{K}_{sound}$$

Here $\mathbf{K} = \omega_m/v$, taken in the direction of sound propagation. The two optical wave vectors are of equal magnitude and differ only in direction. To choose sidebands, the sign can be reversed by inverting the direction of sound propagation. There is no need to make the medium dispersive.

Figure 10 also permits another interpretation. Multiply the above equation by Planck's constant h divided by 2π, $\hbar$; the product of a wave vector ($\boldsymbol{\beta}$ or $\mathbf{K}$) and $\hbar$ represents the momentum of a particle, in this case a photon or phonon. The modified equation says that the collision of an incident photon with a phonon produces a new photon whose direction is so changed (by twice the Bragg angle α) that momentum is conserved. Conservation of energy follows from the other equation, which deals with the three frequencies, by multiplying each ω by $\hbar$.

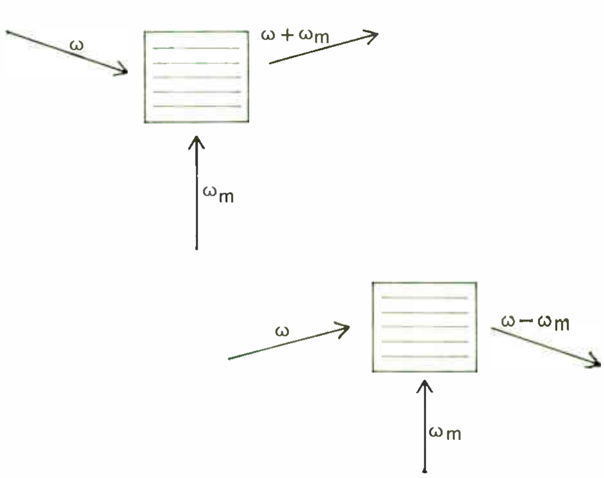
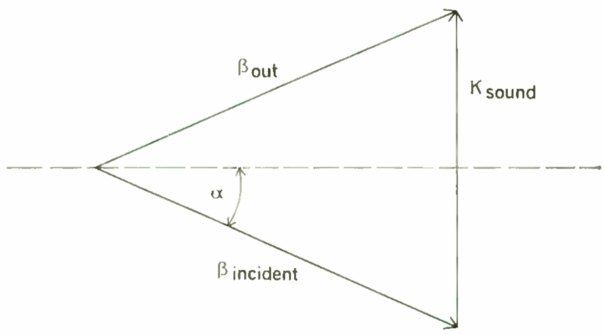


FIGURE 9. Bragg reflection. Upper or lower sideband is selected by making light and sound meet under the appropriate angle.

FIGURE 10. Bragg reflection. The addition of the propagation vectors of incident light and sound yield vector of diffracted light.



Ray bending at low frequencies

Ray bending is a phenomenon easily observed at acoustic frequencies of a few hundred kilohertz, corresponding to sound wavelengths of the order of centimeters (Fig. 11). The cyclic variation of the refractive index (higher at C, lower at D) now takes place slowly, over thousands of wavelengths of light. The change of optical phase along the right boundary is so gradual that diffraction effects are negligible. The sinusoidal curvature of the optical wavefronts causes the rays of light to bend toward regions of maximum sound pressure where the refractive index is highest. The light intensity therefore varies cyclically along the right boundary; a region of maximum intensity accompanies each region of maximum pressure. Fractional intensity variation is about $\frac{1}{2}(l/l_{max})\Delta\phi$. Our use of ray optics methods is justified so long as the interaction length l is shorter than the critical length l_{max}. Because the acoustic frequency is so low, this condition is easily met; for instance, for glass at 500 kHz, $l_{max} = 30$ meters. Substantial phase excursion $\Delta\phi$ (hundreds of radians) may be needed to obtain strong effects; this requires high acoustic intensities, most easily reached in acoustic resonators. It is possible to obtain either focusing (portion a in Fig. 11) or deflection (portion b) of light beams whose width is a fraction of the acoustic wavelength Λ. The maximum deflection angle, measured externally in air, is $(\lambda_0/\Lambda)\Delta\phi$. Many experiments of this type have been made with conventional light sources. Sinusoidal light deflection was demonstrated by Lipnick and

Reich and Schoen[8] and Aas and Erf[9]; the latter obtained 6 degrees peak-to-peak at 320 kHz. Recently, DeMaria and Danielson[10] have studied focusing effects produced by cylindrical acoustic waves in laser rods.

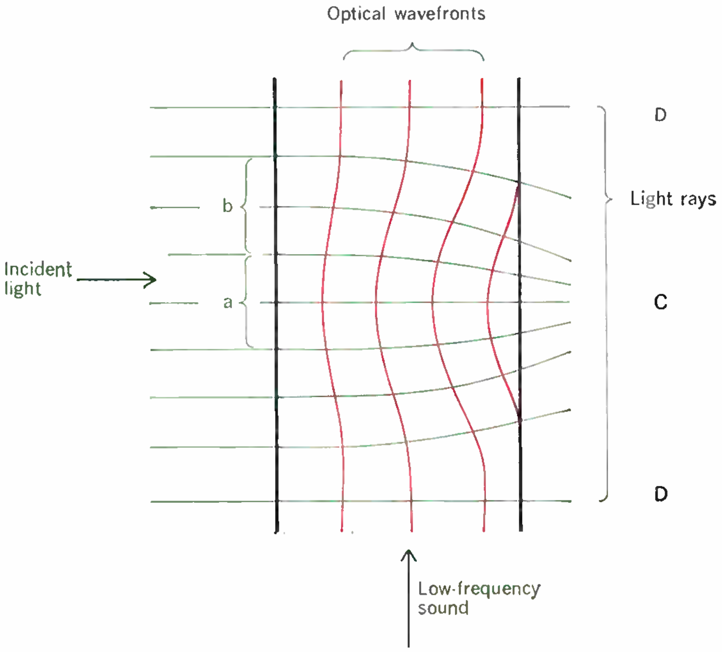
Some useful references. Bergmann's book,[11] particularly the German original, contains an abundance of early references on light–sound interaction. Detailed computations, particularly for the Debye–Sears regime, can be found in Born and Wolf's book.[12] More recently, Quate[13] has given a thorough review of the literature on Bragg diffraction and has calculated the interaction in terms of the classical equations of traveling-wave systems. Papers by Gordon and his co-workers[14] deal particularly with the relationships between the spatial distributions of sound and diffracted light.

I. Comparison of materials

Material	ρ, Mg/m³	v, km/s	n	p	dB	M_w
Water	1.0	1.5	1.33	0.31	0	1.0
Dense flint glass	4.8	3.80	1.72	0.30	−12	0.06
Extra-dense flint glass	6.3	3.10	1.92	0.25	−9	0.12
Fused quartz (SiO_2)	2.2	5.97	1.46	0.20	−22	0.006
Polystyrene	1.06	2.35	1.59	0.31	−1	0.8
KRS-5	7.4	2.11	2.60	0.21	+2	1.6
Lithium niobate ($LiNbO_3$)	4.7	7.40	2.25	0.15	−19	0.012
Lithium fluoride (LiF)	2.6	6.00	1.39	0.13	−29	0.001
Rutile (TiO_2)	4.26	10.30	2.60	0.05*	−29*	0.001
Sapphire (Al_2O_3)	4.0	11.00	1.76	0.17*	−29*	0.001

* Estimated from Quate's data[13]

FIGURE 11. Ray bending. Portion a is focused, portion b deflected. The illustration encompasses one wavelength of sound, with the central region C compressed and the top and bottom regions D dilated.



Efficiency: how materials compare

In any device that makes use of acoustic Bragg reflection or of the Debye–Sears effect, efficiency is of practical interest. Let us define efficiency as the fraction of the incident light intensity that is diffracted by the acoustic wave. We have calculated this fraction for a given phase excursion $\Delta\phi$, and we also know that $\Delta\phi$ equals $\beta l \Delta n$. But what is the relationship between the acoustic power and Δn for a diffraction cell of specified dimensions?

Analysis shows that Δn equals the acoustic strain s multiplied by the factor $-n^3p/2$. Here n is again the refractive index; p is the elastooptic coefficient, defined as the derivative of the reciprocal dielectric constant ϵ_0/ϵ (for optical frequencies) with respect to s. At low sound levels, the intensity of the diffracted light increases linearly with acoustic power and is proportional to $M = n^6p^2/v^3\rho$, where ρ is the density of the interaction medium.[15] All four parameters in this equation are properties of the material in which the interaction takes place. Coefficient p does not vary much; it is about 0.3 for most usable liquids and between 0.3 and 0.15 for many solids. In crystals, p is a tensor and directions must be considered, but for the best combination of directions p still falls into the usual range. By far the greatest variation is caused by the terms n^6 and v^3. Liquids, with their lower sound velocities, have higher M values than solids; the best solids are those (glasses or crystals) with high refractive index. Table I gives an approximate comparison between materials.

Liquids cannot be used at the higher frequencies because of their excessive attenuation of ultrasound; loss per unit length increases with the square of frequency. In water, for example, the attenuation at 50 MHz and room temperature is about 6 dB/cm. Attenuation is much smaller in solids and increases more slowly with frequency. Quartz, fused and crystalline, as well as rutile and sapphire are used at microwave frequencies. Spencer[16] showed that lithium niobate has excellent properties: very low attenuation and fairly good M.

For Bragg reflection, the power ratio of diffracted light to incident light is $I_1/I_0 = \sin^2(1.4l\sqrt{M_wP_s})$, where l is the interaction length in meters, M_w the numerical figure of merit referred to water (for example, −12 dB corresponds to $M_w = 0.063$), and P_s the acoustic power density in watts/square meter. The simplified form $I_1/I_0 = 1.9\, l^2M_wP_s$ can be used so long as it yields $I_1/I_0 \ll 1$; this equation also holds for each of the two first-order sidebands in the Debye–Sears regime, with the same restriction. The figure of merit M must be used with caution. We will later encounter a situation where a modified form of M is more appropriate. Nevertheless, M is a useful guide when different materials are compared.

Light modulation and frequency shifting

The ultrasonic light modulator was the first device to make use of the diffraction of light by ultrasound. Its development came just a few years after the discovery of the Debye–Sears effect and preceded the first laser by a quarter of a century. Referring to Fig. 12, a well-collimated beam of conventional light passes through a column of liquid bounded by two parallel glass plates and is then focused upon an intercepting obstacle. A beam of ultrasound, traveling through the liquid across the light beam, diffracts some of the incident light past the obstacle and thus generates an optical output whose intensity is a function of the acoustic power.

Early modulators used flat quartz crystal transducers in the 10-MHz region to produce sound power levels of a few watts; the radio-frequency voltage applied to the transducer was modulated with the desired signal. The efficiency of such a modulator is quite good if light from all the various sidebands can be recombined and put to use. As we saw in the analysis of the Debye–Sears effect, the incident light beam vanishes when the phase excursion $\Delta\phi$ equals 2.4 rad. At this point, all the light goes past the obstacle.

If we desire to modulate the light intensity at a fairly high video frequency, we must make the incident light beam (aperture D in Fig. 12) quite narrow. Strong and weak portions of the sound wave, corresponding to peaks and valleys of the video signal, travel across the light beam at sound velocity—millimeters per microsecond—and if strong and weak portions are present in the beam at the same time, their effect on the total light output cancels. In prelaser days, a narrow, highly collimated light beam could be produced only by sacrificing a great deal of light. This disadvantage was ingeniously circumvented in the Scophony light modulator, designed specifically for television projection by Okolicsanyi[17] and Robinson.[18] To understand their method, let a broad beam of light traverse a radio-frequency sound wave modulated with a video signal. Many video peaks and valleys are illuminated simultaneously. The video peaks diffract more light than the valleys. Together, they form a luminous replica of the video signal, a line of the desired television image that is ready for projection except for the fact that it moves forward at sound velocity. Okolicsanyi and Robinson stopped this motion by means of a rotating mirror and projected the entire line simultaneously on a screen.

The luminous replica of a video signal that the Debye–Sears effect produces in an ultrasonic delay line has also been put to use in signal-processing devices. In Slobodin's[19] correlator, a stationary transparency carrying a pattern of dark stripes serves as replica of a reference signal. This transparency is optically superimposed upon the moving luminous pattern produced by the video signal and intercepts a portion of the acoustically diffracted light. What remains is focused on a photocell. A current component corresponding to the correlation product of the two signals appears in the photocell output.

The angle at which the various sidebands produced by the Debye–Sears effect diverge is proportional to the frequency of the acoustic wave causing the effect. If several acoustic waves of different frequencies are introduced simultaneously, linear superposition applies, at least at low acoustic power levels; each frequency then produces its own pattern of light, undisturbed by the presence of other frequencies. Lambert[20] has described an instantaneous spectrum analyzer based on this principle.

An interesting modification of the Debye–Sears modulator was used by Hargrove[21] to lock the phases of the many axial modes of a gas laser to each other. This required a device capable of periodically introducing a moderate amount of optical attenuation into the light path, alternating with complete transparency at a rate of about 100 MHz. Hargrove produced a standing acoustic wave at half that frequency in a block of fused quartz. In a standing wave, all strains, and therefore all point-to-point variations of the refractive index, disappear twice during every cycle, and all light then goes straight through. When strains are present, light is scattered from its original direction and, in this experiment, is lost.

Let us now turn to acoustic modulators, which operate in the Bragg regime. In most cases, one wishes to modulate light that comes from a laser. One simple modulator (Fig. 13) uses water as the active medium, with an ultrasonic carrier frequency of about 50 MHz that is modulated by a video signal. The deflection angle is $2\alpha_0 = 1.2$ degrees,* permitting easy separation of the diffracted and undiffracted beams. Either one can be used as the output beam, depending on whether one desires positive or negative video modulation. With the ultrasonic signal cut off, the diffracted beam goes to zero; with a carefully measured amount of sound power, over 90 percent of the transmitted light is transferred into the diffracted beam. In a practical modulator, a few percent may remain in the undiffracted beam or go into higher orders.

There are cases in which the ultrasonic wave itself constitutes the desired modulation. We may, for instance, wish to modulate a light beam with a 30-MHz carrier, which itself may perhaps be modulated by a video signal. The light deflected by a Bragg diffraction cell operating

* In the following discussion of Bragg reflection devices, including Figs. 13 through 16, the zero subscript is no longer used; angles and light wavelengths are assumed to be measured in air.

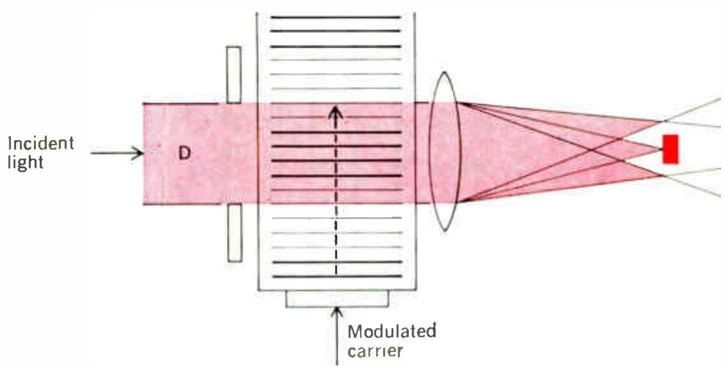
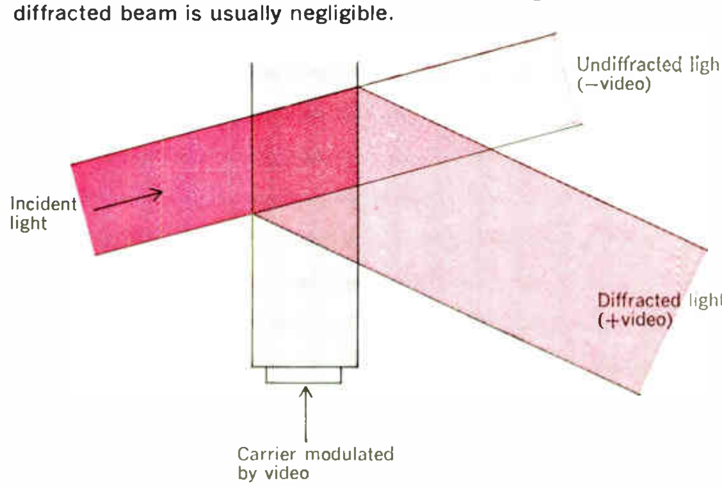


FIGURE 12. Early ultrasonic light modulator.

FIGURE 13. Bragg-reflection light modulator. In practice, angles are smaller than illustrated, and broadening of the diffracted beam is usually negligible.



at 30 MHz is not modulated at 30 MHz, but its optical frequency is shifted by 30 MHz from that of the undiffracted light. Thus, if we recombine the diffracted light with undiffracted light, we are adding an optical sideband to its optical carrier; the result is a light beam simultaneously modulated in phase and amplitude at 30 MHz. A photodetector exposed to the combined beams exhibits a 30-MHz component in its output (Fig. 14). Cummins and Knable made this experiment[5] in 1963 to prove conclusively that Bragg diffraction shifts the frequency of the light by precisely the frequency of the ultrasonic wave. The experiment was later repeated at microwave frequencies, using solid interaction media such as quartz or rutile, by Siegman, Quate,[22] and others. Dixon and Gordon[23] pointed out that the depth of amplitude modulation so obtained is proportional to the square root of the power in the diffracted light. At high ultrasonic frequencies (hundreds or thousands of megahertz), where acoustic power is difficult to obtain, reasonable modulation depth is achieved with remarkably little power. For example, diffracting 1 percent of the incident light intensity, and recombining, produces 10-percent modulation.

The possibility of obtaining by very simple means a well-defined frequency difference between two light beams is particularly useful in systems where a beam, sent out to bring back information of some sort, is strongly attenuated before it can be collected. Combination of the

FIGURE 14. Optical heterodyne detection, which recovers the carrier frequency of the ultrasonic wave.

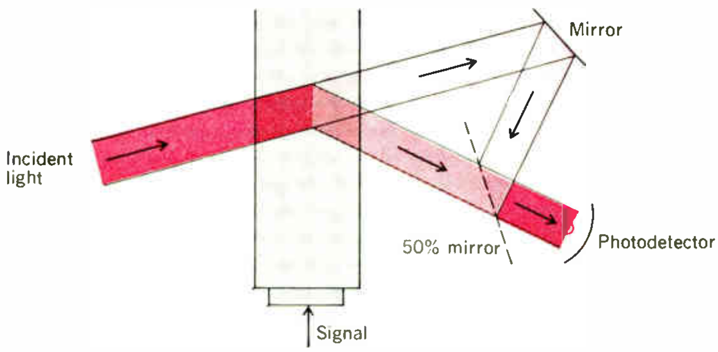
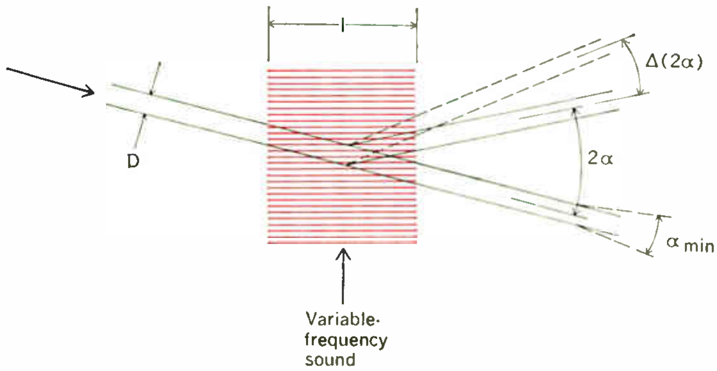


FIGURE 15. Light detection. Change of sound frequency swings the deflected beam by $\Delta(2\alpha)$. The beam spreads unavoidably by α_{min}. The ratio of these two angles gives the number of resolvable spots.



weakened beam with a second, unattenuated beam, which differs in frequency by a known amount, permits us to use a photodiode as an optical superheterodyne detector. This process eliminates the effects of dark current and low-frequency noise encountered in photodiodes and multipliers. To produce an output, the received light must be of the correct frequency, and it must also arrive with its wavefronts aligned with those of the reference beam that serves as the local oscillator. The superheterodyne arrangement therefore provides very good discrimination against unwanted signals, including conventional light sources of high intensity. Its sensitivity is limited, in principle at least, only by the quantum efficiency of the photodetector. A number of applications that have been suggested resemble continuous-wave radars or interferometers. But perhaps the most important use to date has been the detection of weak acoustic waves in solids—particularly at high frequencies, where other methods fail.

Brienza and DeMaria[24] have used optical superheterodyne detection to read out acoustic delay lines operating at several hundred megahertz. Optical readout permits continuously variable delay, and no output transducer in the usual sense is required. The width of the light beam determines the bandwidth that can be reproduced. If a photocell were exposed only to the diffracted light, it would produce a small video output current corresponding to the envelope of the signal; by recombining diffracted and undiffracted light in a photodetector, one obtains the video-modulated high-frequency signal directly, with much better signal-to-noise ratio.

There is one practical detail that renders superheterodyne detection particularly well adapted to the observation of small acoustic signals. We normally expect to be able to distinguish between the light scattered by a weak sound wave and the major portion of the incident light that has not been scattered, simply on the basis of direction. The acoustically diffracted light is deflected by 2α and the remaining light goes straight on. Laser light is usually so well collimated that there should be no problem. And there would be none, except for dust. A few tiny particles, scattering the incident light in all directions, can drown the small amount of light diffracted by a weak sound wave. But the light scattered by dust particles is not shifted in frequency; in superheterodyne detection, this light simply merges with the local oscillator signal and never interferes with the desired signal. In fact, enough dust may render a separate local oscillator beam unnecessary. The desired signal—a high-frequency component of the photodetector current—can be produced only by a sound wave.

The process of shifting the frequency of light by a controlled amount has found at least one application that does not involve detection: Crumly, Foster, and Ewy[25] demonstrated that when light from a gas laser is shifted up or down by the intermode frequency and is then returned to the laser, mode locking is obtained. An acoustic diffraction cell outside the laser cavity, operating in the Bragg regime, is used in this experiment. The diffracted and frequency-shifted beam is reflected by a mirror to make a second pass through the cell on its return trip; this doubles the frequency shift.

Light deflection

Light deflection by ultrasound is based on the linear relationship between the acoustic frequency and the sine

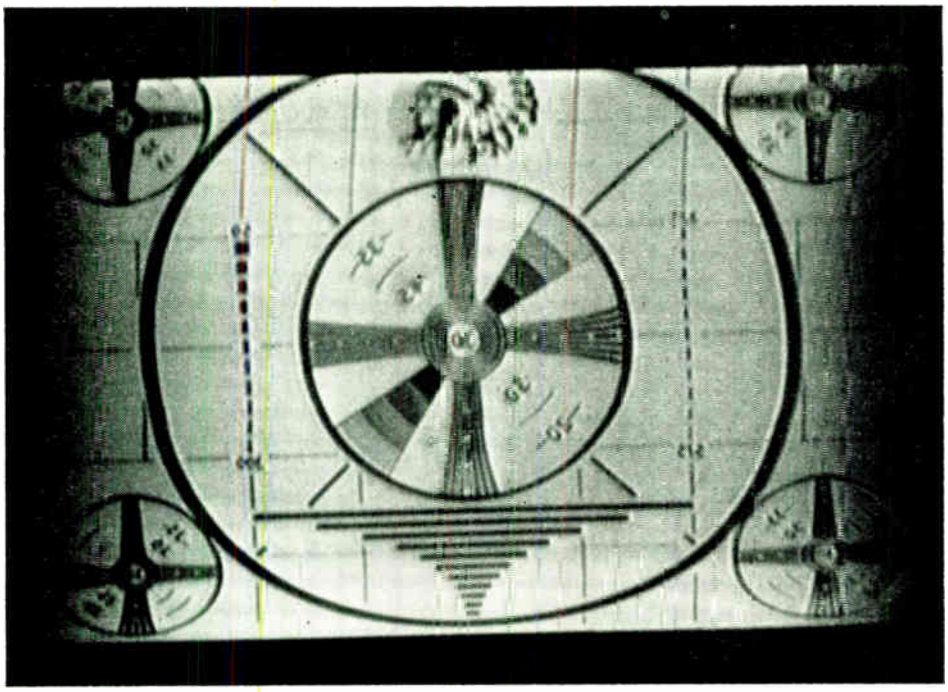


FIGURE 16. Test pattern produced by experimental display system. (Ultrasonic modulation and deflection of He-Ne laser light; there are 200 resolvable spots along the horizontal.)

of the Bragg angle.[26] To obtain this relationship, substitute the quotient of sound velocity v and sound frequency f for the sound wavelength Λ in the Bragg diffraction equation:

$$\Lambda = \frac{v}{f} \qquad 2 \sin \alpha = \frac{\lambda}{\Lambda} \qquad 2 \sin \alpha = f\frac{\lambda}{v}$$

Let us write 2α for $2 \sin \alpha$ since Bragg angles are usually small. Now, 2α represents the angle by which the diffracted beam departs from the path of the incident beam. To vary the direction of the diffracted beam, we vary f:

$$\Delta(2\alpha) = \Delta f \frac{\lambda}{v}$$

Light deflection is potentially useful for television projection and for memory or switching devices. What counts most in a light deflection device is not the deflection angle obtained (this is easily magnified by a pair of lenses) but the number of angular positions that can be clearly distinguished from each other, usually called the number of resolvable spots. Magnification does not change this number, which determines the detail of a television picture or the number of switching elements that can be placed in a linear array.

To determine the number of resolvable spots, we divide the angular displacement $\Delta(2\alpha)$ by the unavoidable diffraction spread $\alpha_{min} \approx \lambda/D$ of a light beam projected from an aperture D (Fig. 15). This spread determines how small a spot we can make. We find

$$\frac{\Delta(2\alpha)}{\alpha_{min}} = \frac{\Delta f(\lambda/v)}{\lambda/D} = \frac{\Delta f D}{v} = \Delta f \tau$$

Term D is the width of the light beam that the sound wave traverses at its velocity v; hence D/v is the transit time τ of the sound across the optical aperture. The number of resolvable spots equals this transit time multiplied by the peak-to-peak frequency change Δf of the acoustic wave.

In light-deflection systems that require random access to any angular position, such as light-switching systems, τ must be less than the access time; otherwise different parts of the light beam, simultaneously present within the aperture D, might be directed to different points. Some systems of this sort permit an access time of only about 1 μs, so Δf must be 1 MHz per resolvable spot; hundreds of megahertz of frequency change may be required in such a system. Cadmium sulfide or zinc oxide film transducers, capable of efficiently producing ultrasound in solids at 500 to 1000 MHz, render such light deflectors feasible.

In a television system with linear horizontal scan, the acoustic transmit time τ may be made much larger than the short time interval that corresponds to one picture element. The deflection angle 2α then changes linearly along the optical aperture, making the deflected light diverge as if it had passed through a cylinder lens.[27] The focal length of this fictitious cylinder lens remains constant throughout the scan, so that its effect is easily corrected. The practical limit for τ in a television system is set by the horizontal retrace time. Typically this is about 10 μs, so that one obtains about ten resolvable spots per megahertz of frequency change.

An experimental television system recently described[28] uses a horizontal sweep with the following parameters: τ = 12.5 μs, f_{min} = 19 MHz, f_{max} = 35 MHz; thus Δf = 16 MHz and 16 × 12.5 = 200 resolvable spots. Resolution of the projected picture (Fig. 16) is good up to video frequencies of 2 MHz, then drops to zero at 3 MHz. This is better than one half of the resolution suggested by U.S. television standards, and it does not appear difficult to achieve the full required resolution. The experimental system employs water as the interaction medium; light comes from a helium–neon laser and is modulated with the video signal in a Bragg diffraction modulator, which also uses water and operates at 43 MHz.

An interesting problem arises whenever a wide-band acoustic signal is to be used in a Bragg diffraction device.

As Fig. 8 shows, entrance and exit angles of the two light beams with respect to the acoustic wavefronts should be equal. If they are not, destructive interference of the kind illustrated in Fig. 7 will occur. A fixed angle of entry is correct for only one frequency. Of course, there is some tolerance (the angle may be off by about $\pm\Lambda/2l$), but in wide-band systems the tolerance may be exceeded. We can overcome this difficulty by rotating the acoustic wavefront in accordance with the acoustic frequency, so the correct angle is always presented to the incident light beam. The television system just discussed uses a simple phased array of four transducers to steer the sound beam as required by the ±30 percent frequency change. This method may also be employed in systems in which different acoustic frequencies occur simultaneously.

Wide-band systems also require another look at the figure of merit M. It was stated previously that the ratio of diffracted and incident light intensities depends on the product of M, the acoustic power density P_s, and the square of the interaction length l. The acoustic beam is often given a rectangular cross section; it must extend over the entire length l, but its width w may be much smaller. The total acoustic power P_T in the beam is $P_s lw$, and the product $MP_s l^2$ may therefore be written $MP_T l/w$. Thus, once the width has been reduced to a practical minimum, acoustic power may be traded for length; less total power is needed if greater length is available. So, if we want only to convert light from one frequency to another, the maximum practical length is the best. But assume that we want to use a wide band of acoustic frequencies. We then run into the angular tolerance problem. Even if we use acoustic beam steering, the correction will not be perfect. And because the tolerance angle $\pm\Lambda/2l$ is inversely proportional to the interaction length, there exists, for any degree of correction, a maximum usable length L.

Gordon[29] pointed out that L depends on some of the same material properties that determine M. Combining L and M, he defined a new figure of merit M' which applies when l is limited by the required bandwidth: $M' = n^7p^2/v\rho$. (For comparison: $M = n^6p^2/v^3\rho$.)

The refractive index n is even more important in M' than in M, the sound velocity v much less so. This changes the relative rank of some materials: glass, with high n and high v, is much inferior to water with respect to M, but is comparable to water with respect to M'.

Acoustic probing and imaging

Gordon and his co-workers also studied the diffraction of light by a column of sound with small l, which might, for example, be the focal region of a large spherical or cylindrical transducer. They probed the column of sound by varying the entrance angle ψ of the incident light[30] (Fig. 17), and recorded the intensity of the diffracted light as a function of angular position. The result, in agreement with their calculations, is this: The angular distribution of the diffracted light intensity duplicates the distribution of power density in the far-field diffraction pattern of the sound beam (the angular distribution of sound power we would observe at a very large distance if the sound continued to travel within the same medium). It is therefore possible to explore acoustic radiation patterns in detail by optical probing.

Recently, Korpel[31] went one step further and showed that the process of acoustic Bragg diffraction possesses image-translating properties. Interaction between the waves emanating from a point source S of single-frequency sound and a point source O of monochromatic light (Fig. 18) produces diffracted light that appears to come from a point O'—a virtual image of the sound source, but one that is visible to the eye. For a number of sound sources S_1, S_2, S_3, etc., the virtual image points O_1', O_2', O_3', etc., form a corresponding pattern. In this translation process, amplitude ratios and phase angles are preserved; an acoustic field is transformed into an equivalent optical field. The first experimental pictures (Fig. 19) show simple metallic objects, illuminated with 22-MHz sound in water.

In optical microscopy, resolution is limited by the numerical aperture (the sine of one half the angle formed by the most divergent rays that the optical system accepts from the object) and the wavelength of light. In acousto-optical imaging, the same rule applies. We must substitute the wavelength of the sound for that of the light

FIGURE 17. Sound field in cell probed by rotating cell while intensity of diffracted light is observed. Plot shows result for uniform acoustic beam with sharp edges.

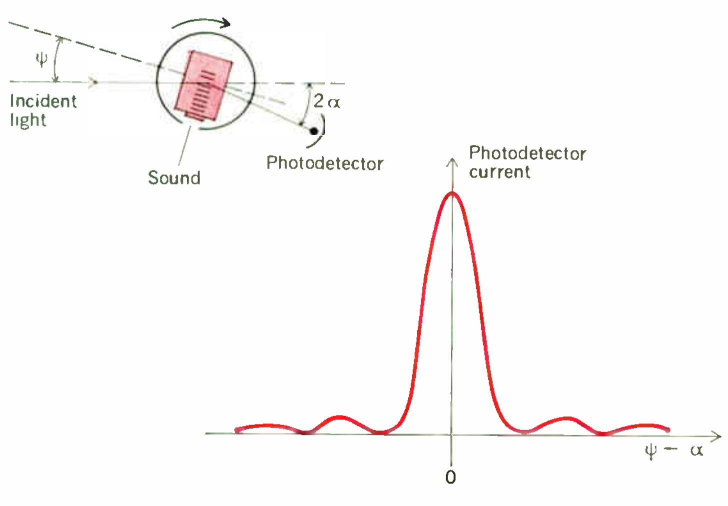
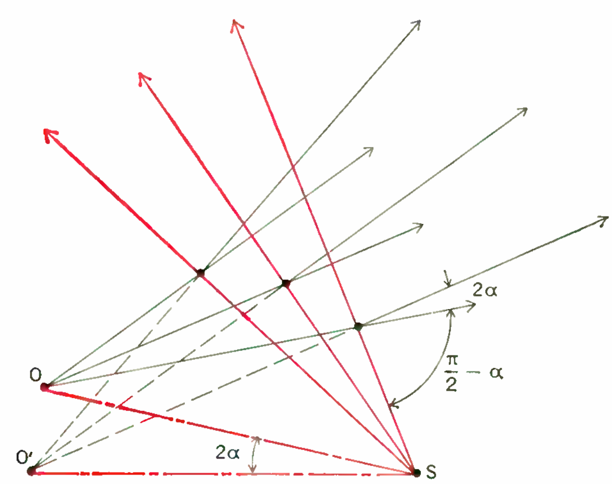


FIGURE 18. Acoustic imaging. Acoustic rays from source S interact with optical rays from source O to form new light rays, which seem to come from O′, a virtual image of S.



and consider the angles formed by acoustic as well as optical rays. With acoustic frequencies in the microwave range, resolution should approach that of optical microscopes.

Measurement of the Bragg angle with monochromatic light permits us to determine directly the acoustic wavelength and thus find the sound velocity if we know the acoustic frequency. Frequencies and angles can be measured with great accuracy. Even the acoustic attenuation can be found from optical measurements; sound waves that travel only a short distance across the incident light beam before fading out simulate the effect of a narrow optical aperture. The deflected light shows a large diffraction spread, which we can measure in order to find the attenuation. Such data, taken at microwave frequencies over a wide range of temperatures, provide information that is useful in the study of the physics of liquids and solids. Measurements have been made with acoustic waves generated by microwave generators and piezoelectric transducers; they have also been made using thermal phonons (the sound waves that are the acoustic counterpart of thermal agitation noise in electric circuits and are always present in all materials). It was these thermally generated sound waves that Brillouin had in mind when he made the first calculation of acoustic diffraction of light many years ago. The term Brillouin scattering in its narrow sense refers to light diffraction by thermal phonons.

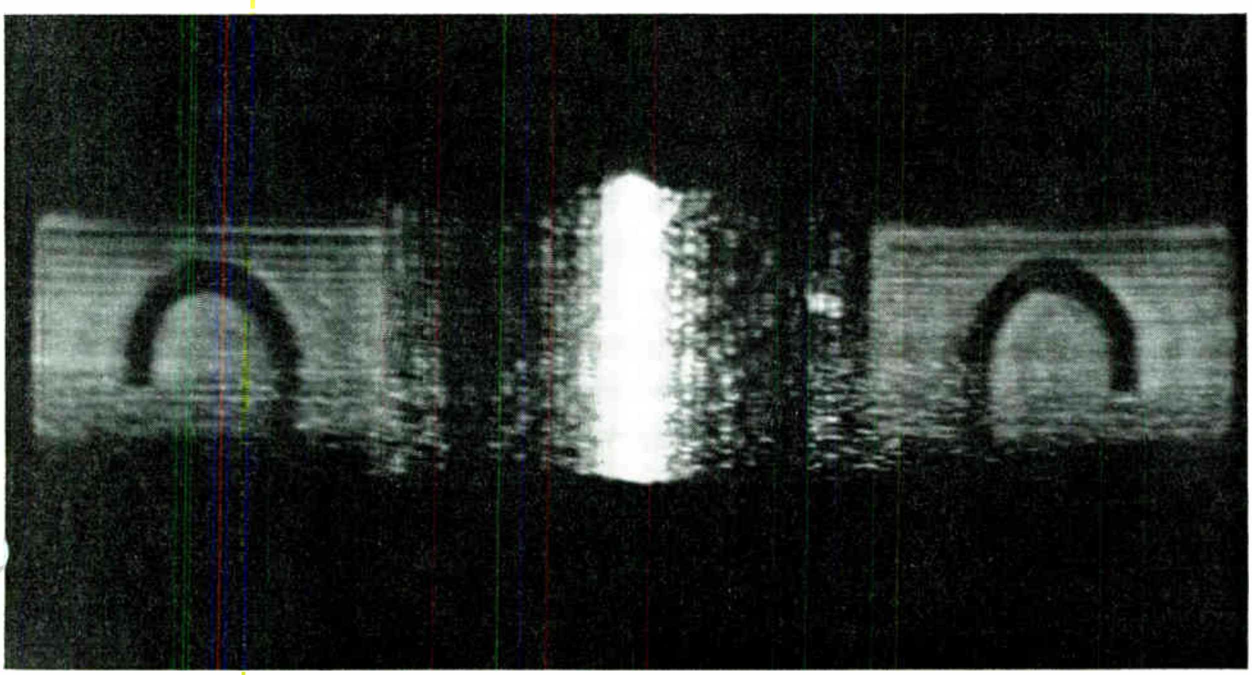
Thermally generated sound covers an enormous frequency range—up to about 10^{12} hertz, where the wavelength of sound approaches the distance between two atoms. Wavelengths down to $\lambda/2$ (light wavelength λ in material) can be observed by Bragg diffraction. By measuring the light scattered at a specific angle we limit our observation to phonons of a specific wavelength, but in this experiment we have no advance knowledge of their frequency. We know, however, that the scattered light must show a corresponding frequency shift. Benedek and Greytak[32] have measured this shift (about 6 GHz in one experiment) to about one part in a thousand by means of an optical interferometer. This yields the sound velocity with similar accuracy, and from the spread in the frequency of phonons that diffract light at the specific angle, an approximate value for the acoustic attenuation can be found.

Parametric effects—feeble and violent

We have surveyed a variety of experiments in which two different input signals—one optical, one acoustic—combine to generate an optical output signal. The optical input is used quite efficiently, but the acoustic input remains almost completely untouched by the interaction. Only a tiny fraction of the phonons reacts with photons. If all of them did, the interaction would produce a power gain equal to the frequency ratio of light and sound, about ten million to one at 50 MHz.

Like all processes based on parametric interaction, this process becomes more efficient as the pump power is raised. Let us take a 50-MHz Bragg cell, which, with one watt of sound power, diffracts all the incident light. Let us assume also an optical input power of one watt (this is fully converted into output power). The up-conversion gain (sound to diffracted light) is unity; only one in 10^7 phonons reacts. But now let us raise the optical input power to 10 kW; all the light is still diffracted by one watt of sound. The power gain is now 10^4, and one in 10^3 phonons reacts. If we arrange the angle of incidence to select the upper sideband, 1 mW of sound power is consumed in the interaction process. If we select the lower sideband instead, 1 mW of additional sound power

FIGURE 19. Diffraction images, produced by 22-MHz sound scattered by a wire hook immersed in water. Hook is 5 mm wide and made of 1-mm wire. Bright streak of undiffracted light appears between symmetrical first-order images.



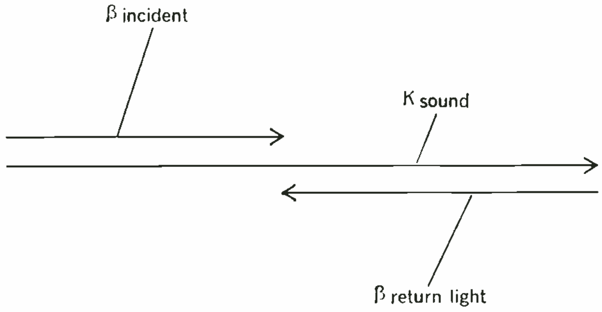


FIGURE 20. Propagation vectors in stimulated Brillouin scattering.

is generated; the interaction of the input light with the frequency-shifted output light produces sound that did not exist before. Proof that sound can be produced by mixing two light beams was first given by Korpel, Adler, and Alpiner,[33] who performed such an experiment at about 50 MHz. Caddes, Quate, and Wilkinson[34] later obtained similar results at 720 MHz. Both experiments were made under the usual small-Bragg-angle conditions.

With higher-frequency sound, the Bragg angle increases. What will we observe if we go all the way to 90 degrees? This requires an acoustic frequency of $2v/\lambda$. The sound wave now runs parallel to the incident light beam; the diffracted light returns along the same path (Fig. 20). Throughout the region in which the two light beams interact, additional sound is generated. Quate,[13] in a detailed analysis, compares this process with the operation of a parametric backward-wave oscillator. Clearly this is a regenerative device, which could become unstable. It takes a great deal of light to overcome the losses, but if the optical input is raised to the megawatt level, the expected instability sets in: sound builds up explosively, even though it has to start from thermal phonons. Such a process, called stimulated Brillouin scattering, was predicted and first observed by Chiao, Townes, and Stoicheff.[35] Intense light pulses from a Q-switched laser are sent into a transparent interaction medium. A large fraction of the incident light returns, downshifted in frequency by 20 to 30 GHz if the experiment is made with a solid, 4 to 8 GHz with a liquid; in each case, the shift equals $2v/\lambda$ for the particular material. This is a spectacular experiment, which demonstrates interaction between sound and light in its most violent form.

REFERENCES

1. Brillouin, L., "Diffusion de la lumière et des rayons X par un corps transparent homogène," *Ann. Phys.* (Paris), 9th ser., vol. 17, p. 88, 1922.

2. Debye, P., and Sears, F. W., "On the scattering of light by supersonic waves," *Proc. Nat'l Acad. Sci. (USA)*, vol. 18, p. 409, 1932.

3. Lucas, R., and Biquard, P., "Optical properties of solids and liquids under ultrasonic vibrations," *J. Phys. Rad.*, 7th ser., vol. 3, p. 464, 1932.

4. Ali, L., "Uber den Nachweis der Frequenzanderung des Lichtes durch den Dopplereffekt bei der Lichtbeugung an Ultraschallwellen in Flussigkeiten," *Helv. Phys. Acta*, vol. 8, p. 503, 1935; vol. 9, p. 63, 1936.

5. Cummins, H. Z., and Knable, N., "Single sideband modulation of coherent light by Bragg reflection from acoustical waves," *Proc. IEEE (Correspondence)*, vol. 51, p. 1246, Sept. 1963.

6. Raman, C. V., and Nath, N. S. N., "The diffraction of light by sound waves of high frequency, Pt. II," *Proc. Ind. Acad. Sci.*, vol. 2A, p. 413, 1935.

7. Tien, P. K., "Parametric amplification and frequency mixing in propagating circuits," *J. Appl. Phys.*, vol. 29, p. 1347, 1958.

8. Lipnick, R., Reich, A., and Schoen, G. A., "Nonmechanical scanning of light using acoustic waves," *Proc. IEEE (Correspondence)*, vol. 52, pp. 853–854, July 1964.

9. Aas, H. G., and Erf, R. K., "Application of ultrasonic standing waves to the generation of optical beam scanning," *J. Acoust. Soc. Am.*, vol. 36, pp. 1906–1913, Oct. 1964.

10. DeMaria, A. J., and Danielson, G. E., Jr., "Internal laser modulation by acoustic lens-like effects," *IEEE J. of Quantum Electronics*, vol. QE-2, pp. 157–164, July 1966.

11. Bergmann, L., *Ultrasonics*. New York: John Wiley and Sons, Inc., 1938. Also, *Der Ultraschall*, 6th ed. Stuttgart: S. Hirzel, 1954.

12. Born, M., and Wolf, E., *Principles of Optics*. New York: Pergamon, 1959.

13. Quate, C. F., Wilkinson, C. D. W., and Winslow, D. K., "Interaction of light and microwave sound," *Proc. IEEE*, vol. 53, pp. 1604–1623, Oct. 1965.

14. Gordon, E. I., "A review of acoustooptical deflection and modulation devices," *Proc. IEEE*, vol. 54, pp. 1391–1401, Oct. 1966.

15. Smith, T. M., and Korpel, A., "Measurement of light-sound interaction efficiencies in solids," *IEEE J. of Quantum Electronics (Correspondence)*, vol. QE-1, pp. 283–284, Sept. 1965.

16. Spencer, E. G., Lenzo, P. V., and Nassau, K., "Elastic wave propagation in lithium niobate," *Appl. Phys. Letters*, vol. 7, p. 67, 1965.

17. Okolicsanyi, F., "The wave slot, an optical television system," *Wireless Eng.*, vol. 14, pp. 527–536, Feb. 1937.

18. Robinson, D. M., "The supersonic light control and its application to television with special reference to the Scophony television receiver," *Proc. IRE*, vol. 27, pp. 483–486, Aug. 1939.

19. Slobodin, L., "Optical correlation technique," *Proc. IEEE (Correspondence)*, vol. 51, p. 1782, Dec. 1963.

20. Lambert, L. B., "Wide-band, instantaneous spectrum analyzers employing delay-line light modulators," *1962 IRE Internat'l Conv. Record*, pt. 6, pp. 69–98.

21. Hargrove, L. E., Fork, R. L., and Pollack, M. A., "Locking of He-Ne laser modes induced by synchronous intracavity modulation," *Appl. Phys. Letters*, vol. 5, p. 4, 1964.

22. Siegman, A. E., Quate, C. F., Bjorkholm, J., and Francois, G., "Frequency translation of laser's output frequency by acoustic output coupling," *Appl. Phys. Letters*, vol. 5, p. 1, 1964.

23. Dixon, R. W., and Gordon, E. I., "Acoustic light modulator using optical heterodyne mixing," *Bell System Tech. J.*, vol. 56, p. 367, 1967.

24. Brienza, M. J., and DeMaria, A. J., "Continuously variable ultrasonic optical delay line," *Appl. Phys. Letters*, vol. 9, p. 312, 1966.

25. Crumly, C. B., Foster, L. C., and Ewy, M. D., "Laser mode locking by an external Doppler cell," *Appl. Phys. Letters*, vol. 6, p. 6, 1965.

26. Korpel, A., Adler, R., Desmares, P., and Smith, T. M., "An ultrasonic light deflection system," *IEEE J. of Quantum Electronics*, vol. QE-1, pp. 60–61, Apr. 1965.

27. Gerig, J. S., and Montague, H., "A simple optical filter for chirp radar," *Proc. IEEE (Correspondence)*, vol. 52, p. 1753, Dec. 1964.

28. Korpel, A., Adler, R., Desmares, P., and Watson, W., "A television display using acoustic deflection and modulation of coherent light," *Proc. IEEE*, vol. 54, pp. 1429–1437, Oct. 1966.

29. Gordon, E. I., "Figure of merit for acousto-optical deflection and modulation devices," *IEEE J. of Quantum Electronics (Correspondence)*, vol. QE-2, pp. 104–105, May 1966.

30. Cohen, M. G., and Gordon, E. I., "Acoustic beam probing using optical techniques," *Bell System Tech. J.*, vol. 44, p. 693, 1965.

31. Korpel, A., "Visualization of the cross-section of a sound beam by Bragg diffraction of light," *Appl. Phys. Letters*, vol. 9, p. 425, 1966.

32. Benedek, G., and Greytak, T., "Brillouin scattering in liquids," *Proc. IEEE*, vol. 53, pp. 1623–1629, Oct. 1965.

33. Korpel, A., Adler, R., and Alpiner, B., "Direct observation of optically induced generation and amplification of sound," *Appl. Phys. Letters*, vol. 5, p. 86, 1964.

34. Caddes, D. E., Quate, C. F., and Wilkinson, C. D. S., "Conversion of light to sound by electrostrictive mixing in solids," *Appl. Phys. Letters*, vol. 8, p. 309, 1966.

35. Chiao, R. Y., Townes, C. H., and Stoicheff, B. P., "Stimulated Brillouin scattering and coherent generation of intense hypersound waves," *Phys. Rev. Letters*, vol. 12, p. 592, 1964.

Limitations in solid-state technology

With today's exploding technologies, products are technically obsolete by the time they are introduced, a situation that obviously calls for a change. Clearly, technologists must find ways to ascertain the theoretical limits of their capabilities

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In a field in which success is a matter of record some constructive criticism is in order to spur even greater and more meaningful progress. In this vein the present article highlights shortcomings and limitations in the burgeoning area of solid-state technology. One of the main problems is that practice so often outdistances fundamental theory and understanding. Thus it is important that we be able to predict the growth and changes in the technology, but unfortunately our techniques of analysis, simulation, and measurement are inadequate and the number of theoretical limits pitifully small. Undoubtedly, more effort is essential.

Judging by the fantastic achievements that have taken place in the field of solid-state technology, any article on the subject should be a laudatory one. The solid-state engineers have increased computer speeds by two orders of magnitude in ten years. They have made it possible to increase the scope and number of data-processing systems by one order of magnitude and the data processing per dollar by two orders of magnitude. Therefore, congratulations should be in order. However, instead I intend to express my discontent about a number of items that I believe are being neglected. I believe that constructive malcontent serves the role of the mainspring of progress and if I can point the way to some further progress through this approach, this article will have achieved its purpose.

I would like to highlight shortcomings rather than accomplishments, weaknesses rather than strengths, limitations rather than capabilities, and our lack of understanding rather than the great things to come.

The problem of obsolescence

First, let us consider the question of technical obsolescence, and here I will limit myself to digital applications.

If one designs systems in a period of exploding technology, the time span from the completion of a feasibility study to the delivery of machines is an extremely important factor. The length of this span has been surprisingly constant in the past, averaging about four years. If I include research, advanced development, and product engineering and manufacturing, perhaps my four years might seem unduly short. Clearly, this delay will always cause early product obsolescence, especially when technologies explode at the rate that the solid-state technology is today. We are technically obsolete by the time products are introduced. Therefore, we have a critically short system life. Let me call your attention to Fig. 1.

I am not sure that the particular parameter chosen for this diagram is the one that everybody would choose, but I am convinced that whatever parameter we take, the curve would look very much the same: an order-of-magnitude improvement every five or six years.

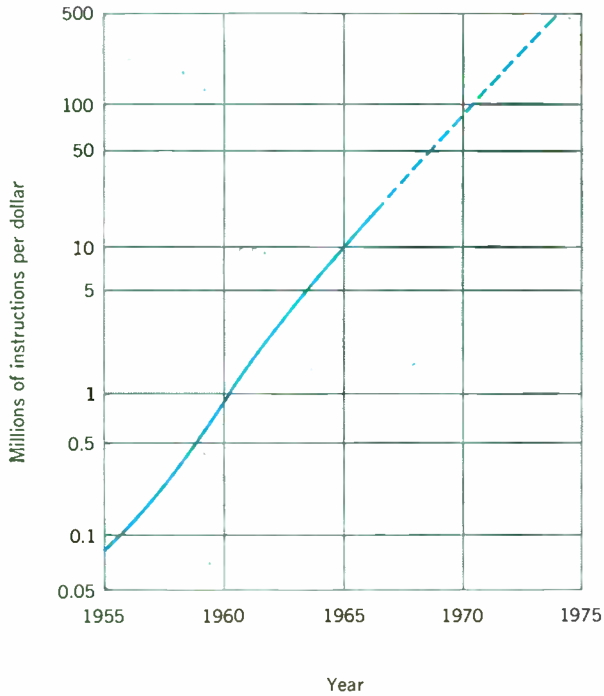


FIGURE 1. Increase in data-processing value.

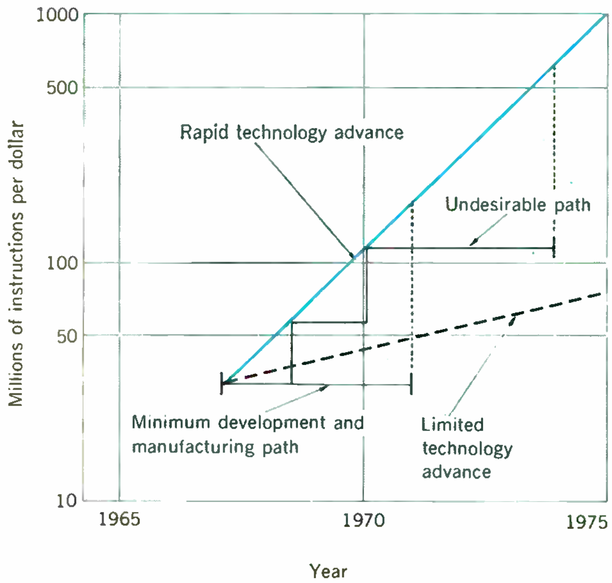


FIGURE 2. Ramifications of introducing a new system in a changing environment.

Figure 2 presents the typical problem of a system designer. Should we anticipate that the rate shown in Fig. 1, that is, an increase of about an order of magnitude every five years, will continue in the foreseeable future? My answer to this question would be "yes" and I would conclude, of course, that a system started today would be nearly an order of magnitude below the performance level for 1971 indicated by our technology advance curve. When a situation such as this arises, a great deal of thinking and care are required in all hardware and software design. We must freeze our design at some early point if we expect to obtain a result.

It is interesting to note that the technology advance is, in its turn, not independent of our efforts and our successes. Technologies are not meaningful if they are not employed, a fact that tends to reduce the true rate of increase of technology by the partial drag of the system considerations. How can we foreshorten our development time in the face of complex technological advances such as large-scale integration (LSI)? We could, of course, try to predict, as shown in Fig. 3. Here we indicate a projected advance not quite as great as a technological advance that actually occurred. We indicate a prediction made regarding this advance, i.e., the penalties that one has to assume in advance because of this difference and the penalties that one may have to pay as a result of mistakes made in assumptions.

Let me emphasize the importance of the "block," shown in Fig. 3. In fact, the equipment will never leave the plant unless we erect a semipermeable wall that will prevent those who do the engineering from observing the exploding technology but will permit those who develop the technology to see what happens to the engineering. As indicated in this illustration, the block extends over the entire development and manufacturing period. If we don't use such a block, the engineers will try to keep up with expanding technology, and the result will be significantly increased costs and relatively little success.

Obviously, the ability to predict technological expansion becomes a most essential part of the system design. Unfortunately, in this area, it is common for practice to outdistance fundamental theory and understanding. And it is to this point that I would like to address most of the balance of this article.

Understanding the limitations

Theory is more difficult to formulate in an environment such as this, in which so many different phenomena and disciplines exist. Our systems are big, interdependent, and complicated. Although this fact may explain why our theoretical achievements are not outstanding, it is also a good reason why more effort is essential. *We cannot continue to permit the distance between practice and fundamental understanding to increase, especially as we press closer to our boundaries.*

Where do we stand and what do we need?

1. *The number of theoretical limits is pitifully small.*
2. *The characterization of applications is inadequate.*
3. *The analysis, simulation, and measurement techniques are far too limited.*
4. *There are too few trade-off relationships.*

This situation will have to change. *Technologists must begin to look for the theoretical limits of their capabilities.* The passages in italics present the essence of this article.

In Fig. 3, where we were pointing out the importance of our ability to predict the changes in technology, it would have been extremely useful to know if, at a given time, we are at one tenth of one percent of the theoretical limits or at 80 percent of these limits. If we are close to the limits, the chances of progress are small. If we are far from them, the chances are that we can advance at a constant growth rate.

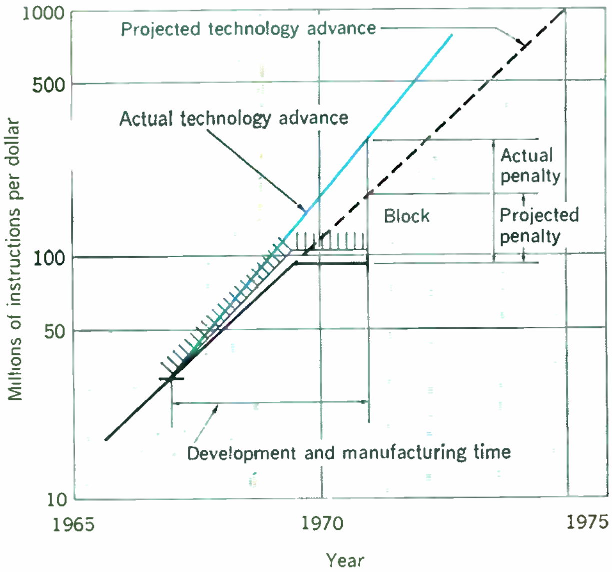


FIGURE 3. Minimizing obsolescence.

We note, for example, that Rolf Landauer, in a paper written in 1961, pointed out that the minimum energy dissipation in switching a specific device must be at least somewhat larger than the energy kT where k is the Boltzmann constant. By introducing a kT/q voltage limit, as was done by Robert Keyes in 1962, we can relate circuit power, circuit delay, and capacitance in an approximate way: $P \approx (C/\tau) \times 10^{-2}$ watt. The following conditions are assumed: voltage must be several times kT/q (valid for transistor circuits as we now understand them); the circuit is switching at a maximum rate as determined by the RC time constant; and delay time ≈ time constant.

This is a reasonably generalized expression that is valid for typical semiconductor devices, at least. I will try to use it, not because it is necessarily very good, but because it helps to give an example of the type of information that a system designer needs more and more and that has not been supplied in enough quantity by the theoreticians.

Assuming certain photolithographic limitations, we can postulate that all elements of the circuit, the devices and and interconnections, cannot be smaller than 5–10 μm. We would then conclude from the foregoing expression that the capacitance of the device could not be smaller than 5×10^{-16} farad and that it may be as much as five times greater for a logic gate and 20 times greater for a typical interconnected array of gates. Thus, one would expect, on the basis of the previous formula, a product of power times delay time of about 10^{-16} watt-second.

This fact permits us to make one comparison between the theoretical limitations and what is possible in practice. The typical circuit component used today has 10-ns delay and dissipates 20 mW; thus, the delay–power product is 2×10^{-10}, that is, six orders of magnitude from the postulated theoretical limit. The question arises as to whether a present technology is this far away from the theoretical limits or whether other limits exist that we don't understand as yet. Would they enter into the picture long before the kT limit that we have employed for this comparison? As for the very near future, LSI could give us a reduction of an order of magnitude in capacity, and in the power–delay product, but this is only a small step toward the 10^{-16}-watt-second limitation.

In addition, one should ask what latitude we have in taking advantage of this power–delay time product. The density that we have implied by assuming the one-micrometer limitation would correspond to about 150 000 gates per square centimeter. With this density, what problems will cooling present? If this cooling were restricted to 1 kW/in² (150 W/cm²)—not necessarily a maximum—then the maximum average gate dissipation would be one milliwatt and the minimum gate delay would be about 10^{-13} second. However, propagation delays would dominate and the effective delay τ would be closer to 10^{-12}.

We could use these figures to give a somewhat different picture. Suppose the system could be measured in terms of millions of instructions per second (MIPS) per kilowatt; the 10^{-16}-watt-second limit then would translate to about 100 000 MIPS per kilowatt.

I. MIPS and MIPS per kilowatt for representative machines (for logic only)

Machine Central Processing Unit	MIPS	MIPS/kW
A	0.5	0.3
B	1	0.3
C	1–4	0.2
D	3–12	0.6

If speed is the principal consideration, then, using only the preceding assumption of a 10^{-12}-second gate delay and today's system organization and size (Table I), we could conclude that a maximum performance is of the order of 10 000 to 100 000 MIPS. What would it mean to our present thinking to have machines capable of such performance? A 10 000 MIPS number represents 10^{10} instructions per second. Assume that a user is willing to wait one second for an answer. A machine could, without any of the software complications needed in a shared-terminal teleprocessing system, cope with 10 000 users, each of them asking the machine to finish jobs that require a million instructions before it goes to service the next user. At these speeds, and with this organization, the entire concept of the employment of data-processing machines may have to be modified. I don't know that the theoretical limits that I have set here are indeed the limits, nor do I want to imply that it will ever be possible to achieve them even if they are. I do maintain that it is proper to ask the question, and that it is essential that we work toward finding an answer.

Two further points need to be considered regarding these figures. First, it is not clear at all that MIPS is a good figure of merit for a machine. Second, we have assumed present-day organizations without including such items as parallel processors or pipelining, and greater system-design sophistication will increase the figures by more than an order of magnitude. In addition, we have assumed that the increases in speed can occur not only in the logical devices, but in the memory and in other supporting circuits and equipment as well. Finally, we may have made some unwarranted assumptions regarding the organization of future designs.

Many questions need answers

We have also made mistakes in another direction; we have not allowed for submicrometer dimensions. We must remember that if we can ever go to dimensions corresponding to delays of the order of 10^{-14} second for the logic gate, we may have to consider physical limits, such as the uncertainty principle.

Still I wonder whether there will be limits before the kT limit that will preclude significant advances. Are we really that far from the theoretical limits? Do we have that much growth ahead of us? In designing a system, should we predict a technology growth rate far higher than those rates based on extrapolation of past performance? These are key questions that need to be answered.

I remember being present at the IRE Convention at which Shannon announced his law for the first time. I remember quickly computing with his formula how close a particular communication channel was to the theoretical limit—and finding that it was about a factor of 400 below that theoretical limit. In past years, our channels have come very close to the Shannon limit, and it would not make very much sense for anybody to try to gain the last increment of capacity. If we did not realize this we might waste a lot of time. Why is it that we don't have similar general relationships in computer design?

I am concerned to find that with all our capabilities in complex data-handling problems, we have only very recently ascertained the minimum number of logical levels required for addition. We are functioning in our data-processing environment with limited vision, learning mainly by experience within a particular set of existing conditions. The brilliant intellectual conquests of von Neumann, Turing, and a few others, must be considered as examples to follow.

Quite aside from whether we are or are not approaching fundamental limits, we should be able to characterize all our system designs and performance factors in a general and meaningful way so that we can perform the necessary trade-off exercises. Obviously, trade-off's are required in areas of system work and yet we are pretty far from a satisfactory capability today. I am not sure that we have acquired the level of breadth, perspective, and judgment necessary to tackle problems at this level, particularly since I am not only including machines, but applications as well.

We have methods for examining applications, proceeding from mathematical formulation through numerical analysis and flow charting, and procedures for determining the types and amounts of input and output data and data-processing requirements. Yet, we have not really learned, in general, to characterize the problem formally so that we can predict mathematically the optimum system for a particular problem. We do not have mathematical tools to examine the trade-offs between various approaches and changes in parameters; for example: What should the software be and what do we put into hardware? How large should each memory hierarchy be? How many levels should we have? When do we consider multiprocessing? How should we structure it? Erroneous answers to these questions can have a profound impact on many of our systems.

What type of organization should we use? If we could write algorithms, hardware, and software in the same language, it is conceivable that we could make trade-offs by giving general rules for optimization, which are not dependent upon implementation. Of course, we always include cost and performance in our analyses. In many ways we are quite successful, because our people are competent and have a very good intuitive knowledge of the issue. But I am not really satisfied with our accomplishments.

Even in the areas where we think we are pretty good, we have weaknesses. In circuit design, for instance, we have not seriously tried statistical approaches. In addition, we

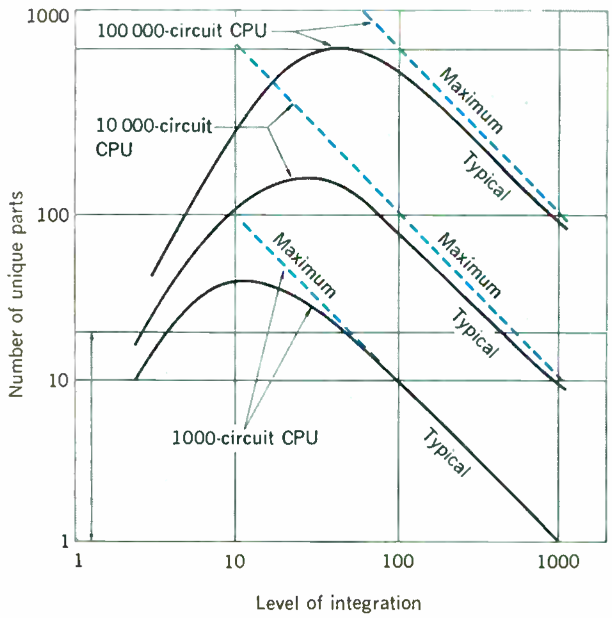
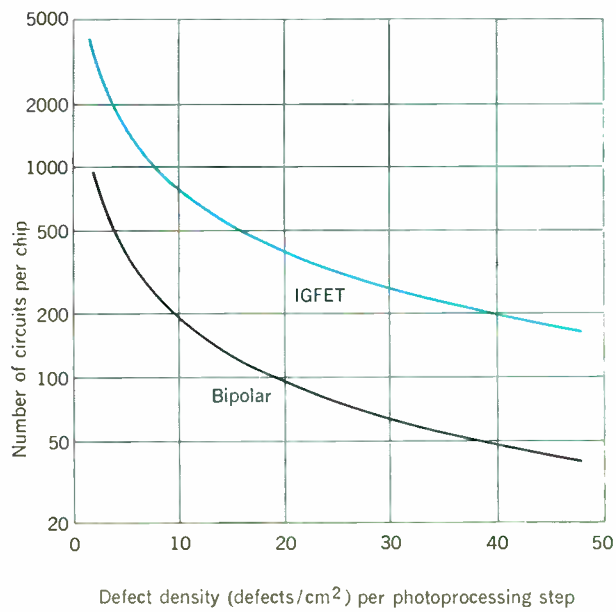


FIGURE 4. The part-number problem (CPU = central processing unit).

FIGURE 5. Integration level for a 20 percent chip yield (photoprocessing defects only) for bipolar and insulated-gate field-effect transistors.



try to forget the fact that high-performance systems constitute highly complex microwave problems. A system may have tens of thousands of nodes, each one different, complicated by a wide variety of loads, stubs, and other discontinuities having a variety of lengths and terminations, including nonlinear loads. None of these can be precisely specified prior to the completion of an extremely exhaustive study of the physical layout. Can we continue to apply a semiempirical design process or will we be compelled by our own success to pause and reset the theoretical basis of our work?

Since we are dealing with very complex problems, we cannot really expect to have a comprehensive and all-inclusive equation of all possible parameters ranging from material properties to applications. This is obviously impossible, so we tend to be happy with the little that we do, but I'm not sure that I can be happy with it. I think we should learn to break up the problem, identify the dominating and fundamental parameters in more detail, and thus reduce our problem to a comprehensible form. I am sure that we would all be embarrassed to know, in our multibillion-dollar solid-state industry, how few people there are who are really trying to pull the whole theory together with all the trade-off problems that are essential to this design—and very few people are identifying and promoting the generation of the necessary fundamental parts of the theory.

The importance of LSI

A substantial part of solid-state technology is concerned with LSI. What is the system impact on LSI? Since the influence of the circuit cost on the ultimate price of a machine is relatively small, a reduction in the circuit cost, even by an immensely large factor, would have little influence on the price to the user. Thus, unavoidably, we will find engineers making use of LSI, not to reduce prices, because they cannot, but to increase capability. And among the capabilities, of course, reliability is one of the most important.

We have assumed low-cost circuitry, and perhaps one can hope that a fantastic reduction in the cost of semiconductors will provide the motivation for the necessary efforts in supporting areas. When will we see people reducing the price of the associated costs (per circuit), such as the cost of generating the layouts and of testing the circuits, packaging them, and, especially, powering them and cooling them? Unless these costs decrease in the same time scale as our semiconductor progress, the effect of LSI will be essentially negated.

Many of us may think that the reason we cannot reduce some of the other costs more significantly is that many hardware components are already much farther out on the learning curves. But I am convinced that this is not so. I think that in many instances we do not devote the resources and intellect to these problems that we devote to the semiconductor aspects. It is a matter of fad, personal taste, and community impact. The interest of the researcher in these areas is not intense because he feels that he is not working at the very forefront of the technology. Of course, there are good reasons why we cannot reduce associated costs. Many components have less uniformity and commonality when we get further from the semiconductor chips, and effort is diluted. On the other hand, I believe it would be technically possible to standardize to fewer component types. For instance, even in the input-output area, we could create a substantial volume if we could do a better job of analyzing all the necessary technical and human factors.

I have heard some people say that if all our components could be converted to solid-state (particularly to semiconductor) components, they would attract the necessary attention. Is it always necessary that research and development people be so heavily influenced by the human desire for conformity?

Another limitation that I would like to consider is a subject that has been discussed a great deal—the part-number problem in LSI. Figure 4 is a rather common representation of what happens to the number of different parts required as a function of the level of integration and of the size of a machine. With certain additional assumptions, the situation in Fig. 4 indicates that the total number of unique part numbers the industry may require for a typical group of different machine types may be as large as 100 000. Can machines be designed to reduce part numbers? Certainly, the hope of reducing part numbers by using extra circuits must be bounded by how much we can waste this way and by the fact that competitive non-LSI approaches, without waste, will prevent this trend from going too far. Would system reorganization be useful to reduce part numbers or might this prove too wasteful?

The problem of generating a new LSI part or a change in a part is much more than just cost per se. The turnaround time becomes an essential element of the picture. Can we set up a manufacturing facility that is optimized for both fast response and low cost? Or should we expect to have two facilities—one for low-cost large production and one for high-cost fast turnaround time?

We must realize that LSI requires a level of process control that may be beyond what we have realized up to now. Figure 5 shows, for instance, the required density level of defects necessary to achieve high-level integration. In this diagram, defects include any defect in the photoprocessing steps. It was assumed that a defect would have a maximum size of two mils and that the number of defects increases more than proportionately to the decrease in defect size. The illustration shows the limits of the level of integration at which one can achieve 20 percent chip yield, assuming no other defects. On the basis of present experience, we would expect, unfortunately, to be on the right side of the curve for both field-effect and bipolar transistors. How far can we expect to go to improve technology? And beyond the yield question, are we going to increase the number of circuits and, at the same time, increase the reliability, or are we not?

Conclusion

The solid-state engineers have pushed so far, so fast, that their empirical ability has outdistanced their theoretical interference. The theoreticians should be encouraged to review the basis of their work. We should try to examine all the items that, from a system point of view, limit our capabilities in cost/performance, in density, in speed, in yield, and so on.

I hope that the limits are far beyond our present level. If this is so, as it may well be, our present technology has a long road ahead for further improvement.

Revised text of the keynote address by Dr. Fubini at the 1967 International Solid State Circuits Conference, Philadelphia, Pa., February 15–17.

Practical experience and engineering education

Myron Tribus — *J. Herbert Hollomon*
L. A. Zadeh — *Thomas F. Jones*
Ernst Weber — *R. H. Lyon*

There have been many changes in the practice of engineering education in recent years, in large part leading to a more scientifically and theoretically trained graduate but one less familiar with the real world of engineering practice. At least two articles have appeared lately in IEEE SPECTRUM (Harvey Brooks' "Dilemmas of Engineering Education," Feb., pages 89–91, and Aaron J. Teller's "The Philosophy of an Engineering Educator," Mar., pages 124–128) that raised a red flag and either described or suggested programs intended to provide a more realistic and practical experience for the engineering student.

In order to give our readers a wider sampling of opinion on this subject, several leaders in education, government, and industry were asked to present their pertinent thoughts in a written panel discussion, or collection of short essays. Each was furnished with a preprint of Dr. Brooks' article with the suggestion that he direct his attention to the question: "Is more industrial involvement or practical experience important to engineering education and, if so, how can this best be implemented?" The resulting observations, with some afterthoughts, are rather interesting.

The comments by R. H. Lyon actually constitute the concluding section of his paper on "The Training of Engineers," which he offers to make available to our readers on request.

C. C. Cutler

Myron Tribus

Dartmouth College

Myron Tribus, dean of the Thayer School of Engineering at Dartmouth College, Hanover, N.H., received both the B.S. and Ph.D. degrees from the University of California at Berkeley. He joined the Dartmouth staff in 1961 after serving as a member of the faculty of the University of California at Los Angeles. A 1952 Alfred Noble award winner, he was writer and host of the CBS television series "Threshold" in 1958.

The article by Dr. Brooks throws into sharp focus a very difficult problem that will soon face schools of engineering as they move to strengthen their ability to offer meaningful education in the design aspects of engineering. The conflict is essentially one between academic and professional value systems.

Academic values are centered around the university cultures: the world of ideas, the discovery of new relations, the understatement, the unraveling of logical inconsistencies, the abstraction of problems, the conceptualization, the attempt to find the invariants, the concern for timeless issues. Members of this community are apt to regard themselves as "called" to their profession and until recently could point to their smaller share of the gross national product as evidence of the sacrifices being made for the noble cause of education. The academic community does not identify with industry and commerce. Its spokesmen often give the appearance of believing that the commercial world is inherently evil and that they have a major responsibility to so prepare their students that they will not succumb to the temptations therein. Academically oriented professors will point with pride to a student turned poet but not to a student turned financier.

Professional values, on the other hand, are centered around the industrial culture: the world of products, goods, and services; the invention of new techniques for using or exploiting resources; the reach toward socially significant and visible progress, the accomplishment attained in spite of ignorance, the synthesis of form and system even when improperly or inconsistently conceptualized; the concern for temporal affairs, the *here* and *now*. Members of this society are apt to regard themselves as the men who make things "go," the "doers," the "spark plugs" of the social system. They see themselves as *responsible* for the gross national product. They are proud to be "where the action is," and when they can, they bring it with them to the campus. The professional community believes that the evils that occur in the commercial world are no different than those that occur anywhere else, even in academia, and they treat the problems of ethics with much less emotion but no less honesty than their academic colleagues. The professionally oriented professor is proud of a student's patent. He is less impressed by publications and degrees.

Ogden Nash once remarked in one of his poems that there are two kinds of people in the world: those who arrive at the railroad station just as their train is pulling out and those who go to the station at least a half hour early and sit in the train waiting for it to leave. He wisely commented that both types can be happy but that they should never marry one another!

The same difficulty occurs in institutions of higher learning. Both kinds of people are capable of finding satisfaction in education but it is extremely difficult to mix them together in common cause. Yet it seems to me that the future of engineering education requires that we learn how to enable these two distinguished types to get along with each other. Few professors belong entirely to one school of thought or the other but they do tend to plan more of their activitives in one of the areas.

Engineering education needs both types and it seems to me that the professional societies can play an important role by expressing their concern in tangible ways to see that an appropriate balance is maintained in our schools of engineering. I doubt that the job can be done entirely from within the walls of the university.

L. A. Zadeh

University of California

L. A. Zadeh (F) was born in Baku, Russia, and attended the American College in Teheran, Iran, the University of Teheran, and the Massachusetts Institute of Technology. He joined the staff of Columbia University and received the Ph.D. degree in 1949, and in 1956 he became a member of the Institute for Advanced Study at Princeton. At present he is head of the Department of Electrical Engineering and Computer Sciences, University of California, Berkeley.

In his thought-provoking article, Dean Brooks presents an incisive analysis of some of the serious dilemmas facing engineering education today. Related to these dilemmas is a set of basic and intertwined questions that beg for answers: To what extent should engineering curricula be oriented toward the immediate needs of industry? What role should industry play in continuing education? What should be the relationship between industry and the universities? Obviously, these and similar questions do not admit of simple and universally valid answers. Nevertheless, they must be posed and answered, at least in part, in order to clarify the goals of engineering education.

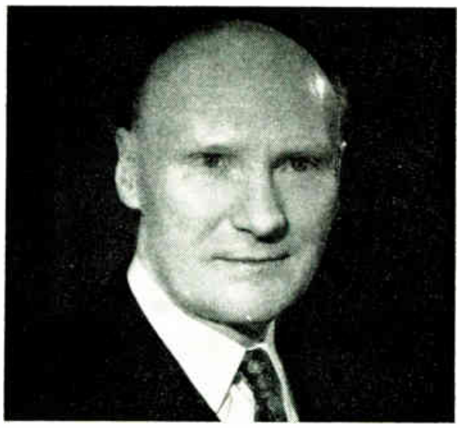
Before expressing my views on some of the issues in question, I should like to observe that most of the problems presently confronting engineering education are traceable to the abnormally rapid technological progress of the past two decades—progress brought about largely by the efforts of competing world powers to maximize their military capabilities. Certainly, our technology would be far less advanced today if the Department of Defense had not expended tens of billions of dollars since the beginning of World War II in support of research and development in industry and universities.

Traditionally, engineering has been associated with "know-how," whereas science is concerned with "know why." Naturally, in times of rapid technological change, know-how loses much of its value—and it is this devaluation that explains the profound changes in engineering education that have taken place during the past 20 years. Chief among these changes is the marked shift in emphasis from practice to theory in engineering curricula, the blurring of the dividing line between engineering and science, and the large increase in the number of Ph.D. degrees awarded by engineering colleges (417 in 1948–49, 2350 in 1965–66).

Changes are particularly apparent in electrical engineering, which is without doubt one of the most rapidly evolving fields within engineering and science. As an electrical engineering educator, I am naturally very conscious of the difficult problems that the rapid evolution of electrical engineering is posing in regard to the content and objectives of electrical engineering curricula. What should we teach our students? Should we stress basic subjects in mathematics, physics, chemistry, mechanics, etc., subjects that are likely to be of long-lasting value but do not prepare the graduate to do engineering work in industry? Or should we stress current technology at the risk of providing the student with information that is likely to be out of date by the time he receives his degree? Clearly, we should do both. Thus, the real question is: In what relative measure?

It is here that I believe the need arises for re-examination of the traditional roles of engineering colleges and industry. Specifically, I believe that an industrial company should not regard an engineering graduate who enters its fold as a finished product, ready to perform useful engineering functions. Rather, he should be regarded as a young man with a good basic education who needs additional specialized training while in the company's employ to become a fully qualified engineer. In effect, this means that engineering education should be a divided responsibility, with the engineering colleges mainly providing the basic part of it and industry mainly the specialized part. The latter could be done through on-the-job training or by releasing the employee to attend specialized courses or otherwise continue his education at an academic institution. In any case, continuing education should be accepted by industry as an important, indeed indispensable, activity of an engineer employee; it would not be unreasonable to allow him to devote as much as 20 percent of his time, on the average, to study.

Essentially, what I am arguing for is the adoption on a wide scale of what is currently practiced by only a few enlightened and rich companies on a rather limited scale. We, as engineering educators, could do a much better job of training our students if we could assume that most of them will continue their studies in specialized or even basic subjects for a long time after they receive their degrees and become employed by industry. It is high time that industry, in its own interest, pay more than lip service to the cause of continuing education and take concrete steps, in partnership with educational institutions, to make it a reality.



Ernst Weber

Polytechnic Institute of Brooklyn

Ernst Weber (F) received the Ph.D. degree from the University of Vienna in 1926 and the D.Sc. degree from the Technical University of Vienna in 1927. He began his career with the Polytechnic Institute of Brooklyn as a visiting professor in 1930. After serving in various posts, he was named acting president in 1957 and later assumed his present position as president. He was elected IRE President in 1959 and IEEE President in 1963.

Engineering education does need to relate to technically oriented industry. This does not mean that the graduate of a four- or five-year engineering curriculum should be able directly to contribute finished design methods or system analysis upon joining industry, but he should be a willing and very *capable* learner of the methods of the industrial organization he joins and he should retain an open mind so that he can contribute new approaches and refinements based upon his broader understanding of principles as gained at school.

How can the engineering faculty be kept in tune with the significant problems in industry and the advances looming in technical development so as to transmit to the student an engineering "feeling" for art of design and for methodological approach? The two most potent ways are (1) meaningful contacts in industry through consulting engagements and (2) appropriate broad research programs at the university that lead to exchanges with industrial colleagues. Both alternatives become more effective if faculty members are required to have direct industrial experience, either for several years before joining the university staff, or by taking a leave of absence for a year or so while they are serving as instructors or assistant professors.

Obviously, the practice of true engineering is a behavioral attitude just as the practice of scientific research is. And attitudes are matters of personal inclination that can only be bent, not created. It is, therefore, most important to make the proper selection of faculty.

J. Herbert Hollomon

Acting Under Secretary of Commerce, U.S. Department of Commerce

A biography of **J. Herbert Hollomon** appears on page 78 of this issue.

Harvey Brooks touches upon a dilemma that has long interested me, and consequently I am happy to make some observations on the subject. He expresses the dilemma of the engineer in the engineering school in two rhetorical questions and several statements: "Who is he and what is he? Where does he come from, and how is he trained? I must confess that here the medical profession has a happier situation, at least in theory, than does the engineering profession. For the teaching hospital provides a natural meeting place for the clinician and the basic scientist, for the student and the practitioner, for which there is no effective counterpart in the engineering school. The basic problem is that, contrary to the situation in the pure sciences, the real professional environment of engineering lies in industry or government."

I agree, and I see ways in which the problem may be handled. Let me set down some aspects of this basic problem and then suggest one way out of the dilemma.

Science and engineering in our society

Science and technology have important significance in our contemporary culture and will have even greater significance in the future. The interplay of science and technology with each other and with the modern world in general has encouraged the interaction among the various engineering specializations, the sciences, and the humanities. Science and engineering, already interdependent, are becoming even more so, yet in most universities there is a separation between science and technology, on the one hand, and the humanities, on the other.

Science is tending toward the study of ever-more-complex systems. Not surprisingly, systems studies increasingly involve interaction between traditional fields such as biology and physics. Engineering and technology also are changing rapidly. Those most successful at developing and using science and technology during the next decade will be those who continue their education.

Estimates of the number of engineers and scientists to be needed vary, but their ratio to the total nonagricultural wage earners will increase. The types of engineers needed by a society depend on its phase of development: the resource-based phase, the converter phase, or the complex systems phase. The United States is in the advanced systems phase whereas the undeveloped nations are for the most part in the first or second stage. In the United States and abroad, engineering education is needed that will provide training in all these phases.

Future engineers will fall into two overlapping classifications. Those in the first category will be not too dissimilar from today's engineers. Their training will be discipline-oriented, but the engineering itself will change because new disciplines will emerge. Engineers in the second category, which I call socially oriented, will have less training and skill in a given discipline. They will be able to work in many phases of complex engineering problems that cut across particular skills. The results of their work will be imaginatively designed products and services useful to people, industry, and society.

Thus the present and future engineer needs a basic understanding of his culture and society, as well as his technical discipline, both of which he can acquire from his university.

Engineering education

As a result of the advances in science, the changing needs of our time, and the development of new tools, engineering education is undergoing rapid change. Engineering education is seeking new goals, techniques, and methods.

This quest for quality in engineering has accompanied a decline in quantity of engineers. For the nation the undergraduate registration in all other fields has risen sharply since 1959 whereas that in engineering has remained relatively constant. The percentage of freshman engineers has shown a steady decline since 1957. The reasons for this relative decrease in engineering enrollment are not obvious, and there are no indications that the trend will change. The number of engineering degrees, at the bachelor's level, awarded by public institutions is increasing compared with the number awarded by private institutions. The number of students enrolled in graduate schools is increasing very rapidly. The number of Ph.D. degrees awarded in engineering throughout the nation is growing at a very fast rate. The idea of a basic engineering core curriculum lasting the first two, three, or even four years is gaining acceptance. The current trend is toward a graduate degree as the first professional degree in engineering. Many educators and engineers feel that this should be the master's degree; others believe that the doctoral degree should be required. Graduate engineering education is following the sciences by becoming more specialized in professional function.

Where is engineering's clinical practice?

The total educational system of a country is the fire in the boiler that makes the country travel at the speed its people want it to travel. Engineering education is only a part of the total educational system. It should borrow freely from the other parts, as Brooks implies when he deplores the absence of an engineering internship, with "clinical practice" analogous to that of the medical profession. He cites M.I.T.'s Lincoln Laboratory and Instrumentation Laboratory as having some of the educational value for the engineer that the teaching hospital has for the physician.

There are, of course, other institutions, such as the School of Engineering at Dartmouth College, that offer students clinical-type experience in dealing with real-life problems, but there should be more. Support for engineering education at the graduate level should include support for students to build experimental computers, crashproof vehicles, buildings, and systems of various kinds. I'm sure any engineering school could get serious consideration for a grant from the National Science Foundation, any of several major philanthropic foundations, or even from local industry, for a program offering students experience in real or realistic problems. I would like to see this kind of demonstration of the application of graduate engineering education principles tried at a number of schools.

If such a program could be devised and funded, projects might be carried out in a profit-making engineering organization such as Houston Research Institute, which is owned by the University of Houston. Projects also might be carried out in industry, or in a contract research organization such as Arthur D. Little, Inc., or, quite appropriately, they might be conducted within the engineering school itself, on the university's own technical problems. Why shouldn't engineering students devise a campus traffic control system, or work on the parking problem of an institution such as the university of a hospital? And speaking of hospitals, why shouldn't students try to design patient-monitoring or laboratory work-flow systems that improve on what the hospital now has? A university has all the complex management science, supply, logistics, and housekeeping functions that a hotel or a city of comparable size has.

The university is the institution, the "community," if you please, whose function is education. It also forms a ready-made laboratory for the real-life practice of engineering techniques. If the university is providing proper leadership in education, it should welcome the opportunity to extend clinical practice to the engineer as well as to the medical student.

Thomas F. Jones

University of South Carolina

Thomas F. Jones (F) became president of the University of South Carolina in 1962 where his particular interests have included curriculum reform. He received the bachelor's degree from Mississippi State and the master's and doctor's degrees from the Massachusetts Institute of Technology. He became a member of the M.I.T. faculty in 1947 and headed the School of Electrical Engineering at Purdue University in 1958–62. His memberships include the National Science Board.

Near the end of his article, Dr. Brooks tries to suggest practical ways of bringing engineering education closer to reality by arranging an educational experience that is more than an academic exercise. He tries to suggest some way of providing a case study of design or research that is not *just relevant* to the present, but *is* the present. Any possible method of achieving this end will greatly enhance engineering education.

It is my impression that in the past 30 years just about every kind of university–industry joint effort for the education of engineers has been tried. No one effort has been so obviously superior as to gain universal acceptance, or even broad acceptance. Yet, the very survival of several modes of cooperation indicates that both education and industry have adjudged those modes to represent "three-way streets," with value to the student, to the educational institution, and to the industry. On the other hand, neither education nor industry has clamored very loudly for new or expanded or broader relationships.

The question of industrial involvement in education is especially timely because the technological explosion has already brought about a revolution in the university—basic science and mathematics are in; applications and extensive design are out.

Suppose we try an engineering approach to the problem of developing effective engineers. Let us set up specifications, and try to devise a system, or systems, for meeting them.

1. We want an engineer to have basic knowledge relevant to learning the things he will need to know and relevant to the practice of his profession.

2. We want him to develop skill in determining what new knowledge is relevant to achieving engineering goals assigned to him, and in mastering that new knowledge.

3. We want a system that allows each engineer trainee to get any new knowledge that he needs when he needs it. This means that training can't be in lockstep unless projects are—but things just don't work that way.

4. We want a creative outlook because broader utility or function may be achieved and/or cost may be reduced.

5. We want the engineer trainee to so schedule and direct his efforts that a useful and economic end is achieved, with economy, and in a reasonable time.

Let us assume that the first specification is being met, and let us further assume, perhaps falsely, that it is being met adequately and efficiently with room for only minor improvement. (These assumptions will provide adequate employment for the years to come to those faculty members who smugly resist change!)

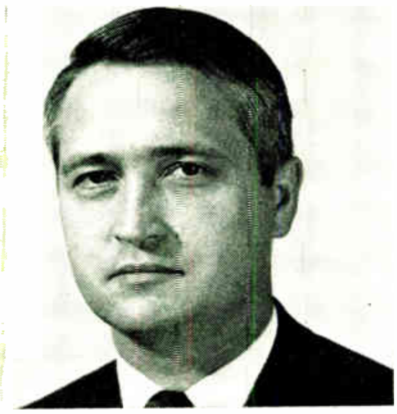
The second specification depends largely on selecting the right persons to be engineers (but we don't really select persons to be engineers; instead, persons choose to be engineers). Nevertheless, we all must agree that apprenticeship to a man who is a master at determining what new knowledge is relevant to achieving engineering goals assigned to him, and the mastery of that new knowledge, would be greatly beneficial to any trainee. On the other hand, apprenticeship to a man who was neither so gifted or trained would be of little value. True masters are in short supply and very busy because they are very valuable to industries who are insisting on getting things done. If we are to increase the supply of these people above the number who "just seem to have it" we will have to divert some of the effort of the existing seasoned ones to "seed corn," in other words, to training other "masters."

The third specification poses a problem. Obviously we can't afford to assign a $20 000 professor, or even a $4000 graduate assistant, to teach electromagnetic waveguides, or Fermi surfaces, or physical chemistry, or switching circuits to a trainee at the very moment he requests such instruction. However, this is what seems to be specified, for when the need to know arises the trainee should be able to find his answers at once. At this point we realize what a blessing the invention of the book has been. But books can be tedious, tiresome, and frustrating without a tutor, instructor, or other aids, and, as previously noted, a tutor or instructor is likely to be too expensive to be much available. This is where programmed instructions, video tapes, and teaching films (and very soon the computer as a teaching aid) offer great possibilities. Although sizable investment in such teaching aids seems warranted, the slow development of really good material reflects two things: (1) Most outstanding technical minds consider themselves too busy to bother with "games." (2) The development of these aids for the high level of technical competence to which we here address ourselves is not yet profitable. This can be paraphrased by saying we are not willing to designate top-flight men as "seed corn" in this area, and that we are really waiting for usage to develop naturally—"a chicken and egg" situation.

Specifications 4 and 5 resemble specification 2. It is best to be born with creative ability and ability to organize one's work, but anyone can improve by working with a master. However, gifted masters are in short supply and much in demand. Again, if we are to really increase the supply we must divert some of the masters' efforts to "seed corn."

In summary, we can, with our present technology, synthesize a system for "manufacturing" engineers. The system would utilize both university and industry, with the latter providing a rather new kind of work experience in that the young engineer trainee would have to be assigned to the best performers in the industry. In order to minimize delays in reaching engineering goals, the process of finding and learning new mathematics, new sciences, or new technology, at the very time they are needed, would employ new and emerging teaching technologies. The cost to industry might prove to be substantial, but on the other hand, the gains might well exceed the wildest hopes.

The era approaches when learning of even very sophisticated and technical material may be achieved by the average engineer with the proper aids in a fraction of the time and effort required by a man alone in the past. Although what has been proposed here is certainly not a unique solution for educating engineers, I hope that it stimulates educators and industrialists alike (1) to explore the impact of new communications systems and teaching aids on engineering education, and (2) to examine the way in which young engineers are assigned initially. Are we planting the optimum amount of seed corn? Do we really think and act in terms of the long view—beyond the retirement of the present section head?



R. H. Lyon

Bolt Beranek and Newman, Inc.

R. H. Lyon received his Ph.D. degree from the Massachusetts Institute of Technology in 1955 and was a National Science Foundation postdoctoral Fellow at the University of Manchester, England, in 1959–60. He has been associated with the firm of Bolt Beranek and Newman since 1960 and is currently vice president and associated division director for physical sciences. He is a Fellow of the Acoustical Society of America.

The great change in engineering curricula after World War II resulted in the addition of many new courses and the formation of new academic departments in mechanics and materials, applied science, and engineering science. To some degree, these movements attempted to find scientific fields common to all branches of engineering—such as fluid and continuum mechanics and solid-state physics—and to teach these to students interested in all forms of engineering. This approach is natural to a science-minded faculty and has resulted in a better scientific background among engineering students. It has not been very helpful in developing within the student the "art of the particular," which is central to good engineering practice. As the courses become more basic, they become more general, and the student must integrate these technical concepts into a package consistent with his professional goals. He has even less time or opportunity then to concern himself with the nontechnical areas involved with being an engineer.

How can the school experience give the student a more integrated and professional view of his chosen field? Should we copy the earlier period and institute new sets of courses or perhaps generate new departments? There may be a place for such action. In dealing with highly complex problems of business judgment, the Harvard Business School several years ago borrowed the so-called case-study method from the law schools. This format has now achieved wide popularity in business courses. Perhaps case-study courses in engineering would help the student to integrate the viewpoints of the diverse disciplines that he must cover. The Engineering School at Stanford has been spearheading an impressive attempt to develop a library of engineering "cases" for use in such courses.

Another development has been the rise of the "systems engineer." In that field, great emphasis is placed upon the accounting for time and costs and technological state of the art, for the purpose of developing a strategy for the timely and successful completion of a complex engineering project. Should we then have departments of aerospace systems, transportation systems, urban systems, etc.? There is certainly room for courses in systems engineering but academic "systems" departments would not serve to define the student professionally. Systems engineers are notoriously peripatetic and generally have only marginal allegiance to any particular technological field. An overemphasis on systems might weaken the very desirable gains that have been made in the scientific and mathematical training of engineers.

The growth, since World War II, of a highly technical portion of industry has led to a new phenomenon. It is probably fair to say that now a greater development of new engineering methods is taking place within industry than in the university. Each industry has always trained engineers in those aspects of technology peculiar to itself, but I do not believe that it has ever done so in the United States on so large a scale. But training is not a primary function of industry. In many cases, industry is not suited to the job because of the pressures of productivity, schedules, and costs.

I believe that the best long-term answer is an amalgam between the engineering school and industrial activity. Engineering is a vocation that does not have significance apart from its professional practice. The courses in shop and foundry practice existed because engineering is vocational. But we do not want those courses back. Engineering practice should not be immobilized within a curriculum. It should be learned and exercised in an environment that forces the practice to change when it is no longer pertinent. Students and faculty cannot share this experience in a classroom but that does not mean it should be denied to them.

There are already some movements toward a more intimate relationship between the practice of engineering and the university. One idea is the "engineer in residence," in which practicing engineers are brought into the university. Unfortunately, when they arrive, they may be asked to teach seminars and classes and participate in academic research—in short, to become professors! I believe these engineers could be more effective if they were to continue with their regular engineering work, using the campus as a base of activity. Their obligation to the university should be to get students and faculty members involved in real-life engineering projects.

This does not mean that we should discourage practicing engineers as part-time faculty. Rotating professorships (alternate years in industry and at universities) and student cooperative programs have beneficial effects on the student's (and professor's) professional development.

Technological industries also hire faculty and students on a part-time basis. Many faculty members consult on a regular basis or they may participate in the operation of a small company in which they have an interest. Such activities benefit staff members and students, but usually only the more senior men and relatively few students have an adequate opportunity to participate.

Even the welcome consulting activity that involves one in outside work is frequently merely an extension of the faculty member's research work or it is so peripheral to the total engineering job that little experience is gained in the nontechnical aspects of the problem.

What kind of institution should we seek to realize this amalgam? The "not-for-profit" organizations that are associated with many universities are a partial model for such an enterprise, but a large part of their effort is traditionally in basic research, which has relatively little content of scheduling, communication, and policy aspects of engineering. However, a selected group of faculty and students has a chance to participate in engineering problems. A better model is the Institute of Sound and Vibration at the University of Southampton, England. In this organization, the staff is encouraged to carry out commercial consulting as well as sponsored research. A teaching program is also maintained as a part of the institution's regular activities. During its existence, the Acoustics Laboratory at M.I.T. had a similar spectrum of activities.

By far the best model of what I am proposing is the university hospital as it relates to the medical school. Let's call its engineering counterpart an "engineering institute." Participation in the institute activities on a scheduled basis would be a requirement for a professional degree in engineering. Faculty members would be on the institute staff, but the institute would have an additional staff to handle day-to-day operations. Finally, the activities of the institute would be on a "paying basis," made possible by its sale of services, consultation, and research to the industrial and commercial community.

The existence of an institute integrated with the academic departments might well make it easier to hire younger staff members into the university at an age period when the differential between industrial and academic salaries is the greatest (to the disadvantage of the university). The institute should also impose requirements on both students and staff to do a job within the limits of time and money. It would thus develop attitudes that would produce better preparation for an engineering career.

I believe that the engineering schools must come to terms with the vocational requirements of their students and must develop institutions that will unite the faculty and student in an effort toward professional excellence in the broadest sense.

The comments indicate unanimity on the existence of a problem, but less certainty as to what can be done about it. The solutions range from requiring industrial experience as a condition for faculty promotion to the creation of industrial institutes for "clinical" engineering practice of faculty and students.

Although the teaching hospital is frequently cited as the prototype of the ideal pattern for "clinical" education in the professions, it is evident from conversations with colleagues in other professions that this is not a complete solution. The medical profession appears to be torn by the same struggle between disciplinary and professional orientation as the engineering profession. Furthermore, there are deep-seated conflicts between the service mission of teaching hospitals and their educational mission (see *The Teaching Hospital*, edited by J. H. Knowles, Harvard University Press, 1966).

The use of the "case" system seems to be on the way out in many business and law schools, and it is being replaced by much more emphasis on relevant disciplines, with an increasing proportion of academic specialists on the faculty.

Economics is a formidable barrier to the introduction of industrial-type experience into engineering. An associated problem is the increased emphasis in industry and elsewhere on problem solving by expert teams rather than individual practice. Clinical activities are increasingly difficult to finance on an educational basis alone, but must be economically viable in their own right. Students must have a chance to learn from their mistakes, but such mistakes are difficult to tolerate when time schedules and cost criteria have to be met. Furthermore, the type of quasi-industrial institute suggested by Dr. Hollomon runs into severe criticism on the grounds of "unfair competition" from industry and private consulting firms.

Harvey Brooks

Bulk negative-resistance semiconductor devices

Negative resistance exhibited by bulk material, such as GaAs, makes possible new devices with high speed and power capabilities. These devices amplify and oscillate, and multi-input versions perform AND and OR functions

John A. Copeland Bell Telephone Laboratories, Inc.

Recent research on semiconductors that exhibit bulk negative resistivity has led to new devices for pulse regeneration, logic function generation, amplification, and millimeter-wave power generation. These are bulk devices in the sense that ac gain is derived from the bulk negative-resistance property of certain uniform semiconductors, rather than from the properties of junctions between different types of semiconductors. Bulk devices are capable of operating with more power at higher speeds and frequencies than conventional junction devices such as transistors.

During the past year the physics of negative resistivity, which appears in n-type GaAs, InP, and CdTe, has become much better understood, and the art of making high-quality GaAs and fabricating GaAs devices has advanced appreciably. The following sections will discuss the theory of operation and the electrical characteristics of a number of developmental devices, including those shown in Fig. 1.

Like charges attract?

The simplest device is a cube of uniform n-type GaAs with ohmic contacts applied to opposite faces, as shown in Fig. 2. When a small voltage is applied, the electric field and conduction current density are uniform throughout the diode. The current is carried by free electrons, which are drifting through a background of fixed positive charge, so no space charge exists within the diode.

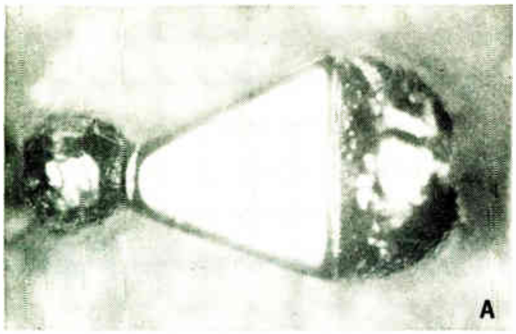
The positive charge, due to impurity atoms that have lost an electron (donors), is sometimes reduced by impurity atoms that have gained an electron (acceptors). As long as the fixed charge is positive, the semiconductor is n-type, since the principal charge carriers will be negative (electrons rather than holes). For simplicity, the density of donors less the density of acceptors will be referred to as the "doping." When there is no space charge, the carrier density is equal to the doping.

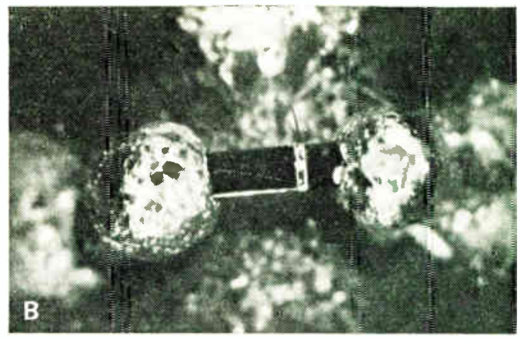
At low voltages, the GaAs is ohmic because the drift velocity of the electrons is proportional to the electric field (voltage/length of diode). Interesting things happen as the voltage on the diode is increased above threshold (about 3000 V/cm × length). The electron drift velocity now begins to decrease as the electric field increases, as shown in Fig. 3, and the material exhibits negative resistivity. When the field was below threshold, a group of excess electrons would disperse, because of electrostatic repulsion, until the negative charge density of the electrons was equal to the positive background charge density—that is, until the space charge disappeared. Above threshold, the excess electrons will not disperse, but pile up at a rapid rate as though they were attracted to each other. This piling-up process occurs because the increased electric field in front of the excess electrons now makes the electron stream slow down, and the decreased field behind makes the electron stream speed up.

Similarly, if there is a region in which there is a deficiency of electrons, so that the space charge is positive, the electron stream will move away from this region faster than it moves toward it and the deficiency will grow. This region may become completely depleted of electrons. As a result of the space-charge growth the diode breaks up into domains (regions) of high and low electric fields separated by layers of space charge that are parallel with the contacted faces. The space-charge layers drift with the carrier stream, which is moving at about 10^7 cm/s (220 000 mi/h).

History and physics

In 1961 Ridley and Watkins discussed the possibility of finding bulk negative resistivity in certain semiconductors, and Ridley later correctly predicted that due to the instability of space charge in such a bulk semiconductor, it would break up into domains of high and low electric fields, which would drift along with the carrier stream, producing oscillations.[1,2] Almost at the same time Hilsum predicted that bulk negative resistivity should exist in n-type GaAs and calculated a threshold field of 2800 V/cm, very close to what is now observed.[3]





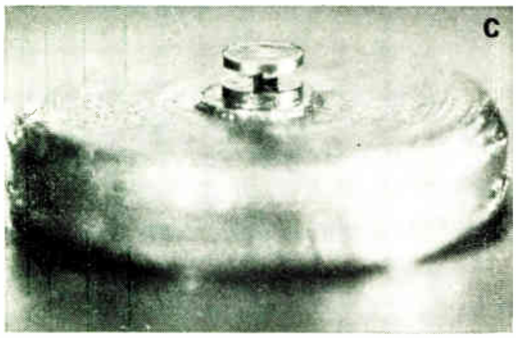
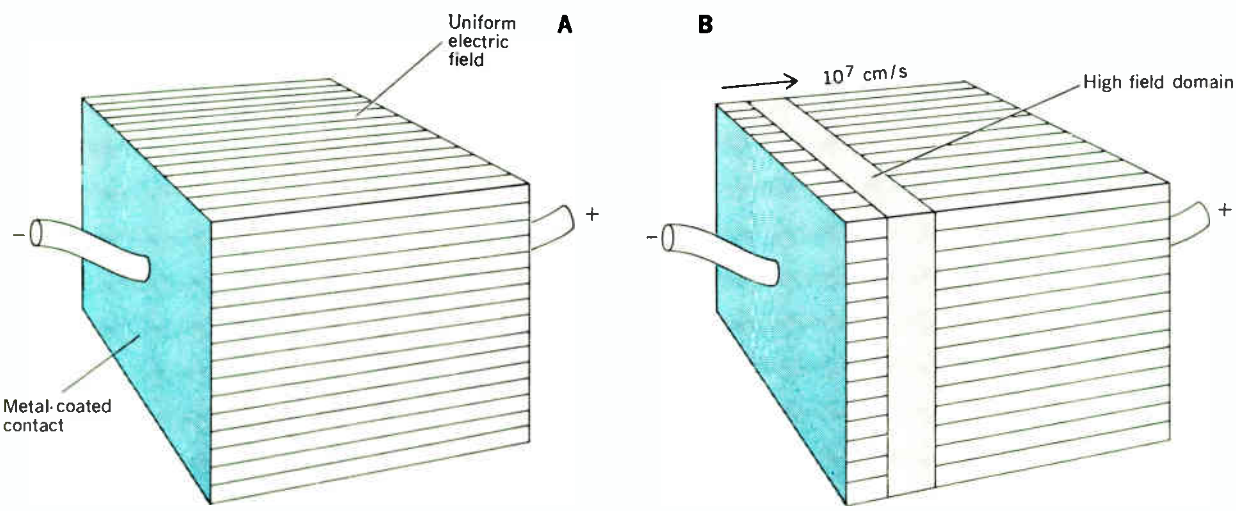


FIGURE 1. Bulk negative-resistance semiconductor devices. A—Sawtooth-wave-function generator and voltage-tunable oscillator. B—Three-terminal AND or OR logic gate. C—Epitaxial diode mounted on heat sink for 90-GHz LSA oscillator.

FIGURE 2. Diode made by contacting opposite faces of a cube of uniform n-type GaAs. A—When the voltage is below the threshold for negative resistivity, the field is uniform. B—Above threshold, a high field domain forms near the negative contact and drifts through the diode.



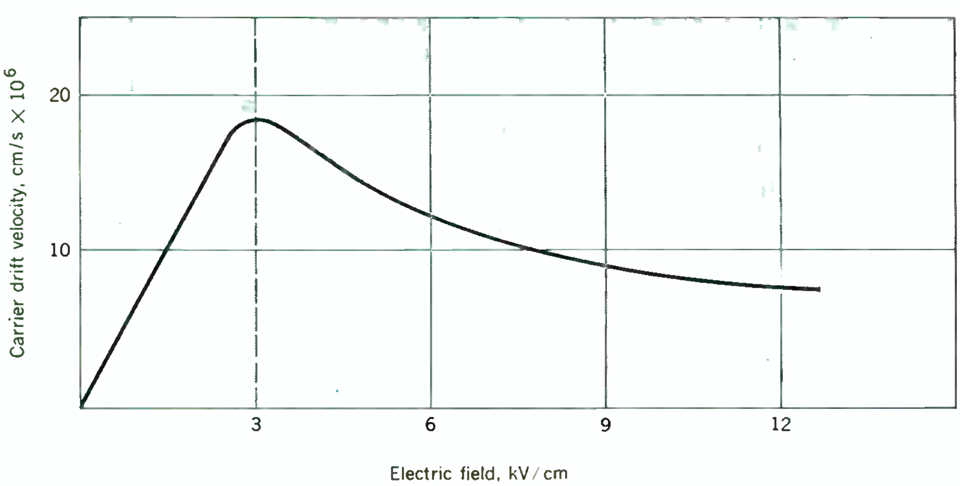


FIGURE 3. Drift velocity of conduction-band electrons in GaAs vs. electric field. The ac resistivity is negative when the electric field is biased above 3000 V/cm.

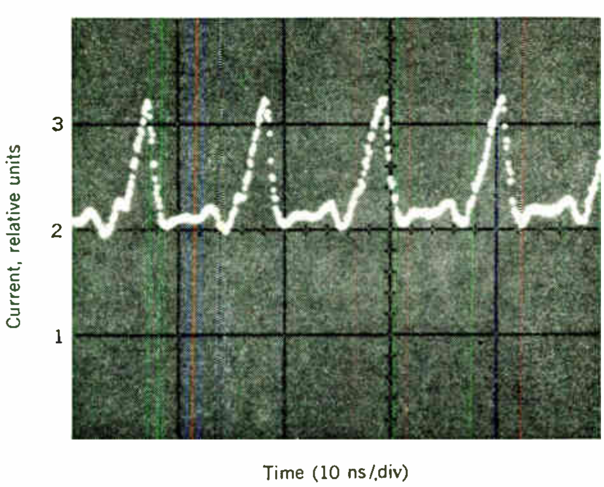
Two years later, while working on electrical noise emitted by semiconductors, Gunn observed that microwave noise powers of the order of a watt were emitted from GaAs and InP when they were subjected to pulsed electric fields of several thousand volts per centimeter.[4] When short samples were used (less than 0.2 mm), the noise changed to coherent oscillation at a frequency with a period close to the time needed for carriers to drift from one contact to the other (transit-time oscillation).

Gunn then developed an elaborate capacitive probe that plotted the electric field distribution within samples while they oscillated. These measurements showed that as the voltage was increased past threshold, a high field domain formed near the cathode that reduced the electric field in the rest of the diode and caused the current to drop to about two-thirds of the maximum value. The high field domain would then drift with the carrier stream across the sample and disappear at the anode contact. As the old domain disappeared at the anode, the electric field behind it increased (to keep the voltage, $\int E\,dx$, constant) until the threshold field was reached and the current had increased back to the threshold value. At this time a new domain would form at the cathode, the current would drop, and the cycle would begin anew.

A current waveform produced by this type of operation is shown in Fig. 4. The flat valley occurs as the domain drifts across the sample. The upward spikes begin as a domain reaches the anode, and a new domain forms at the cathode. The small current fluctuations in the valley occur as a domain passes through regions in the diode of varied doping or cross-sectional area.

At first, many explanations were considered for the phenomena Gunn observed, which soon became known as the "Gunn effect." The usefulness of the effect was immediately apparent, since the transit-time frequency of a 100-μm-thick diode was about 1 GHz, and diodes could be made thinner by an order of magnitude. In 1964 Kroemer pointed out that Gunn's observations were in complete agreement with the earlier predictions of Ridley, Watkins, and Hilsum, whose two-valley theory will be described in the next section.[5]

FIGURE 4. Current waveform due to Gunn-effect oscillations. Current rises each time a domain drifts into anode and drops again as a new domain forms at cathode.



The two-valley model

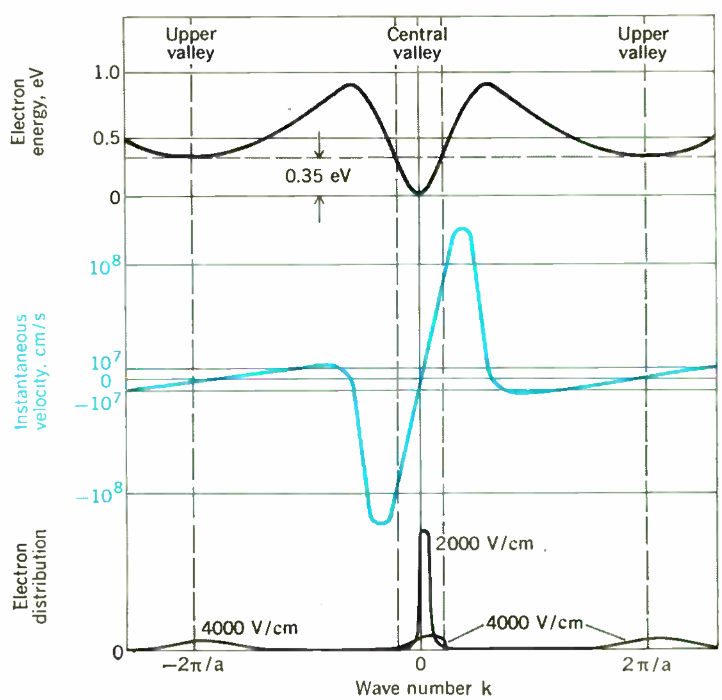
The physical model for GaAs that gives rise to the decrease in average drift velocity at high electric fields is depicted in Fig. 5. At room temperature with no applied electric field, almost all of the electrons are in their low-energy states ($\epsilon \lesssim 0.03$ eV) close to $k = 0$ (the wave number k plays an important role in the quantum mechanics of solids, but need not concern us here). Many electrons have instantaneous velocities of plus or minus a few times 10^6 cm/s due to their thermal motion, but the average drift velocity is zero.

When a small electric field is applied, the electron distribution shifts so that more electrons are moving with the electric field than against it (shown by the slightly shifted electron distribution for 2000 V/cm). The electron stream has an average drift velocity that increases with increasing electric field until the fraction of electrons with energy greater than 0.35 eV begins to increase rapidly. Electrons with energy greater than 0.35 eV transfer to the more numerous states in the upper valleys where they have the same energy but much less average velocity (shown by the electron distribution for 4000 V/cm, which is shifted farther to the right of the valley minima).

At the threshold electric field, about 3000 V/cm, the average electron drift velocity reaches a maximum value of 20×10^6 cm/s. At higher fields the electrons are mostly in the upper valleys and the average velocity decreases to a more or less constant value of 8×10^6 cm/s, as indicated in Fig. 3.

Three criteria on the band structure (energy, ϵ, and k) of a semiconductor must be met in order for the semiconductor to exhibit a negative resistance because of upper valleys: (1) The energy difference between the bottom of the

FIGURE 5. Two-valley model. As the electric field increases, electrons transfer from high-velocity states in the central valley to low-velocity states in the upper valleys, causing the average velocity to decrease.



lower valley and the bottom of the upper valley must be several times larger than the thermal energy (about 0.025 eV at room temperature). (2) The energy difference between the valleys must be smaller than the energy difference between the conduction and valence bands, or the semiconductor will break down (become highly conductive because of hole–electron pair formation) before the electrons begin to transfer to the upper valleys. (3) The electron velocities ($d\epsilon/dk$) must be much smaller in the upper valleys than in the lower valley.

Not all of these criteria are met by the two most common semiconductors, silicon and germanium. They do appear to be fulfilled by some compound semiconductors, including gallium arsenide (GaAs), indium phosphide (InP), and cadmium telluride (CdTe), but not by others such as indium arsenide (InAs), gallium phosphide (GaP), and indium antimonide (InSb).[6] The practical uses that are being found for bulk negative resistance should give additional incentive to the present research effort on compound semiconductors.

The energy gap between the conduction-band valleys in GaAs can be varied by putting the material under high pressure or by alloying GaAs with GaP. The measurement of threshold voltage as a function of pressure on GaAs by Hutson, Jayaraman, Chynoweth, Coriell, and Feldman showed that the threshold voltage varies with the intervalley energy gap as predicted by the two-valley model.[7] Similar results were obtained by Allen, Shyam, Chen, and Pearson from alloying experiments.[8] The validity of the two-valley model for GaAs was confirmed by these experiments and by computer-generated movies of domain behavior based on the two-valley model made by McCumber and Chynoweth, which agreed with experimental observations.[9]

There are mechanisms for bulk negative resistance, in addition to the two-valley mechanism, that have been suggested but not yet observed. A closely related phenomenon is the high field domains due to direct interaction between the carrier stream and phonons (quantum lattice vibrations) that have been observed in GaSb, CdS, and in a few samples of GaAs oriented so that current flows along the (111) crystal axis. These domains travel at the speed of sound in the material (about 5×10^5 cm/s), which is much lower than the Gunn domain velocity (10^7 cm/s), and in the case of GaAs, appear at lower fields (about 100 V/cm) than the true bulk negative resistance threshold field (about 3000 V/cm).

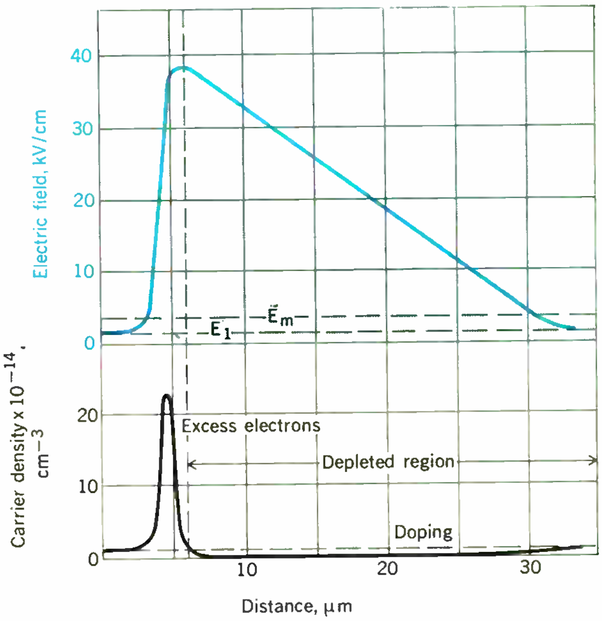


FIGURE 6. Electric field and carrier-density configuration in a high field domain. Outside the high field domain the field E_l is below threshold E_m.

Properties of domains

Because of the negative resistivity, space charge grows until it reaches a stable configuration, which usually consists of a single dipole layer (some exceptions to this rule will be discussed later).[10,11] Inside the dipole layer is the high field domain, where the electric field may be greater than 60 000 V/cm. Outside the domain, the field is below threshold (<3000 V/cm) and the resistivity is positive. The shape and behavior of the domain depend on the device doping and size, the bias voltage, and the circuit. Typical field and charge configurations for a domain are shown in Fig. 6. Some general properties of the domain are:

1. A domain will start to form whenever the electric field in a region of the sample increases above the threshold electric field, and will drift with the carrier stream through the device.

2. If additional voltage is applied to a device containing a domain, the domain will increase in size and absorb more voltage than was added and the current will decrease.

3. A domain will not disappear before reaching the anode unless the voltage is dropped appreciably below threshold (for a diode with uniform doping and area).

4. The formation of a new domain can be prevented by decreasing the voltage slightly below threshold (in a nonresonant circuit).

5. A domain will modulate the current through a device as it passes through regions of different doping and cross-sectional area, or it may disappear. The effective doping may be varied in regions along the drift path by additional contacts.

6. The domain's length is generally inversely proportional to the doping, so devices with the same doping $\times$ length product will behave similarly in terms of frequency $\times$ length, voltage/length, and efficiency.

7. A domain can be detected as it passes a point in the device by a capacitive contact, since the voltage changes suddenly as the domain passes. The presence of a domain anywhere in a device can be detected by the decreased current or by the change in differential impedance.

Properties 3 and 6 are valid only when the length of the domain is much longer than the thermal diffusion length for carriers, which for GaAs is about 1 μm for 10^{16} cm^{-3} doping and about 10 μm for 10^{14} cm^{-3} doping.

Two-terminal devices

The foregoing properties can be used to design a more efficient oscillator than the one that produced the waveform of Fig. 4. To increase the power content at the fundamental frequency, the waveshape should be made more symmetrical. If the diode is made shorter, the flat valley of the current waveform will become narrower, because the domain will spend less time traveling through the device, whereas the width of the upward spike will not change.

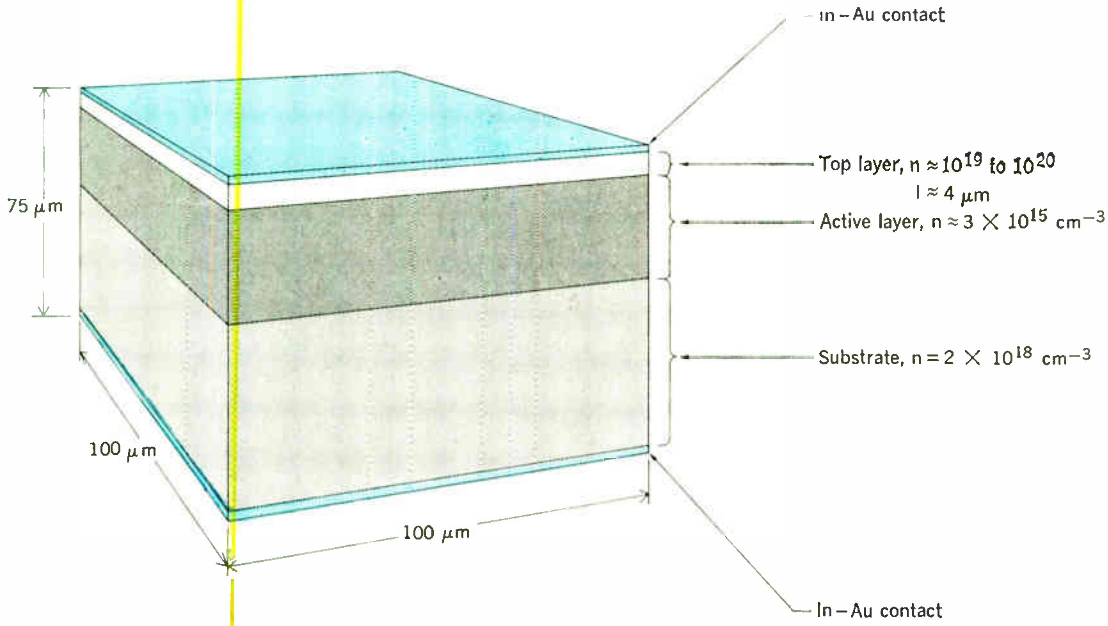


FIGURE 7. GaAs bulk diode, made by epitaxially growing the active layer (doping $n = 3 \times 10^{15}$) on a high-conductivity substrate ($n = 2 \times 10^{18}$). Top layer was highly doped ($n = 10^{19}$ to 10^{20}) before contacting.

By property 5, we could change the waveform in the same manner without changing the frequency, by reducing the doping. This makes the upward spike wider at the expense of the valley because the domain becomes wider and takes longer to build up and disappear. Theoretical calculations indicate that the efficiency of GaAs Gunn oscillators is best when the doping × length product is one to several times 10^{12} cm^{-2}, so the domain is about half as large as the sample and the current approximates a sine wave.

High efficiency could also be obtained from the diode used for Fig. 4 by applying property 4. If the new domain is inhibited from starting for a time equal to the domain transit time, then the waveform will approximate a symmetrical square wave. The highest efficiencies reported, which approach 20 percent, were obtained in this manner by operating diodes in a resonant circuit tuned to half the transit-time frequency. The output power obtained on a pulse basis was approximately 100 watts at 1 GHz.[12]

Even while a diode has a high field domain and is oscillating, it may show a negative resistance at other frequencies due to negative resistance of the domain (property 2). Diodes that are oscillating at 1 GHz or above are frequently observed to modulate themselves at frequencies from a few kilohertz to hundreds of megahertz because of parasitic oscillations due to resonances in the bias circuit. This effect is a nuisance if one wants a clean microwave signal. However, if the microwave oscillations are filtered out, this effect can be used to oscillate, amplify, and generate pulses at frequencies below the transit-time range.

Property 5 results from the tendency of the carrier stream near the domain to move at a constant velocity. If the area of a diode increases as the domain travels through it, then the current will also increase. Further, if the carrier density increases because of increased doping, the current will increase. By physically shaping a diode, the output current waveform can be tailored. The device shown in Fig. 1(A), made by M. Shoji, produces a sawtooth waveform.[13] It is also voltage tunable over a wide frequency range since the domain will disappear before reaching the anode when there is insufficient voltage to sustain both the domain and the increasing *IR* voltage drop over the rest of the device.

By cutting notches in a device that otherwise has uniform doping and cross-sectional area, a desired sequence of pulses can be produced each time a domain passes through. Such sequences can represent binary numbers (zeros and ones), which are used in most computer circuits. Because some impurity atoms can be temporarily ionized (traps) to change the doping, it is also possible temporarily to "write" binary numbers on devices that can be read from the output signal as a domain passes through.

Large Gunn-effect oscillators are produced by cutting wafers (thin disks) and then strips from a piece of bulk-grown material. The contacts are made by alloying balls of indium or tin to the ends, as was done on the devices shown in Fig. 1(A) and (B). For devices with cross-section dimensions greater than their length, the wafer is contacted on both sides by vacuum-evaporating metal films on each end and then it is diced into separate diodes. Diodes with this geometry can be mounted in packages with pressure contacts.

The best devices for practical applications are produced by growing thin films of n-type GaAs on a substrate of either high-conductivity or high-resistivity GaAs. Contacts to the epitaxial film are best made after growing thin high-conductivity layers on the surface. The structure shown in Fig. 7 was used by Brady, Knight, Lawley, and Uenohara for devices with active layer thicknesses of from 20 to 8 μm, which produced 0.1 watt continuously with 3 percent efficiency at frequencies from 6 to 15 GHz (a particular device could be tuned over a 2 to 1 frequency range).[14] The power and efficiency of thinner diodes decreased rapidly at higher frequencies (1 mW and 1 percent at 30 GHz).

For frequencies below 6 GHz, a GaAs diode is too thick for heat removal through the contact surfaces without excessive temperature rise in the center. This problem may be alleviated by making diodes from thin films on high-resistivity substrates so that heat can flow perpendicular to the current.

Multiterminal devices

If a diode is dc biased just below the threshold voltage, a single domain can be triggered by a short pulse of additional voltage.[15] The output current pulse will generally be independent of the shape of a small triggering pulse; bulk diodes can therefore be used as pulse regenerators. The triggering sensitivity can be improved and the input isolated from the output by adding a third contact near the cathode, as was done by Hayashi on the device of Fig. 1(B).[16] The output current waveform from this device is shown in Fig. 8.

Because of the definite threshold, it is possible to perform binary logic functions by mixing input signals. Isolation between inputs can be achieved by using separate contacts, as illustrated in Fig. 9, or by dividing the cathode end of the device into several legs. A capacitive output contact will produce output pulses whose duration is of the order of the time that it takes the domain to pass under the contact, rather than the transit time for the whole device. Ultimately these types of devices should be capable of performing simple logic functions in a fraction of a nanosecond, since a domain's drift velocity is about 10^7 cm/s and its width can be of the order of 10^{-3} cm.

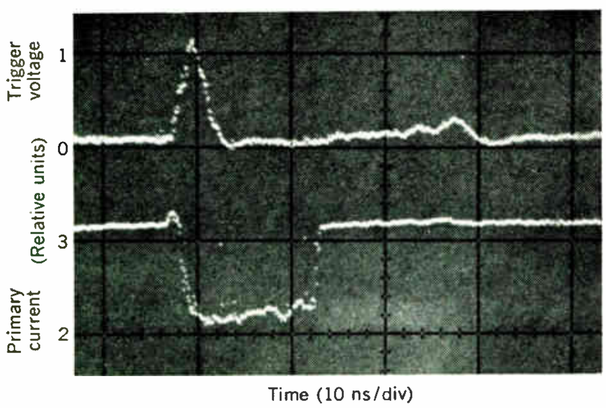
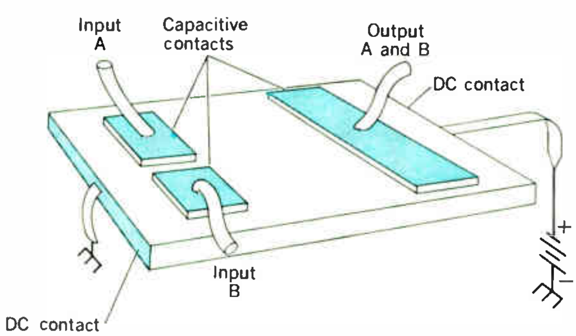


FIGURE 8. Capacitive contact voltage and current through the device shown in Fig. 1(B). This device can be used as a pulse generator or a logic gate.

FIGURE 9. Logic gate using multiple capacitive contacts. When pulses are applied simultaneously to both inputs, a domain forms and creates an output pulse as it drifts under the output contact.



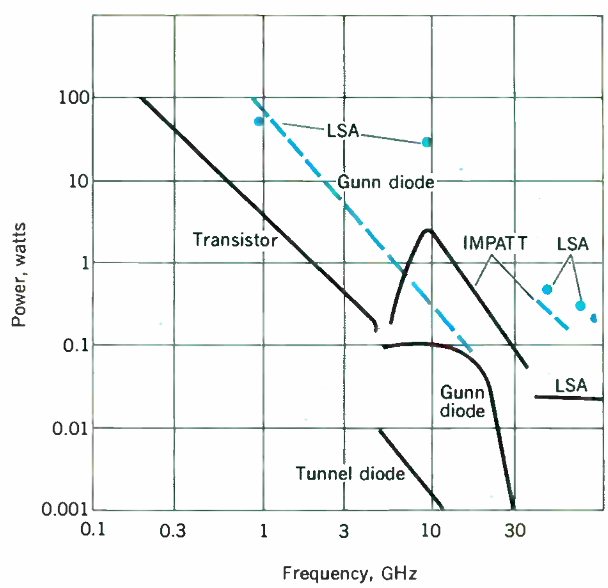
Amplifying diodes

In 1965 Thim, Barber, Hakki, Knight, and Uenohara discovered that an n-GaAs bulk diode can amplify signals in the vicinity of the transit-time frequency without oscillating if the doping × length product is of the order of 10^{12} cm^{-2} or less.[17] In this mode of operation the diode is filled with an excess of carriers (negative space charge) and the electric field continuously increases from the cathode to the anode. The dc resistance is always positive, but an applied ac signal will set up waves in the space charge that grow because of the negative resistivity. The phase relation between current and voltage at the terminals is such that a negative resistance is obtained when the space-charge wave is slightly longer than the diode. If the doping × length product is not too small, a negative resistance will also appear when a small whole number of space-charge wavelengths is slightly longer than the diode. The negative resistivity of the stable bulk diode produces a negative resistance at the diode terminals only for frequencies just below the transit-time frequency and perhaps just below the first few harmonics.

If a stable diode is put into a circuit with sufficient positive feedback at a frequency where the resistance is negative, it will oscillate. It was demonstrated by Hakki that if the oscillation voltage is not so large that it changes the initial space-charge distribution, amplification at nearby frequencies is possible and a single bulk diode can be used as an amplifier, local oscillator, and mixer.[18]

When a bulk diode with a doping × length product

FIGURE 10. Maximum power vs. frequency (1966) for a number of solid-state oscillators. Solid lines are for continuous, room-temperature operation; dashed lines and points (in color) are for pulsed operation. Gunn and LSA results are from bulk n-GaAs diodes.



that is too large for stable amplification oscillates because of the Gunn effect, it exhibits a negative resistance at direct current and at frequencies above and below the oscillation frequency. This result of domain property 2 was used recently by Thim to make amplifiers that are linear until the output power approaches the power that could be obtained from the oscillation. Five-decibel amplification at 6 GHz was achieved with 1-dB compression when the output power reached 60 mW. This is approximately a 15-dB increase in linear range over the stable amplifier diode.[19] The noise figure of these bulk diode amplifiers is about 20 dB above the thermal limit. The noise is largely the result of the internal amplification of thermal noise because of the negative resistivity.[20]

Millimeter-wave power generation

By the proper design of a bulk n-GaAs diode and corresponding resonant circuit, it is possible to prevent domains and other types of space charge from building up within the diode. This mode of operation, called LSA for limited space-charge accumulation, makes it possible to build oscillators with higher frequencies, and with higher power at a given frequency, than can be obtained with a transit-time device.[21]

Devices such as transistors and IMPATT (avalanche) diodes, as well as Gunn-effect oscillators, must be thin enough that carriers can move through the active region during one cycle or less. This means that the thickness and voltage must be decreased to raise the frequency of operation. To maintain a reasonable impedance, the current also must be decreased. The result of these considerations is that the maximum power for a given transit-time or subtransit-time device falls off faster than $1/(\text{frequency})^2$, as shown in Fig. 10. The LSA oscillator is the first practical solid-state oscillator that is free of this limitation, since in principle it can be made thick compared with the distance a carrier drifts during one cycle.

For LSA operation of a bulk n-GaAs diode, the voltage must swing below the threshold voltage each cycle long enough to dissipate space charge. Also, the part of each cycle during which the voltage is above the threshold must be too short for space charge to build up and form a domain. Since the speed of space-charge dissipation and growth is proportional to the doping, the ratio of the doping to frequency must be within 2×10^4 to 2×10^5 cm^3/s. The circuit must be lightly loaded to achieve the necessary ac voltage swing. For high efficiency, the doping should be uniform within 10 percent.

Preliminary experiments with epitaxial LSA oscillators [Fig. 1(C)] have produced 0.7 watt and 9 percent efficiency at 50 GHz on a pulse basis and 0.02 watt with 2 percent efficiency at 88 GHz on a continuous basis.[21] Experiments with bulk-grown diodes have yielded 33-watt pulses at 10 GHz and have led to predictions that 250-kW pulses from a single block of n-GaAs are theoretically possible up to 100 GHz.[22] The upper frequency limit for LSA operation of GaAs has not been determined, but it seems certain that an appreciable amount of power can be produced at frequencies of several hundred gigahertz.

The future

Bulk negative-resistance devices offer both opportunity and challenge. The opportunity is to build devices with better combinations of power and speed than is now possible with junction devices. The challenge arises because much of the existing electronics technology concerned with device characterization and circuit design cannot be applied to bulk devices (particularly multi-terminal devices), so new techniques must be developed. Also, the materials technology for GaAs is years behind that for silicon and germanium, and is in its infancy for other III–V and II–VI compounds that look promising as bulk negative-resistance semiconductors.

REFERENCES

1. Ridley, B. K., and Watkins, T. B., "The possibility of negative resistance in semiconductors," *Proc. Phys. Soc. (London)*, vol. 78, pp. 293–304, Aug. 1961.
2. Ridley, B. K., "Specific negative resistance in solids," *Proc. Phys. Soc. (London)*, vol. 82, pp. 954–966, Dec. 1963.
3. Hilsum, C., "Transferred electron amplifiers and oscillators," *Proc. IRE*, vol. 50, pp. 185–189, Feb. 1962.
4. Gunn, J. B., "Microwave oscillations of current in III-V semiconductors," *Solid-State Commun.*, vol. 1, pp. 88–91, Sept. 1963; also "Instabilities of current and of potential distribution in III–V semiconductors," in *Plasma Effects in Solids*. New York: Academic Press, 1965, p. 199.
5. Kroemer, H., "Theory of the Gunn effect," *Proc. IEEE (Correspondence)*, vol. 52, p. 1736, Dec. 1964.
6. Foyt, A. G., and McWhorter, A. L., "The Gunn effect in polar semiconductors," *IEEE Trans. on Electron Devices*, vol. ED-13, pp. 79–87, Jan. 1966.
7. Hutson, A. R., Jayaraman, A., Chynoweth, A. G., Coriell, A. S., and Feldman, W. L., "Mechanism of the Gunn effect from a pressure experiment," *Phys. Rev. Letters*, vol. 14, pp. 639–641, Apr. 19, 1965.
8. Allen, J. W., Shyam, M., Chen, Y. S., and Pearson, G. L., "Microwave oscillations in $GaAs_xP_{1-x}$ alloys," *Appl. Phys. Letters*, vol. 7, pp. 78–80, Aug. 15, 1965.
9. McCumber, D. E., and Chynoweth, A. G., "Theory of amplification and of Gunn instabilities in 'two-valley' semiconductors," *IEEE Trans. on Electron Devices*, vol. ED-13, pp. 4–21, Jan. 1966.
10. Butcher, P. N., Fawcett, W., and Hilsum, C., "A simple analysis of stable domain propagation in the Gunn effect," *Brit. J. Appl. Phys.*, vol. 17, pp. 841–850, July 1966.
11. Copeland, J. A., "Stable space-charge layers in two-valley semiconductors," *J. Appl. Phys.*, vol. 37, pp. 3602–3609, Aug. 1966.
12. Dow, D. G., Mosher, C. H., and Vane, A. B., "High peak-power gallium arsenide oscillators," *IEEE Trans. on Electron Devices*, vol. ED-13, pp. 105–110, Jan. 1966.
13. Shoji, M., "A voltage tunable Gunn effect oscillator," *Proc. IEEE (Letters)*, vol. 55, pp. 130–131, Jan. 1967.
14. Brady, D. P., Knight, S., Lawley, K. L., and Uenohara, M., "Recent results with epitaxial GaAs Gunn effect oscillators," *Proc. IEEE (Letters)*, vol. 54, pp. 1497–1498, Oct. 1966.
15. Heeks, J. S., Woode, A. D., and Sandbank, C. P., "Coherent high field oscillations in long samples of GaAs," *Proc. IEEE (Correspondence)*, vol. 53, pp. 554–555, May 1965.
16. Copeland, J. A., Hayashi, T., and Uenohara, M., "Logic and memory elements using two-valley semiconductors," *Proc. IEEE (Letters)*, vol. 55, pp. 584–585, Apr. 1967.
17. Thim, H. W., Barber, M. R., Hakki, B. W., Knight S., and Uenohara, M., "Microwave amplification in a dc-biased bulk semiconductor," *Appl. Phys. Letters*, vol. 7, pp. 167–168, Sept. 1965.
18. Hakki, B. W., "GaAs post-threshold microwave amplifier, mixer, and oscillator," *Proc. IEEE (Letters)*, vol. 54, pp. 299–300, Feb. 1966.
19. Thim, H. W., "Linear negative conductance amplification with Gunn oscillators," *Proc. IEEE (Letters)*, vol. 55, pp. 446–447, Mar. 1967.
20. Shockley, W., Copeland, J. A., and James, R. P., "The impedance field method of noise calculation in active semiconductor devices," in *Quantum Mechanics of Atoms, Molecules, and the Solid State*, P. O. Lowdin, ed. New York: Academic Press, 1966, pp. 537–563.
21. Copeland, J. A., "A new mode of operation for bulk negative resistance oscillators," *Proc. IEEE (Letters)*, vol. 54, pp. 1479–1480, Oct. 1966; also "CW operation of LSA oscillator diodes," *Bell System Tech. J.*, vol. 46, pp. 284–287, Jan. 1967.
22. Kennedy, W. K., Jr., and Eastman, L. F., "High power pulsed microwave generation in gallium arsenide," *Proc. IEEE (Letters)*, vol. 55, pp. 434–435, Mar. 1967.

New patterns of

It is strongly believed that many of the most pressing problems that plague our society today could and should be solved not by the government alone but by industry in cooperation with government; and on a profitable basis

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Acting Under Secretary of Commerce,

U.S. Department of Commerce

The character of our American society has changed slowly over the past 50 to 100 years, but peoples' aspirations, both in the United States and abroad, have changed abruptly in just the last 5 to 10 years and are still constantly changing. We haven't seen anything yet; mankind's aspirations are going to soar to new heights. Furthermore, technology provides the power with which society can meet these new, higher aspirations, if we but put our minds to it. Whether we can, in 5 years, or 50, or 100, attain such social goals as eliminating poverty, disease, and ignorance from the United States and spreading literacy, freedom, and governmental stability throughout the now less-developed areas of the world rests chiefly on social decisions. These social decisions must be made soon. To make them intelligently—in fact, to make any decisions at all—will require new patterns of industry-government partnership.

Today we can communicate readily, by means of all sorts of miraculous inventions, throughout the whole world. Those of us who are fortunate to be among the "haves" of the world cannot escape being exposed to the suffering of the "have-nots." Those who are unfortunate enough to be among the have-nots readily learn what the haves have, and they want some of that good life too. We already have instant communication via radio, television, and the like, combined with expanding literacy and the questioning that comes with seeing, hearing, reading, and thinking. The spread of communication and comprehension throughout the world has caused millions of people to have higher aspirations than ever before. This development of the technology of rapid communication and transportation has already changed the character of the world. The resulting comprehension is responsible for the uprisings in Africa; it is responsible in large measure for the change in aspirations of the subcontinent; and it is responsible to some great degree for the Negro uprising, after 100 years or more of repression, in the United States. Through communications technology, millions of people throughout the world now, for the first time, recognize the ways in which they could improve their lives if they had the appropriate tools.

Some characteristics of our society

The nature of the American society has changed slowly over the last 50 to 100 years. We now live mostly in cities.

industry–government partnership

We are spending our money increasingly on what I refer to as public goods as contrasted to private goods. We are spending greater and greater sums of money on schools and medicine and transport and recreation (which are basically public goods) as contrasted with food and fiber and shelter (basically individual, private goods). Living in complex cities, in a complex interacting society, means that each man is infinitely more dependent on each other man than was the case in the more rural society that existed just a few years ago. Today each system intimately reacts with every other system in the society. One cannot introduce a new interstate highway system without disrupting the distribution patterns of many industries or the character of urban and suburban development, in the towns the highways traverse and in others, too. One cannot change a town's educational system in any major respect without changing the character of the social life of that town.

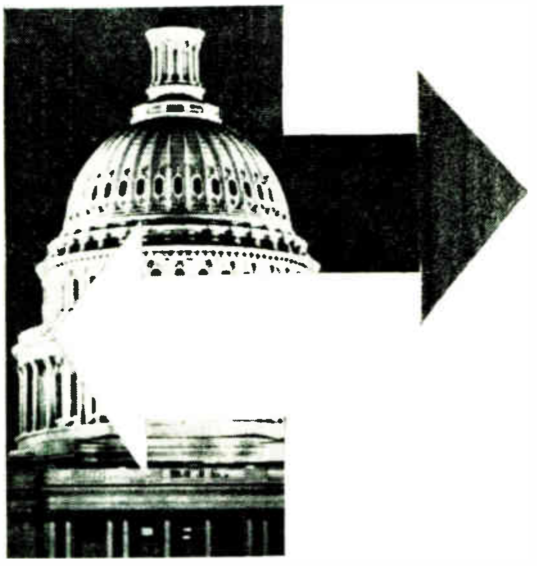
We are all familiar with the population explosion. If our world population were evenly distributed over the land areas, and all regions of the land were equally productive, the mere increase would not in itself produce a powerful force for change. But when people are concentrated in a small space, the force for cultural, social, and technological change increases—in much the same way that if gases are pumped into a container, the number of collisions between the molecules in the gas tends to rise. You can determine the character of a rare gas by simply looking at the character of its individual parts. Collisions between molecules are infrequent because they are separated. We were, in our American society 50 to 100 years ago, essentially a "rare gas," that is to say, the people were dispersed; they rarely interreacted and almost never collided. Today we are rather what the scientists call a "condensed system," in which the behavior of the individual is intimately connected with the behavior of all other individuals in the society. The character of a condensed system is determined more by the interactions of its parts than by the individual behavior of its component particles. An analogous change has taken place in the American society. It should not be surprising that aspirations have also changed.

Revised text of an address presented at the Conference on the Challenge of Technology, sponsored by the National Industrial Conference Board, New York, N.Y., November 30, 1966.

Some trends in our society

A trend in the individual's life within the society is that the amount of work that the average person in the United States does during his lifetime has decreased by a factor of two from 1900 to about 1955. During the next 30 or 40 years the amount of work a man does in a typical lifetime will decrease again by a factor of two. Therefore, young people will enter the work force later in life, they will enjoy a shorter workweek with more vacations and holidays, and they will retire as much as a decade earlier than today's customary retirement age of 65. Through technology, we increase our productivity. We use about two thirds of this increase to make ourselves wealthier (that is, we produce more goods and services) and we use the other third to decrease the amount of work we do. It has been a long, hard dream of man throughout the ages not to have to work merely to earn a living but to be able to work creatively with enough leisure time to enjoy the fruits of his labors. Society has no greater challenge today than that of the typical lifetime devoted mostly to nonwork. Preparing young people for such a lifetime is one of the great challenges of our educational system. In my view, this situation is one that the typical educator did not anticipate. Even today, in a sense, education prepares a young person to spend most of his lifetime working in order to earn a living, whereas most of the kids graduating from college today will spend most of their waking lifetimes enjoying life, if they know how.

That is not the only way in which education is inadequately or incorrectly preparing young people for the world of tomorrow. Here is a surprising anomaly: as our society becomes more scientific and technological, we are educating relatively fewer young people in science and technology. Fewer and fewer of our college graduates are being educated in science and engineering. Relatively fewer of our high school students are taking chemistry and physics courses. So as the society becomes more scientific and technological, a very large fraction of the society knows less and less about science and technology. This



situation has great dangers, it seems to me, for industry, for the university, for government, and for the future of our society.

We have traditionally been a society in which the individual bought the product he wanted at an open marketplace. Our primary industry was serving private needs, whether they were industry's private needs or the private needs of the individual. We had a laissez-faire attitude because of the rare-gas characteristic of our society. If one lived out in the woods somewhere, it didn't make much difference whether he bought a gun, and if he did, it didn't matter whether it had a safety device on it, or how it was used, because the likelihood that a shot might hit a person was relatively small. That likelihood is tremendously increased in the city. And the likelihood that one might be provoked into misusing a gun for unlawful purposes is growing greater all the time. The social pressures of city life push many persons to use firearms in crime or violence or carelessness. Some restrictions simply have to be placed on the use of guns. The same thing is true of automobiles. When there weren't many automobiles on the streets or people in the society, and the automobiles were not interacting very readily, acting like a rare gas, one didn't have to worry about the social cost of traffic safety. The social pressures, too, were less; there was less drinking, and there were fewer appointments to keep; nobody had to rush. Today, with 50 000 deaths a year on our highways, society has decided that steps must be taken to reduce this senseless slaughter.

Technological advance has other harmful effects. Air and water pollution, transportation glut, crime, and the misuse of our natural resources—these are a few more of our technological problems.

What are the lessons for industry?

Enough about the great problems of today, which you appreciate as well as I. What are the lessons for industry? I believe the greatest future for American industry is to organize itself in an imaginative way to deal with these social problems through participation in the public market. An increasing number of goods and services are going to be bought by groups of people rather than by individuals. I can't buy a school system for my sons; all I can do is to buy a public-school education for them, through taxes, or a private-school education, through tuition. However, a group can get together and develop an educational system. We see this situation frequently in cooperative nursery schools or kindergartens, which mothers form when the public school system does not provide these facilities. There is no reason why other groups—say, profit-making companies—shouldn't do just what those mothers do, that is, fill a vacuum, meet a need for high-quality educational facilities and services. At the nursery or kindergarten level, it's relatively inexpensive, and mothers volunteering their services can often meet the need. In high school, technical, or college education, more professionalism is required—often more than the traditionalists are prepared to supply. That's when the group I referred to should get together, and they might find that they can supply a social good or a social service or a public good or a public service through the play of the public market.

Industry needs to organize to reach that market to sell all kinds of goods and services. It is obvious that the public needs and is willing to pay for those goods and services. I further believe that it is appropriate that industry find ways of providing them. Imagination, invention, innovation, risk, venture, and capital will be required; and there will be an impressive series of failures. The needs of the public market will not be met by having the same general attitude that is prevalent today among many space and aerospace companies—in other words, through simply getting contracts with the Federal Government. "Let Uncle Sam pay for it" is not entrepreneurship. The reason it is not is clear, as illustrated in the educational system analogy. There isn't a Federal Government for education, a Federal Government for police records, a Federal Government for traffic safety, nor one for driver education, medical services, urban development, or for thousands of other essential public services that are best provided at the state or local level. There are thousands of governments, municipalities, school boards, police departments, medical centers, and the like. Those companies that think that the public market I'm talking about is a "federal" market for these kinds of services because there is a federal market for military and space services are simply mistaken. The creative business concern will locally create the market and sell its products and services at the local level. The creative business enterprise is the one that will survive the intense competition I anticipate. Most U.S. cities, for one reason or another, do not happen to have employees who have the foggiest notion of the kind of information systems that they really require in order to manage municipal affairs. And so someone is going to have to help them; someone is going to have to create that market for municipal information systems. In my view, the central city problem needs at least $100 billion of capital, and it will not be met by a grant of that much money from the Federal Government, even if the Viet Nam situation should be settled soon. Private capital must be drawn in, and, again in my view, it will not be drawn in by nonprofit corporations. I believe that we must make it clear that it is both possible and proper for private industry to make money from eliminating slums. The mechanism must be constructed so that it is an appropriate industrial enterprise, which can and must be profitable.

The relationship between government services and private services in the United States is largely accidental. It is accidental that the Federal Government runs the Post Office while AT&T and General Telephone run the telephone communications systems. In other countries the telecommunications system is operated not by a private firm but by the government. Most of the research and development in our armament production between the wars was conducted by a system of government arsenals. The system was found wanting; it could not keep up with modern industrial technology. So the contract mechanism between the Federal Government and industry was created to supply and produce the military goods. And we created a marriage between the Government and the aerospace companies to meet public needs in aircraft and space.

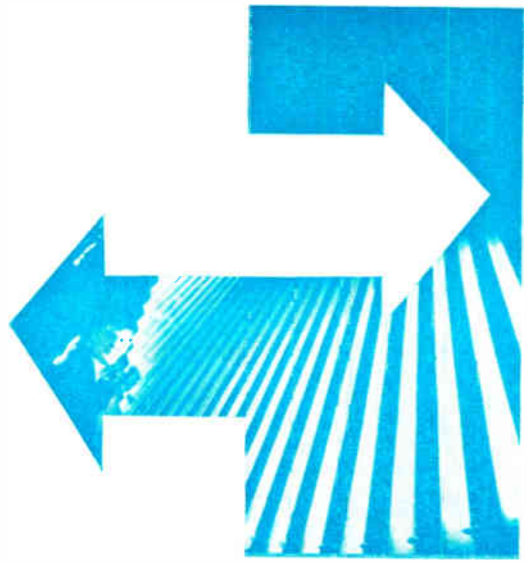
New patterns of industry–government partnership must and will evolve in the coming decade. I have described some of the characteristics of and trends in our society which make new patterns inevitable. Great as the great social problems of our time are, I do not believe that they are comparatively any worse than the great social problems of the past. I do not believe that life in the city of New York today is any worse than life was in the city of London in 1895. I doubt that the air pollution problem in New York or Los Angeles is much worse than that in Birmingham, England, 25 years ago. And I am confident that the public health services in every city in the United States are better today than Calcutta's health services have ever been. Two things have happened: our aspirations have changed, and technology provides the power with which society can meet these higher aspirations.

Questions directed to Dr. Hollomon

Question: Do you believe that machines put people out of work or decrease available work?

Dr. Hollomon: No, I simply don't believe that machines put people out of work. They simply change the job requirements. Other things, social pressures resulting, perhaps, from the use of machines, put people out of work. It's a much more complicated problem having to do with supply and demand in the economy. The National Commission on Technology, Automation, and Economic Progress documented that technology eliminates jobs but not work. Thus, technological change (along with other forms of economic change) is an important determinant of the places, industries, and people affected by unemployment. But the general level of demand for goods and services (and that is favorably affected by machines, or technology) is by far the most important stimulus to employment.

The second point has to do with what I mean by decreased work. I mean that the total time that a man will spend during his lifetime earning his living will decline. That has been the case for 75 years, and I can see no reason why it should change. The average age at which a boy or girl will enter the work force will be higher than ever before—say, age 25 by 1970. Until age 25 he will be "working," but he will not be earning his living. The rest of us will be supporting him while he, mainly, is in school. In addition, he will "retire" earlier. He will also work fewer hours per week and fewer weeks per year during his shorter working lifetime. In our present society, one of our social choices has been that we have chosen to take the increase in productivity due to technology and enjoy both increased goods and services and a decreased



amount of necessary work. Now, if things continue to go as one could expect, with an increase in productivity in this country of 4 or 5 percent per year, we can use that increased capacity in any one of several ways. We can buy more goods, we can work less, or we can devote increasing attention to the major public social needs of our time. The balance we choose rests in the hands of the society. But what I want to make clear is that society is going to require "decreased work" from coming generations; children will enter the work force at later ages than ever before as they enjoy an increased opportunity for education. We're going to invest a fair amount of our increased productivity in education.

Question: Dr. Hollomon, you have several written questions. Would you read and answer them, please?

Dr. Hollomon: Yes, I'll read several of the ones I think we might try to deal with all at once: "To what extent is business hampered by legal and institutional restrictions in meeting the challenges of technology?... Is it realistic to ask existing corporations to meet the challenges referred to?... Will it not require new types of corporate endeavor under new auspices? And how can they be facilitated?... Assuming industry can create markets, should the new developments be allowed to grow at random or should they be coordinated somehow?... What kind of controls, if any, would be desirable if private industry alone is responsible for developing the major new areas? ... How do we counter the bureaucratic tendency to expand regulatory controls over R & D, marketing, and other business activity?..." I think those are quite enough.

It seems to me that we need a recognition and an understanding that there is a potential market sitting out there having needs that are deeply felt in the society as a whole and are particularly deeply felt by the young people of the society. Ways must be invented in order for business to get at these needs. Now we have undertaken such social inventions in the past. We invented the land grants to the private railroads in order to develop the West. We invented all sorts of techniques to bring about the integration of the Bell Telephone System, some of which techniques now, in retrospect, are being questioned. We invented all sorts of institutional arrangements. In the development of the private utilities of this country, the investment people not only owned the production capacity for generators and turbines and motors and what have you, but they lent the money to corporations to enable them to buy those same equipments, thus creating a market. If industry really thinks there's money in the public market, and I believe there is, not only must it invent new corporate endeavors, but we, the people, must arrange the political environment in which those new corporate endeavors are appreciated and countenanced. And that's possible.

I see no fundamental reason why large corporations cannot build cities at a profit. I see no fundamental reason why a company cannot contract with a town to design its educational buildings in cooperation with its teachers. The company might stimulate the educators, and vice versa, and the result might be the design of improved ways to teach teachers and to teach children. I don't even see why such educational systems can't be operated under contract. Now you say, how am I going to do that in Mt. Vernon, N.Y.? I don't know. But if you understand the problem, see the need, and believe that market's there, and if you want to make that market, then I believe you can get at it.

The political institutions of this country, even more readily than the economic institutions, adjust themselves to market conditions. And frankly, we're not going to solve these problems by some masterminding in Washington. At least I hope not. The problems are indigenous. They are indigenous, local, different problems, different in every section of the country. Even so, I don't believe they can best be left wholly to cities and counties, because cities and counties, in a way, are outmoded. The problems must be tackled cooperatively, by corporations, the Federal Government, and local governments.

I'd like to bring up one other point. If we deal with any particular problem in a city, many Federal agencies are somehow involved in the process—perhaps 10 or 15 or 20 or 30, depending upon the kind of subject, whether it be education, medicine, public works, or what have you. But towns don't know how to deal with the Federal Government. They couldn't possibly have the expertise. One of the things that industry could do in cooperation with towns all over the country is to help them to deal more effectively with the Federal Government and to do it in a profitable way. I see no reason why American enterprise cannot deal with these problems and provide these goods and services at a profit. Is the problem fundamentally any different from providing an electric dishwasher at a profit? One happens to be a product that I want to buy as an individual, and another happens to be a product that all of us want to buy collectively. And we have traditionally accepted as a desirable incentive the profit for goods and services appropriately rendered at the market. Why shouldn't the same incentive be used to provide public goods and services? Unless we agree that profit is a desirable incentive in the public market, then the only alternative to meeting these social needs is centralism and government action. I simply don't think that this problem can be done that way alone. This is a cooperative venture. And the government's job, as I see it, is to help provide the mechanisms by which the industry can get at the business.

Question: Is there actually a declining fraction of young people who go into science and engineering?

Dr. Hollomon: Yes. Undergraduate registrations in all fields other than science and engineering have risen sharply since 1959, but the percentage of freshmen engineers has declined steadily since 1957. Many persons believe that the good of the country requires that the ratio of engineers to the general population should be increasing, but the fact is that it is decreasing. Furthermore, of the freshmen students who begin college stating their intention of becoming engineers, about 50 percent drop out of engineering and receive their degrees in other fields. These trends pose problems for the nation. I'm not saying whether the situation is deplorable, but one consequence is, in my opinion, deplorable. Most of the people being educated in the colleges and high schools of America don't know a blessed thing about science and technology.

I think that one of the problems in education is a national need for all students to have an opportunity to understand the consequences of science and technology to the age in which they live. If it turns out that fewer of our young people want to go into a given field, we adjust to it. There are not enough computer programmers around who speak the peculiar language of computer programs. So what happens? People meet the need by designing computer programs based on the use of simple English. My general theory about education is that industry and the rest of us adjust to the output of the educational system and not conversely. In other words, I think we use the raw materials that are produced. I do not think that the educational system really tries to anticipate the need. I do not believe that a shortage of educated people actually exists. I do think that there hasn't been quite enough time for the industries to adjust to the fact that they're not getting the kinds of people they need. The difficulty is that we don't anticipate well enough. Yes, there is a declining fraction of young people going into science and engineering. We need to know what that means, and what we should do about it.

Question: How could the public market provide more opportunities for higher education?

Dr. Hollomon: Let's suppose that a town is going to start a junior college. Instead of the town running the junior college and hiring teachers and so on, why not go to an appropriate industrial firm and say, "You design the junior college, you hire the teachers, you learn how to do it, you work with the educators, you operate the junior college at a profit and, instead of our putting money directly into the junior college, we will give the money to the prospective students, who then can go there or elsewhere, depending on who can offer them the best education." I cannot see any reason why running a college should not be considered an appropriate function for private enterprise. The idea will be new and, to many, shocking. I personally know of only two or three or four proprietary colleges in this country in recent years, and some of them have had very bad reputations. But fundamentally I don't see why we can't go as far as operating part of the educational system at a profit. That's one of the new patterns of industry–government partnership I foresee in the coming decade.

Communications, the police, and the Crime Commission

One important phase of a comprehensive study by the Science and Technology Task Force to determine ways in which science and technology can be applied more effectively to the criminal justice system in the United States has involved the investigation of police communications. Attention has been focused on the problems existing in the major population centers, where message traffic density is high, frequency spectrum crowding is severe, and large numbers of independent networks exist within relatively small geographical areas. This article describes the findings of the investigations and offers some recommendations for solving a number of these problems.

The present status of police communications—a multiplicity of small, overlapping networks, often characterized by severe traffic congestion and by operational inadequacy—indicates a vital need for major steps to improve the situation

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The Science and Technology Task Force had the general mandate from the President's Crime Commission to consider ways in which the method and resources of science and technology could be applied to improvement of the nation's criminal justice system. In this work, the Task Force was required to prepare a report on the subject, to assist the Crime Commission in the preparation of its summary report, and to provide appropriate support to other task forces as required. For the period June 1 to December 2, 1966, a team from the Kelly Scientific Corporation, under the direction of the writer. provided support to the Science and Technology Task Force in the broad area of police communications. The Task Force itself was organized at the Institute for Defense Analyses under the direction of Alfred Blumstein.

Although it was entirely natural that the Crime Commission should seek to relate technology to criminal justice, the particular relationship that developed is believed to be relatively new and unique. In the past, scientific advances have been closely related to the courts and the police, but principally in connection with the detective function and the solving of individual crimes. In the present work, the resources of science and technology have been looked to for aid in attacking the overall problem of the reduction of the general crime rate. The interdisciplinary systems sciences developed in the past two decades have provided the basic approaches.

The criminal justice system comprises the police, the courts, and the penal subsystems. Early in the work, however, it was decided that the prime emphasis of the Science and Technology Task Force should be placed upon problems of the police. The scope of the problems available for study and the limitations of manpower made necessary some selective emphasis. Police problems had a special urgency, and results promised to have a more immediate impact than would results from an equivalent effort in other areas.

Police communications in general

Police communications itself is an extremely broad and complex subject, covering as it does the newly developing nationwide network of the FBI's National Crime Information Center; the various statewide networks, many of them in a bewilderingly rapid stage of growth; and a multitude of county and municipal networks. Early indications were that the most severe problems existed in connection with municipal mobile radio networks and that these problems, in turn, were most acute in the major population centers. Accordingly, the work was focused toward this area of municipal police mobile radio.

The single outstanding problem, but by no means the only one associated with municipal mobile radio communications, is that of severe radio spectrum congestion. The basic problems can be summarized in brief as follows:

- The congestion of the police radio channels is most severe in the areas around the major population centers. In these areas, there are too many police radio users and too few radio channels allocated for police use.
- In these major population areas, as in all areas of the country, police radio is characteristically organized into a large number of independent networks, which are ineffective in terms of interagency communications and coordination and inefficient in use of the limited available radio spectrum. Each little municipality will often have its own small, independent police network.
- Even where large police networks exist, as in major cities or countywide systems, there is virtually no use made of the methods of modern communications technology to even channel loading or relieve congestion.
- New devices required for improved police operation, such as automatic car locators, small personal radios for use away from the car, and Teletype in the car, can be expected to create requirements for additional radio spectrum space for police use.

The spectrum congestion does not normally evidence itself in an actual breakdown in police communications. The dispatchers' messages to the cars are sufficiently imperative that police make certain that these messages get through even in the most adverse circumstances. The spectrum congestion evidences itself more nearly in a gradual deterioration of police capability, which becomes dramatically evident when communications are badly needed and not available, as during the civil rights riots of recent summers.

Large police mobile radio networks are characteristically organized in a centralized geometry, with the two-way communications channels radiating outward from the dispatching center to the mobile units in the field as the spokes of a wheel radiate out from the hub. This network geometry is convenient for the normal mode of police operations, but less well adapted to the emergency mode.

The *normal mode* of operation of a police mobile radio network is built around the individual mobile police vehicle and its occupants as the fundamental guardians of law and order. The mobile units patrol well-defined "beats," receiving assignments from the dispatching center, and monitor the activities of mobile units on adjacent beats—moving to be in a position to render aid in pursuits if needed.

The *emergency mode* of operation of the police mobile radio network must provide for the organization of police mobile units into tactical operational units for dealing with large-scale riots, disasters, or demonstrations. The network topography is no longer a simple wheel-spoke geometry type, since control of the tactical force may be given to a command vehicle on location in the emergency area. This latter mode of operation is one for which police departments generally have not been prepared in the past. In recent years, however, the forward-looking departments have been making substantial changes both in organizational procedures and in design of their communications networks.

The difficulty of area-wide planning and the lack of it are evident in police communications networks. Police radio communications have grown in an informal way in response to the needs of the moment. As will be brought out in the discussion, much can be done to improve them both in terms of flexibility and power as well as in efficient use of the radio spectrum.

Finally, the money allocated in the police budget for equipment as opposed to money for personnel is characteristically extremely small. The Los Angeles Police Department, for example, is completely mobile, yet 93 percent of its budget is for personnel.

The desired capability for police radio networks encompasses operation in the normal mode the majority of the time and in the emergency mode when required, with additional performance refinements thus far not available to the police or available only to a limited degree. These include:

- *Car-to-car capability*. The police are unanimous in their desire to have all cars on a radio channel able to listen to both sides of all conversations and to have a capability for car-to-car communications. The former goal is generally realized although the latter one is not.
- *Interagency communications*. The police require an intermunicipality communications capability, but on the dispatcher's level rather than on a car-to-car basis. In many areas, this capability has been achieved with fixed-station radio equipment.
- *Convenient portable radios*. Police are unanimous also in their desires to extend their radio networks beyond the restriction to mobile equipment to include small, inexpensive, portable radios that can be used by the foot patrolman and by the officer when away from his car.
- *Digital communications*. Many police have expressed a need for Teletype in the car so that long messages can be transmitted and recorded automatically. The primary difficulties in providing this feature have been cost and the lack of available frequencies.

The spectrum congestion problem

There is general agreement that severe spectrum congestion exists in the police radio bands, and that this congestion extends across all the radio bands used in land mobile applications.

The indications from limited field tests undertaken by the Federal Communications Commission in Los Angeles and New York, from the preoccupation with the subject in the *Bulletin of the Associated Public Safety Communications Officers*, from the study made by the Land Mobile Section of the Electronic Industries Association,[1] from evidence gathered and presented in connection with various dockets[2,3] that the FCC has opened in recent years, all indicate serious congestion and a growing demand on the part of all organizations that use radio in land mobile applications. Commissioner Kenneth Cox of the FCC, in a recent article addressed to the engineering profession,[4] pointed out the rapid growth in the Land Mobile Services—from 10000 licensed transmitters in 1948 to over 220000 in 1965—and the reasons for creation of the Advisory Committee for Land Mobile Radio Services. The need for action in this area has been pointed out in Congress.[5]

There are many examples of the effects of the spectrum shortage. Typical ones are given in Table I. Lack of a clear measure of what is available and a firm estimate of what is needed hampers a clear exposition of the problem.

Consider first the situation with regard to the measure of what is needed. Actual channel loadings—that is, measurements of the percentage of time a radio channel is busy—would be indicative of the extent of the crowding. Naturally, the traffic loading in police radio channels varies, the channels being busiest in the evening and on weekends. An average loading of 50 to 60 percent, however, indicates an extremely busy channel.

Surveys made by members of the Science and Technology Task Force have shown that a wide variation in police radio channel loadings exist. In one major city, although several channels were heavily loaded, one was very lightly loaded. Because of the inflexible design structure of police radio networks, there was no way that the city could easily switch channels from one set of users to another to use the lightly loaded channel to ease the total radio traffic burden. In many other cases, small municipalities were found to have lightly loaded (3 to 5 percent) channels although these municipalities were adjacent to a number of other cities with badly overloaded facilities. Thus, radio channel loading averaged over a metropolitan area is not a clear-cut indicator of the spectrum congestion.

Approximate rules of thumb for radio channel requirements might be arrived at on the basis of population. Sample statistics taken in the course of the work indicate that on the average, over a 24-hour day, a police patrol vehicle receives about one call per hour.[2] Further, on the basis of annual calls for police service from the public, it appears that it takes a population of about 25 000 to generate the average one call per hour for a

I. Typical examples of the effects of the spectrum shortage

Area	Description of Magnitude of Radio Congestion
City of New York*	Communications for 2000 police mobile units provided by eight simplex radio channels. (A simplex circuit in a single frequency is used for transmissions in both directions.) The Bronx, population of 1.2 million approximately, is patrolled by about 225 mobile units all using a single-frequency channel for communications. New York City has put 500 police cars on the street without radios because of frequency shortages. In peak evening hours, police in cars must use telephones to contact headquarters in order to leave radio free for dispatchers to send messages out.
Suburban northern Illinois (Cook, Lake, Du Page, McHenry, and Will Counties)	One network in southern Cook County has 35 base stations and 200 mobile units on one frequency. Illinois State Police in Cook County have 200 police mobile units on one frequency. Radio-traffic volume for 1965–66 reported as 374 500 messages—an average of one message every 80 seconds for the entire year. Fifteen municipalities north of Chicago use a total of 306 police mobile units on a single frequency. Twenty-five communities west of Chicago use a total of 231 police mobile units on a single frequency, shared by Gary, Ind.
Southern California	Six cities in eastern Los Angeles County (Pomona, Claremont, La-Verne, Covina, Azusa, and Glendora) with a total population of 250 000 share a single police radio frequency. Eight cities in the South Bay area of Los Angeles County, including Torrance (population 120 000), share a single police radio frequency. The City of Los Angeles has been unable to obtain two additional frequencies, one for city-wide emergency, the other for emergency tactical control. New police cars ordered have been incompletely equipped because of the radio-frequency shortage.
City of Detroit	Development of new police radio network held up because of shortage of radio frequencies.
Washington, D.C.	New police radio network still incomplete after several years' development because of shortage of police frequencies.

* The situation in New York City has been alleviated considerably by the assignment in November 1966 of ten forestry channels to the New York City Police Department.

mobile patrol vehicle.* Thus, tentatively and subject to a more detailed evaluation, it may be said that it takes at least one patrol vehicle on the street at all times for each 25 000 of population. Further, studies by the Rand Corporation indicate that a police conversation lasts on the average from 25 to 60 seconds.† This checks well with the viewpoint accepted by the FCC that about 50 to 60 mobile vehicles make a maximum load for a single radio channel. Finally, these figures are based on an average loading, but a communications system must be designed for the peak load. Assume a 5:1 ratio between peak and average loading. Thus, the figures would indicate the assignment of one police radio channel for mobile patrol purposes for every 150 000 of population, on the basis of 30 cars per channel. The needs for supervisory vehicles, detective channels, and other special-purpose channels would, of course, increase this number.

An alternative method of arriving at a population rule of thumb, suggested by Dr. Blumstein, is as follows: Assume an average of 2.5 police personnel per 1000 population. Assume further that half the force is on mobile patrol beats and that with one-man patrol cars it takes about five police patrol personnel for 24-hour coverage of a beat. This leads to a figure of one patrol beat per 4000 population. If we use the preceding approach, which considers the peak-to-average loading ratio, a figure of one patrol car per 5000 population is obtained. Again, assuming 30 cars to a radio channel leads to the assignment of one radio channel per 120 000 population.

Although the two rules of thumb are in good agreement, neither should be relied upon to provide more than just additional insight into the problem area. When one considers that municipal, county, and state police operate over the same area and that municipal boundaries vary greatly in size, which has no relationship to the area that can be covered by a radio transmitter, it becomes difficult to consider applying any rational guideline in determining the police mobile radio needs of an area. The approach taken in the Crime Commission work was to recommend that the FCC consider developing new procedures for interfacing with the police community.

*Supplied by Dr. J. Kidd, National Science Foundation, on the basis of data derived from the City of Chicago.

† In an informal conversation, Al Hiebert, Rand Corp., supplied this figure with the caution that it is based on inadequate evidence. All other measurements known to the Science and Technology Task Force have been of the number of transmissions rather than the number of conversations and so are much less useful.

The recommendations

Figure 1 gives the gist of the recommendations that came out of the police communications area in the course

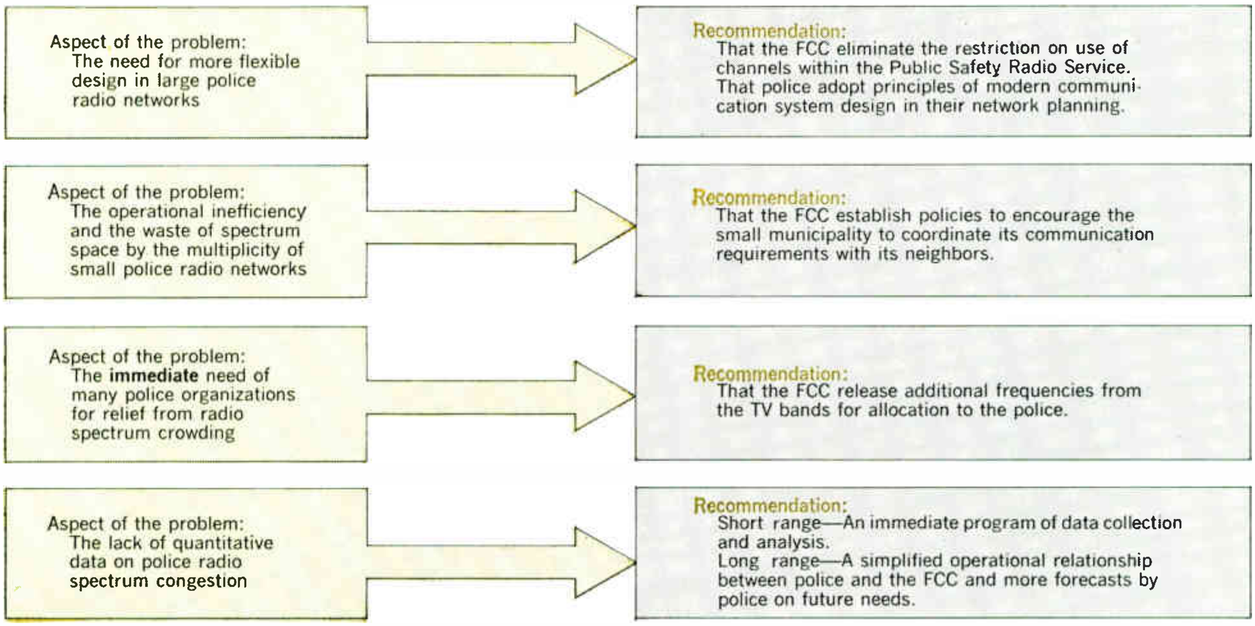

FIGURE 1. Scope of the recommendations concerning police radio communications.

of the Crime Commission work. Briefly, it was felt that in the interest of more efficient communications systems development, the divisions between users in the Public Safety Bands should be eliminated and municipalities encouraged to develop coordinated communications networks to fulfill all their needs rather than individual networks for individual municipal departments. Although the recommendation was oriented toward police needs the impact would obviously be felt in all municipal activities. Further, it was believed that greater efficiencies would result if municipalities below a critical size and located in areas of radio congestion were required to coordinate their needs with neighboring communities to eliminate the inefficient small communications network.

These recommendations, if adopted, should lead to a gradual reduction of the confusion of overlapping municipal mobile radio networks with their wide variations in channel-traffic loading. The immediate problem, however, requires immediate action; accordingly, a recommendation was made for immediate spectrum congestion relief for the police by reallocation of frequencies from the television bands.

As mentioned, changes in the police/FCC working relationship are urged. These changes will, among other effects, require police prognosis of future needs. For the present, however, it was urged that an immediate survey be made to determine quantitatively the extent of the police radio-spectrum shortage.

Basic design concepts of mobile networks

An efficient police mobile radio network should possess two dominant characteristics. It should have a number of "switchable" channels that can be moved from one group of users to another as required by the demands of the moment and so that radio congestion can be relieved as it develops. Second, the system should be characterized by the greater use of trunk groups rather than single channels as in the present mode of operation.

In spite of the radio-spectrum shortage, police do reserve channels for special purposes. These channels are often underutilized as compared with the working channels used for control of the mobile patrol force. The special-purpose channels include those reserved for city-wide emergency and detective channels. Moreover, the police, because of the nature of their operations, require a substantial reserve communications capability for use in major emergencies. Although the need for a reserve capability and the need for special-purpose channels are entirely legitimate, obtaining these capabilities by having channels that are not frequently used is evidently a wasteful technique. In addition, these resources can and should be available when needed for relief of congestion in the normal patrol channels. Their utility would be greatly enhanced if these channels could be switched into or out of various parts of the network as required.

Currently, police radio channels are commonly connected on the basis of frequency; that is, the mobile radio is tuned to the frequency of the transmitter carrying the dispatcher's message and thus a radio link is established. The mobile unit operator can hear no other channel unless he has a multichannel set and, by manually switching, tunes to another channel. The transmitter can address only sets tuned to its frequency. Therefore the system, once established, is relatively inflexible.

It is possible to address police radios by subaudio codes, which are currently used for addressing, though only to a small extent. By this means, one transmitter without changing frequency may be used to send messages to one group of police cars at one time and to a different group at some later time, depending upon the coded address that accompanies the message. A great deal of flexibility is obviously possible since the same channel may be used at different times for detective work, for addressing only supervisory vehicles, or for city-wide purposes by variation of the address. Although some switching capability can be achieved without the use of selective coding addressing, obviously much greater capability is available through its use. Hence, it was strongly urged in the Commission's work that police agencies make greater use of selective coding for addressing in their radio networks.

The second important feature desirable in police radio networks is the greater use of multiple-frequency trunking. This concept, familiar to communications engineers, and the concept of switchable networks were recommended in general principle rather than as cure-alls to be applied in all situations. The extent of their applicability depends upon the system's geography and topography.

Figure 2(A) shows the method currently used to provide radio coverage for a police mobile fleet. The city is divided into major divisions, each of which is patrolled by a number of vehicles (usually 30 to 50). This portion of the police mobile fleet has a single radio channel connecting it to its dispatcher in police headquarters. The channel may be simplex, in which case a single frequency is used for both the dispatcher talking to the car and for the car replying to the dispatcher. It may be duplex, in which case the car replies on a different frequency. For ease of discussion, simplex channels are assumed here.

In Fig. 2(B) is shown a first alternative, using the concept of multiple-frequency trunking. Here two channels, to be used in common, are assigned to two major divisions of the city. Patrol vehicles using the channels will communicate only with their own dispatcher, since addressing is now by selective frequency coding rather than by frequency. In the situation of single channels of Fig. 2 the individual user will occasionally find the channel busy. In the case of Fig. 2(B) it is required that both channels be busy *simultaneously* for the user to be faced with a delay in placing his call; thus, this arrangement generally results in better service. Figure 2(C) shows all four channels in a trunking arrangement. Here, all four channels must be busy simultaneously for a call to be delayed.

It will be noted that in Fig. 2(B) it is not possible to have uneven loading between the two paired channels, and that in Fig. 2(C) it is not possible to have congestion of one channel while the others are lightly loaded. Thus, maximum advantage is taken of total facilities. These principles are utilized in the AT&T mobile radio service. Table II illustrates the advantages derived from multichannel trunking in the configuration of Fig. 2. Although these concepts of trunking and switching are well established, they are not at present used to any extent in municipal mobile radio systems.

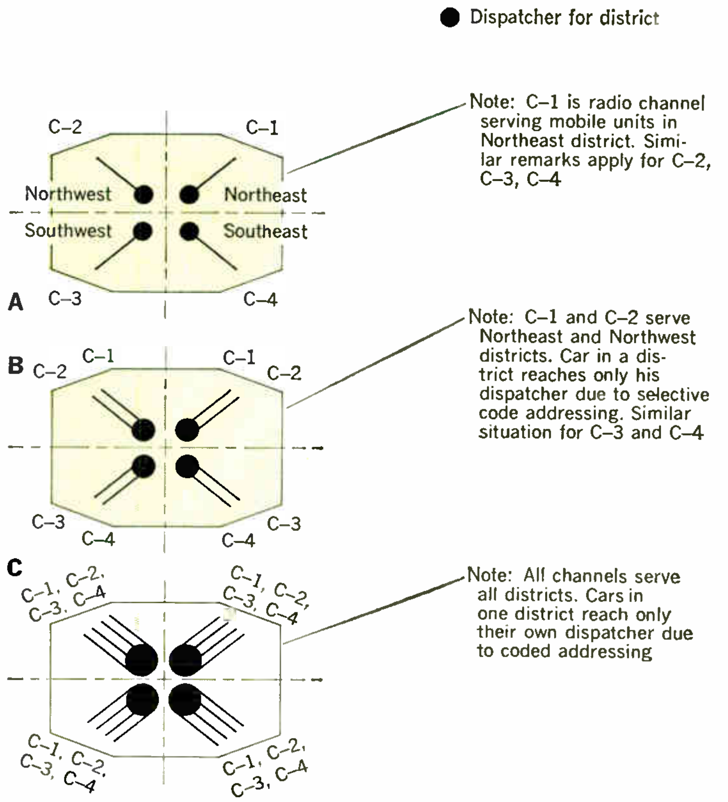

FIGURE 2. Multiple-channel trunking for stylized city. A—Conventional radio network. B—Two-channel trunking. C—All-channel trunking.

Operational aspects of police radio network design

A number of problems peculiar to police communications modify the straightforward application to police radio of the principles just discussed. The dispatcher, for example, is often the controlling factor and the potential "bottleneck" in mobile radio communications. It may well be decided in a particular situation, therefore, that multiple-frequency trunking should not be applied to the dispatcher's situation—that, in fact, he should have his own exclusive channel and so face no possibility of delay in placing his calls. This decision implies the use of a duplex system in which the dispatcher talks out on one frequency and receives incoming calls on another.

The gradual growth of police mobile radio networks had led to an increased concentration in the hands of the dispatcher of effective control of the police mobile forces and a corresponding diminution of the effective authority of the sergeants and lieutenants in the field. This trend can and should be modified to strengthen the position of the field supervisors. Police have insisted that all cars in an area be able to monitor all calls, partly for improved coordination and partly to permit the field supervisors to exercise their functions. This requirement implies, but does not dictate, the use of a simplex system in which both dispatcher and cars talk on the same frequency.

In a duplex system, the car-to-dispatcher conversion can be relayed out to all cars by repeating it and retransmitting it over the dispatcher's frequency; thus, monitoring of all conversations by all cars is still possible in this mode. In simplex operation with both sides of the conversation on a single frequency, monitoring the conversation is very easy. In addition, the fact that car-to-car conversations are possible aids the field supervisor in performing his function and facilitates field operations in general. Simplex operation with selective coded addressing appears to offer an attractive combination of characteristics for police radio use.

By selective addressing, the sergeant should be able to address directly the units under his control without going through the dispatcher. By the same means, all the cars under the direction of the sergeant should be able to monitor the conversation between him and any car in the tactical unit. Further, in case of a large-scale disturbance, the car-to-car communications capability should make it possible for a group of cars to be separated from dispatcher control and to operate as a field force under the direction of the field supervisor. These features can be obtained in a duplex system, but are generally less

II. Reduction in probability of delay in message transmission by the use of multichannel trunking

	Probability of No Channel Available*		
Traffic Loading	Single Channel (Conventional)	Two-Channel Trunks	Four-Channel Trunks
30%	30%	14%	3%
40%	40%	23%	9%
50%	50%	33%	17%
60%	60%	45%	29%
80%	80%	71%	60%

* Based on calculations provided by Dr. Mandell Bellmore, Operations Research Dept., Johns Hopkins University.

Note: Multiple-channel trunking is particularly effective when channels are well loaded (30 to 50%) but not excessively loaded. When channel loads exceed 50%, relief by means of other techniques should also be considered.

expensively realized with simplex. Hybrid systems for operating in different modes at different times, are, of course, possible.

Implications of improved design

Multiple-channel trunking enables the radio channels to be more evenly loaded. Such a feature is not possible, however, in the small networks of many independent municipalities. Since, in addition, these independent networks hamper the ability of the police to carry out coordinated actions in major emergencies, there are powerful reasons for discouraging their further development. Note that there is no implication here that an independent municipality should not have, if it desires, its own police force. The single conclusion is only that such police forces should coordinate their communication needs with those of other forces in the same area.

Channel switching can result in more efficient use of channels through more even loading, provided there are radio channels available to be switched. Such channels exist in the Public Safety Service. Highway-maintenance frequencies and school-bus frequencies are often in such a category. These channels generally are used only during the normal working day or for short periods. The busy hours for the police, when they need extra channels, are evenings and weekends. Thus, a second implication of the greater use of trunking and switching is that the total radio resources of the city be considered in designing a police network and those frequencies that can be utilized should be made available to relieve police radio-traffic congestion at the peak periods.

The third implication of the concepts presented here is that police mobile radio networks of the future will be more costly than those of the past. Very preliminary estimates made on the basis of telephone company experience with its mobile telephone service are that costs can be expected to increase to about 1.5 to 3 times the cost of present systems. The benefits derived in terms of increased police operational capability as well as more effective use of the radio spectrum are considered to be sufficient justification for the additional investment. Further, as mentioned, communication equipment costs are a negligible portion of the total police budget.

A fourth implication is, as previously mentioned, that police agencies must direct more attention to their network design requirements. At present, police radio networks are to a large extent built to accommodate off-the-shelf hardware rather than designed to be responsive to police needs. The situation is caused by the fact that, in general, the suppliers design the system in order to sell equipment. The fault does not lie entirely with them, however, for police agencies often are unwilling to consider design as a separate and distinct effort for which they must provide funds. They assume, and in the past it has been a valid assumption, that the design is a service that the manufacturer provides in order to sell his equipment. The increasingly complex needs of police communications make this approach an inadequate one for the future.

Design concepts applied to specific areas

An attempt was made to evaluate the concepts just presented by applying them to concrete situations in various parts of the country. The three areas selected for examination were the Washington, D.C., metropolitan area, the Los Angeles basin, and New York City. For a number of reasons the results were somewhat uneven.

The analysis went into the greatest depth in the Washington metropolitan area simply for reasons of convenience. Yet, even here, several detailed studies were dropped when it became evident that technical designs did have political overtones and a design developed merely as an example might be construed as a definitive recommendation or an implied criticism.

In the Los Angeles area, similarly, political considerations suggested that hypothetical designs might serve no useful purpose. Although in a number of areas of the country small police agencies, under the pressure of spectrum congestion, will have to work out more efficient methods than are in use at present for utilizing the radio spectrum, there are many different organizational approaches open to those agencies. It did not appear to be appropriate to develop in specific detail any one approach that might be interpreted as "the" solution favored by federal agencies in Washington.

The situation in New York City was refreshingly simple, for several reasons. First, only one police agency was involved. Second, the basic problem was starkly clear. New York at the time of the study had such a critical shortage of police radio channels that nothing could be done until that shortage was alleviated.

The Washington metropolitan area covers about 3600 km^2 (1400 square miles) with over two million inhabitants. It includes the cities of Washington, D.C., and Arlington and Alexandria in Virginia, and the counties of Fairfax in Virginia and Prince George's and Montgomery in Maryland. All of the counties and municipalities mentioned have their own police departments, as do a number of smaller towns in the various counties. Approximate channel loading in the different departments was determined by asking the departments themselves to check, by consideration of the number of patrol cars per channel, and by some monitoring. The loading was found to vary from lows of 2, 3, 6, and 8 percent to highs of 67 percent. The police car loading varies from 2 to 3 up to 40 to 50 cars per channel.

A first attempt at a coordinated network was made on a county basis. Montgomery County, Maryland, has already coordinated its police under the county. In the other counties, it was evident that dramatic improvements resulted when such steps were taken. The reason was that very small communities in the Washington area have assigned lightly loaded police channels, which, when incorporated into a county system, served to reduce greatly the average channel traffic loading. The result was not considered to be artificial, however, for the situation of small communities with lightly loaded police channels located in areas of radio congestion is not uncommon. The loading was so significantly reduced merely by countywide coordination that no attempt was made to reduce it further by trunking or switching. However, practical hardware considerations would require that certain channels be surrendered to the FCC in return for others more closely located in the radio spectrum to most channels in use in the particular county.

An attempt was made to investigate the gains that could be made by organizing communications on a municipal basis, utilizing all the frequencies available to a particular local government. The indications, however, were very strong that such an exercise, though merely being carried out for demonstration purposes, had political overtones, and the attempt was dropped. Facing such problems is a necessity in an actual design development but serves no point in a mere example. Moreover, it was evident from the dramatic results of area-wide coordinated communications that much can be done by the police community to improve its communications.

The situation in the Los Angeles basin is acute as well as complex. The Los Angeles City police, the police of the many smaller municipalities involved, and the Los Angles County police all work in jurisdictions that are a patchwork. One jurisdiction often completely surrounds another, and isolated small county areas are scattered throughout the Los Angeles basin.

A page from one of the Los Angeles area telephone books lists 26 different police emergency phone numbers for 30 localities and includes a footnote that 13 separately identified areas are to use the city police emergency number. These 43 areas are, of course, not clearly identified to the citizen on the street but run one into the other with no clear boundary. From the telephone company's viewpoint, the situation is equally unsatisfactory. The business area served by one central telephone office is divided into six separate police jurisdictions. Thus, coordinated police networks in Los Angeles not only would serve to alleviate the spectrum congestion, but also would considerably simplify the problem of telephone access to the police by the citizen.

Some general features of a coordinated communication system for Los Angeles can be described. Consider a situation in which a number of communities form such a coordinated network. Each community would no longer have channels as such, but *selective calling codes* instead. Assuming the appropriate geography and frequencies, each police car might have six channels for transmission and an automatic channel selector similar to that used in the AT&T mobile dial telephone system.[6]

The occupant of a police car calling in to his dispatching center would literally not know which radio channel he was using, since the channel selector would pre-empt the first channel not in use at the time he decided to place a call. A feature of pre-emptive override for life-or-death calls at times when all channels were busy would be required. Greatly superior communications would result from this mode of communications as compared with the present single-channel system.

At the dispatching point, the dispatcher might have a number of frequencies shared with other communities; he, too, would call his cars, not by frequency, but by the selective addressing code. Pre-emptive override for "hot" calls would be required at this point as well. For those times the dispatcher might require a channel on an exclusive basis, he would obtain it by arrangement with the group coordinator. The overall goal within the communities sharing the system would be the creation of a flexible telephone-like system as opposed to one having the restrictions inherent in present single-channel radio networks.

Selective coding would permit the deletion of frequencies from the pool of spectrum resources when these frequencies were needed for special purposes and also would permit the addition of frequencies to the pool when required for weekend overloads. Probabilities of delays in placing calls would be substantially reduced.

No one department could inadvertently monitor the calls of another department, because the selective coding, now used to a small extent in many police departments, would only "open up" those receivers to which the message was addressed. The need for an area-wide emergency channel would not tie up a radio frequency but would merely require an additional code in the system; thus, switching to area-wide communications becomes a matter of addressing rather than frequency selection.

The approach described here has been shown to give far superior service for the same amount of channel resources, but one might say that it trades frequencies for dollars. Although it is less wasteful of radio frequencies, it can be expected to be more costly in equipment.

The point cannot be stressed too strongly that no municipality will permit its police forces to be dispatched by any person not a member of that police department except under the most unusual and serious circumstances and by carefully worked out prearrangement. The development of efficient large police communications networks by intercity cooperation is critically dependent upon the individual cities retaining control of their own forces and privacy of their own communications at least to the extent now prevailing. There would, in fact, be no motivation at present for the greater efficiencies of pooling resources on an intermunicipal basis were it not for the unyielding pressures of the limited radio spectrum.

The design of Public Safety networks

Since the times of heaviest usage of the different Public Safety communications channels do not coincide, it is evident that major gains in more effective use of the RF spectrum can be made by the creation of such networks. Although the police and fire channels are used night and day, seven days a week, the same is not nearly as true for highway maintenance frequencies or for local government frequencies employed for miscellaneous local activities not directly concerned with public safety.

Police officials generally have serious reservations about the practicability of Public Safety networks. This attitude contrasts with their willingness to participate in sharing arrangements on computer facilities and is quite understandable. The police are a quasi-military organization in which morale and discipline are as important as equipment. In police mobile radio networks the communications situation is virtually identical with that involving the command and control of military forces. Such considerations do not arise in computer sharing. Thus, the police have reservations about a city-wide

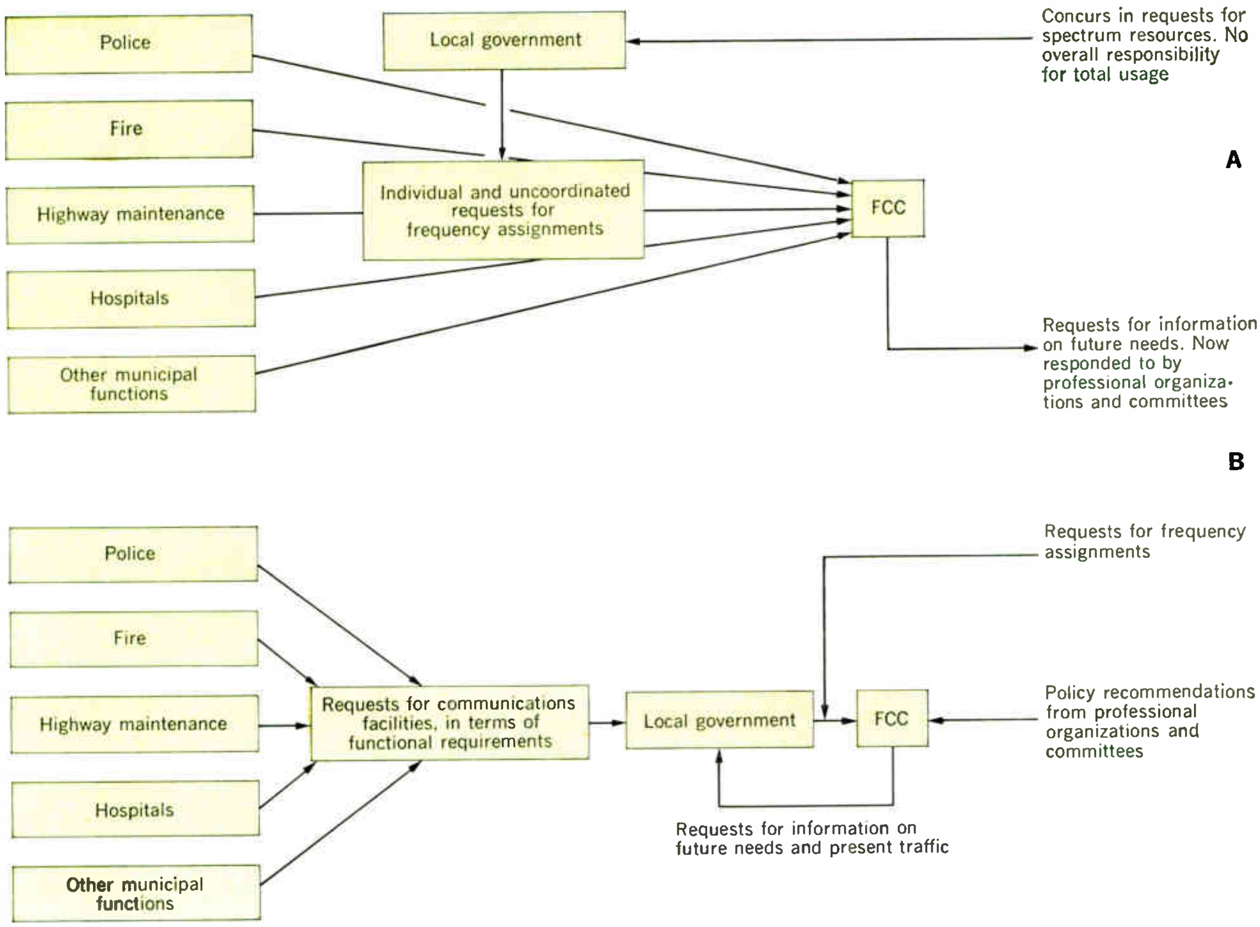

FIGURE 3. (A) Present and (B) proposed systems for Public Safety frequency assignments.

communications system, since its adoption might cause them to lose some of the close contact with their field forces that is essential to good organizational control.

A further objection that has been raised by police communicators is that if they can acquire additional channels, as needed, from other municipal services, then the other services can make a case for using police frequencies when they face critical situations. Therefore, the ability to control and dispatch police vehicles becomes more nearly subject to decisions that may be made by nonpolice personnel. However, a basic set of channels can be provided for such vital operations as those of police and fire, with no technical facilities provided for switching the channels out of those services. Thus the police and fire chiefs can be assured of having a basic communications capability. Other channels, of a less essential nature, can be provided on a switchable basis.

A number of counties in the country do have county public safety communications centers. Several were visited in the course of this work. Although these centers provide impressive advantages in terms of centralization of maintenance and the development of openings for professional caliber personnel, they do not constitute integrated networks in the sense used here. Frequencies are still identified with usage and essentially a central dispatch point is created for a large number of individual mobile radio networks. Nevertheless, these centers represent a distinct advance over the patchwork of small separate centers that exist in most counties.

The relationship between the police and the FCC

The *allotment* of different portions of the spectrum to different usage is carried out by international agreement. Within the United States and in the nongovernment sector of the radio spectrum, the *allocation* of bands of frequencies to different nongovernmental services is determined by the FCC. Within the framework of these allocations, assignments of individual frequencies to individual users, excluding agencies of the federal government, is then made by the FCC. The coordination of activities in the government bands—which refers to the federal government only, since state and local government use of the radio spectrum is under FCC jurisdiction—is carried out by the Intragovernmental Radio Advisory Committee (IRAC). This committee has a permanent staff located in the Office of Telecommunications Management of the Executive Office of the President.

In earlier years, it was not uncommon for considerable sharing of frequency resources to exist on a somewhat informal basis. Thus, before World War II, the communications center of the Washington Metropolitan Police Department as a service dispatched police mobile units for the surrounding counties. The frequencies utilized were in the HF band and, though bothered by skip interference, gave very large local coverage and so were convenient for dispatching distant vehicles.

In recent years, with the increased metropolitan congestion and the shift to the less interference-prone VHF and UHF bands, the large metropolitan police forces have had too large work loads to provide service to their smaller neighbors and too limited coverage to reach distant neighbors reliably.

Matters of frequency assignments come to the FCC on a piecemeal basis, and despite the fact that the FCC has urged users to consider and present the broader implications of their requests, the actual workings of the system have led to keen competition for ever-scarcer frequencies on a highly individual basis. The result has been that, although users need relief from frequency congestion, there is a tremendous variation of traffic loading on the police frequencies in all areas, which indicates inefficient use of the total resources. Another result has been that the FCC does not get a coherent picture of spectrum usage within an area so that it can properly address the policy questions on a national level with which it must be concerned. For these reasons, it was recommended that the FCC limit by rules the size of municipalities in terms of population and/or land area with which it will deal directly in regard to frequency assignments in the Public Safety Radio Service. The size limitation was recommended for application only in areas of major radio congestion. Such areas are amenable to clear definition since they coincide with major population areas.

To qualify for frequency assignments, smaller municipalities would be required to work together as a group or coordinate with the core city of the area. Such a response is what is desired, for it encourages networking without dictating in any way the manner in which that networking should be accomplished on a local level. It is possible that rare cases will exist where it is impossible for a small community to enter into such a network. It was suggested that the FCC rule allow for such exceptions upon the presentation of substantiating evidence. The recommendation was strengthened further by a second recommendation that municipalities fitting into the category just described be notified that, unless they show justifiable cause for exception, they would be required to release within five years of notification date such Public Safety frequencies as had been assigned to them. Note that FCC licenses are issued for periods of no longer than five years in any case.

The second recommendation was aimed at bringing into coordinated networks those municipalities that have no motivation to join these networks because of their present satisfactory situations. The indication is that there is a sufficient number of such communities, and sufficient radio spectrum resources are involved to make the recommendation worthwhile.

It was recommended that, as soon as practicable, the FCC by rule establish a policy of assigning Public Safety Radio Service frequencies only to the local government; these frequencies would not be identified by user and not assigned directly to the users, such as police or fire departments. It was further recommended that frequency advisory matters be handled by one committee in each area instead of by separate committees for police, fire, highway maintenance, and forestry conservation.

The answer to the question of why police communicators do not use the lightly loaded frequency resources that may exist in their municipalities is an obvious one. In most cases, these frequencies are not licensed for police use. The FCC has recognized the need for multiple use of radio frequencies by establishing within the Public Safety Radio Service a band of local government frequencies that can be used for any legitimate local government activity. The majority of the frequencies in the Public Safety bands are, however, specified for type of user. In addition, it is not politic for the police to examine the resources of other local government organizations. Thus, a city may have more than adequate total radio spectrum resources to create a highly efficient radiotelephone network and, at the same time, the police may be desperately short of radio resources. It is probable that this is the case in at least one major metropolitan area with serious police communication problems.

The response from one knowledgeable and experienced individual to the suggestion that the subdivisions of the Public Safety Radio Service be eliminated (for those subdivisions that involve municipal radio services) was that possibly such a move would imply the abdication by the FCC of some of its responsibilities. His point was that the FCC is responsible to see that police, fire, and other municipal functions have adequate spectrum resources.

Careful thought indicates that it is the proper function of the city government to make certain that its people have the necessary police and fire protection. By breaking down the frequency assignments below the municipal government level, the FCC is to an extent inadvertently injecting itself into local government affairs, increasing the difficulty of its own task, and placing artificial restraints upon the municipal government. This, of course, was not the case before radio spectrum congestion became a problem. Under the broader characterization of the frequencies involved, the FCC retains its capability to see that there are adequate spectrum resources for municipal functions, since individual requests for frequency assignments must still develop the justifiable need. The municipality, however, is now responsible for the efficient use of its total radio spectrum resources, and designs based on economies of scale become possible. The proposed change in the assignment procedure is diagrammed in Fig. 3.

Note that the municipality retains the freedom to develop, in cooperation with neighboring cities, a coordinated police network, or its own coordinated public safety network, or any combination of the two. From the FCC viewpoint, the only requirement is efficient use of the limited radio-frequency spectrum.

The role of advisory groups shown in Fig. 3 should not be overlooked. In the present situation they have provided, and in any new situation will continue to provide, invaluable advice and guidance to the FCC on policy matters that transcend the level of local areas. These groups include such important and dedicated organizations as the International Association of Chiefs of Police (IACP), International Association of Fire Chiefs (IAFC), International Municipal Signal Association (IMSA), Association of Public Safety Communication Officers (APCO), Forestry Conservation Communications Association (FCCA), American Association of State Highway Officials (AASHO), Electronic Industries Association (EIA) Land Mobile Section, Public Safety Communications Council, Advisory Committee of the FCC for Land Mobile Radio Services, and Eastern States Police Radio League (ESPRL). The contributions from all of these groups have, in spite of the informal nature of an advisory function, often been substantial, as evidenced by analyses presented in FCC dockets.

Finally, in connection with the frequency assignment procedures, the suggestion has been made on several occasions that the Public Safety bands be placed in a special category distinct and separate from that of the commercial, industrial, and broadcast users and possibly outside the FCC jurisdiction. The approach has obvious merit in that the criteria for evaluation of the needs in Public Safety are, and should be, totally different from those used for the needs of the commercial interests. This difference is emphasized by analyses currently being made of the "dollars value per unit wavelength" of the spectrum. It is difficult but not impossible to apply this dollar approach to the Public Safety users.

Even though the Public Safety users are in a different category than are the commercial and industrial users of the spectrum, creation of a special category for Public Safety does not seem practicable. Three possibilities are:

1. Transfer Public Safety from the nongovernment bands, under the FCC jurisdiction, to the government bands, under IRAC jurisdiction.

2. Create a new category and new agency to handle the Public Safety portion of the spectrum.

3. Retain the present status but create conditions to improve the "bargaining power" of Public Safety users vis-à-vis broadcasters and commercial users.

The first possibility does not appear to offer any advantages to the Public Safety user, and appears to have several disadvantages. IRAC is a committee of government agencies, which operates under the support of the Executive Office's Office of Telecommunications Management. In working with IRAC, Public Safety officials would find themselves immersed in federal government activities with which they were not familiar and, often, would discover that essential information on frequencies was classified by the military. There are obviously enormous advantages to working in a completely open atmosphere with the FCC; for this reason, the shift to IRAC is not recommended.

The second possibility is also considered to be inadvisable, as the creation of a new category and a new agency would further complicate the problem of government administration of spectrum allocations. Considerations of reallocation of spectrum space in the nongovernment bands would involve interactions between two federal agencies that would inevitably slow the process and make the decisions more difficult.

Accordingly, and in spite of the admitted imperfections of the present system, the recommendation was made that the Public Safety Radio Service be retained in the nongovernment portion of the radio spectrum under the jurisdiction of the FCC.

Reallocation of television frequencies for police use

Finally, and of most immediate practical importance to the police community, the recommendation was made that channels be reallocated from UHF television and that from these resources additional channels be made available for police use. The question of radio spectrum allocation is admittedly complex. The situation of one service being extremely crowded and another underutilized, does, however, suggest the need for such a change. In addition, a small fraction—less than 10 percent—of the UHF television channels would represent a very large number of police channels. It is believed to be almost impossible to project ahead the needs of a socioeconomic-technical activity such as television to within 10 percent.

The recommendation was not arrived at lightly, however; before it was made, the potential for using technology to increase the usage of the police bands was explored, the past history of channel splitting was reviewed, and the potential sources of radio spectrum were evaluated. One excellent source of background on the subject was the FCC Dockets themselves, particularly 11997 and 15398.[2,3]

It was evident throughout the work that many of the advances proposed cannot be effected unless and until some readjustment of the spectrum allocation is made.

Related topics in the Crime Commission activity

This article has emphasized the police problems in communications, particularly with reference to what the police can do to help themselves and what the government, through the FCC, can do to help them with particular regard to spectrum congestion. The topic, however, was not dealt with by itself. It provided detailed support in the Science and Technology Task Force Activity for an analysis of the apprehension process. That analysis showed the significance of speed of response to the citizen's call for help and so focused attention upon the police mobile fleet and its control by radio. The analysis, however, with equal emphasis called for increased speed within the dispatching center, which implies greater use of computer aids for dispatching.

Further, much work was done in the communications area in evaluating new equipment techniques, such as automatic police car locators, miniature personalized radios, and digital communication techniques.

The work described is thus that work with which the writer has been most directly associated—the systems aspects of police communications. It should be evident that the work revealed serious deficiencies in the present state of police mobile radio networks. These deficiencies can be corrected partly by the efforts of the police community, but an essential ingredient is the intelligent support of the federal government, particularly on the critical question of radio spectrum needs.

The author acknowledges the substantial support received from many individuals and organizations in the course of this preliminary exploration of a complex subject. The Crime Comission's Gene Muehleisen, Sam Chapman, and Robert Emrick have been particularly helpful. Special thanks are also due to Saul Gass, Richard Larson, E. R. Knickel, and Ronald Christensen, all of the Science and Technology Task Force. A number of police departments cooperated in these investigations, including many of those in the Washington, D.C., and Los Angeles metropolitan areas, as well as the New York City Police Department.

REFERENCES

1. "Study of the Federal Communications Commission frequency cards," Land Mobile Section, Electronic Industries Association, 1964.

2. "In the matter of—an inquiry into the present and future requirements of the Public Safety Radio Services for the allocation of radio frequencies," Docket 11997, Federal Communications Commission.

3. "In the matter of—an inquiry into the optimum frequency spacing between assignable frequencies in the Land Mobile Service and the feasibility of frequency sharing by television and the Land Mobile Services," Docket 15398, Federal Communications Commission.

4. Cox, K. A., "The Land Mobile Radio Services," *IEEE Spectrum*, vol. 2, pp. 42–43, Oct. 1965.

5. Dingell, J. D., "The need for additional radio frequencies," *Congressional Record House*, pp. 23207–23216, Sept. 28, 1966.

6. Nylund, H. W., and Swanson, R. M., "An improved mobile dial telephone system," *IEEE Trans. on Vehicular Communications*, vol. VC-12, pp. 32–38, Sept. 1963.

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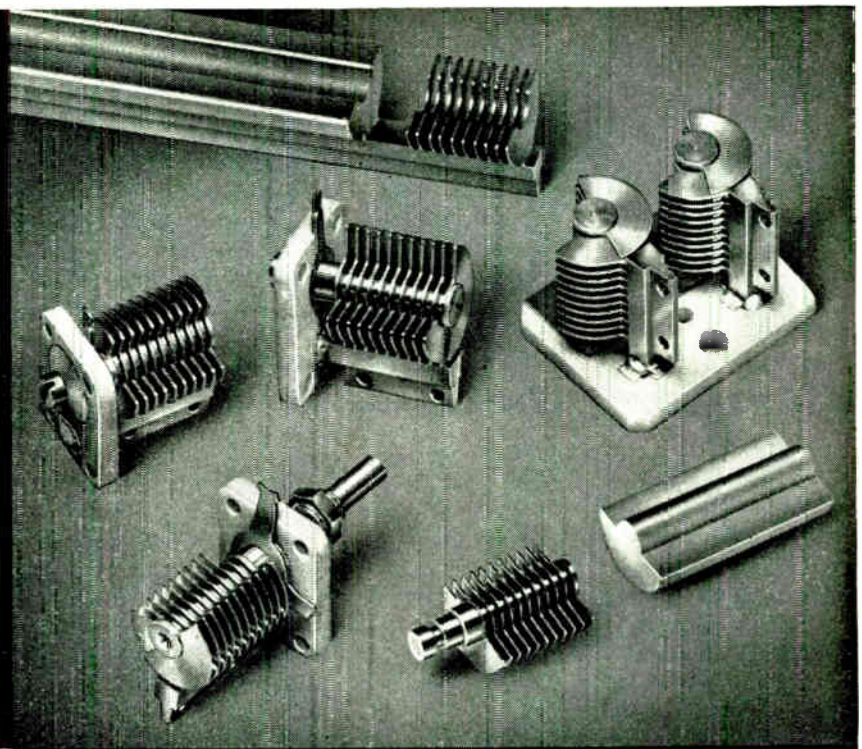

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Scanning the issues

Drift Velocities in Silicon. Three different techniques of measuring carrier drift velocities in silicon at high electric field strengths made by three sets of authors have now set to rest a controversial subject. The papers, appearing in the IEEE TRANSACTIONS ON ELECTRON DEVICES, are: "Measurement of High-Field Carrier Drift Velocities in Silicon by a Time-of-Flight Technique," by C. B. Norris and J. F. Gibbons; "Measurement of the Drift Velocity of Holes in Silicon at High Field Strengths," by V. Rodriguez, H. Ruegg, and M-A. Nicolet; and "Electron Drift Velocity in Avalanching Silicon Diodes," by C. Y. Duh and J. L. Moll. In the work reported, drift velocities have been accurately measured for the first time. Furthermore, the experiments were performed independently, and the data from the three papers are in agreement.

In his introduction to this set of papers, James F. Gibbons, Associate Editor, points out that accurate measurements of the drift velocities of charge carriers in semiconductors at high electric fields are important for several reasons. From a device standpoint, velocity-versus-field data are needed for an accurate mathematical analysis of the properties of reverse-biased p-n junctions, Read diodes, field-effect transistors, and a variety of other devices that operate with large internal field strengths ($\geq 10^3$ V/cm). Velocity-versus-field curves also provide an external manifestation of the interactions that occur between charge carriers and the semiconductor lattice and are, therefore, important in the development of semiconductor physics.

Gibbons says further that data have been available for some time on the velocities of holes and electrons in both silicon and germanium as a function of the electric field strength. However, these data are not entirely self-consistent nor is the measurement technique used free from possible objection. In this light, new measurements assume considerable interest.

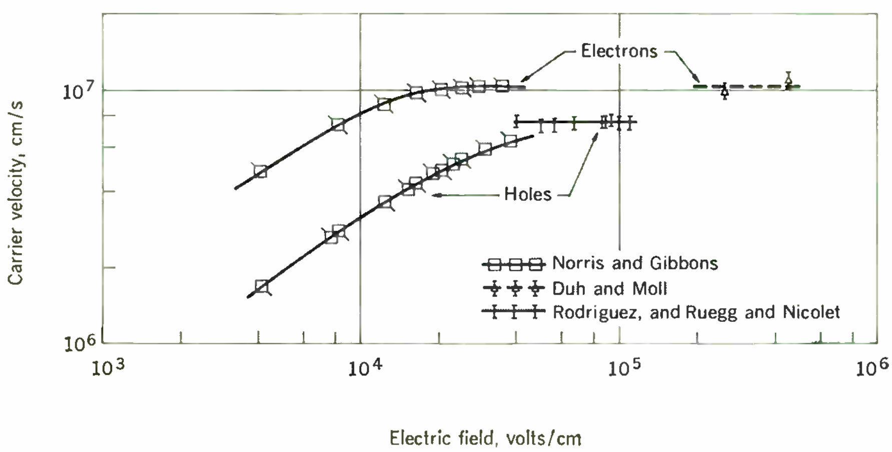
Norris and Gibbons describe a time-of-flight technique that has been used to obtain velocity data for both holes and electrons in the field range 4×10^3 V/cm $\lesssim E \lesssim 4 \times 10^4$ V/cm. Rodriguez *et al.* use space-charge resistance methods in a specially constructed punch-through transistor to measure hole velocity in the field range 4×10^4 V/cm $\lesssim E \lesssim 1.1 \times 10^5$ V/cm. Duh and Moll use a space-charge resistance measurement made on an avalanching p^+-n-n junction to obtain the electron velocity in the field range $2 \times 10^5 \lesssim E \lesssim 5 \times 10^5$ V/cm.

The experiments, Gibbons says, share two important features, namely, that the limits of error assigned to the data are ±5 percent in all cases, and absolute velocity data are obtained in each experiment. Thus, no scaling of results to fit low-field mobility data or other such adjustments are needed in the interpretation or use of the data. Moreover, Gibbons asserts, the velocity measurements from all three papers can justifiably be plotted on the same graph as shown in Fig. 1. These combined measurements probably provide the best velocity data for holes and electrons in silicon that are now available. These three papers, then, should be of real service to workers in a number of different areas of semiconductor electronics. (*IEEE Trans. on Electron Devices*, January 1967.)

Planetary Mapping and Plasmas. The IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS almost consistently publishes papers that should interest many readers beyond those served by the Group. The recent issue is no exception, in which, for instance, a paper, "Aerial Mapping Planetary Bodies" by John L. Sheehan, is of uncommon interest.

Those who grew up in the Buck Rogers–Flash Gordon comic book era, before the real rockets began to be developed, cannot help but feel an eerie pleasure in seeing those earlier four-color fantasies slowly materializing; although, of course, there is still a considerable gap between the evolving hardware and the supermachines of the science-fiction men. Nonetheless, there is a special fascination, even for those of us who are not actively involved in the hard engineering work, in keeping up with the step-by-step more mundane advances. As

FIGURE 1. Measurements on carrier drift velocities in silicon made by three different techniques are compared on this graph.



Sheehan says, we have been studying the planets for centuries through the bleary atmosphere. Now finally we can go out and take a cold, hard look at the planets now known and yet to be discovered. We peeked at the moon with Ranger and Surveyor, Luna, Lunik, and Zond, and at Mars with Mariner IV. Yet, Sheehan stresses, mapping a planet is much more than just a peek, for it yields a wealth of details not available from any other source about planets.

For instance, certain types of informative planetary mapping missions are being conducted about our own planet. Tiros and Nimbus are weather satellites we use to monitor earth-bound weather systems. Since Nimbus used an infrared sensor and a television system to scan the earth, it is called a multiple sensor vehicle. The two systems provided complementary data. It is important that planetary mapping be conducted by a multiple sensor vehicle because photographs alone can be misleading; for instance, Sheehan mentions, people who saw canals on Mars before Mariner IV sent back any photographs can still see canals on Mars and in the Mariner IV photographs.

One of the interesting aspects of the hundreds of Tiros and Nimbus photographs, which has some bearing on the mapping and exploration of other planets, is the almost complete lack of detection of life on the earth. The reason, not so strangely, is that no system in the spacecraft had sufficient resolution. However, the problem of developing good resolution is not an easy one, and the types of systems needed would be different for different planets. Sheehan, in fact, presents a summary of the characteristics of the planets and describes the kinds of systems that might be required to perform adequate mapping missions. In addition to good resolution, he says, the mapping vehicle must take stereo photographs for accurate terrain-slope mapping and must achieve broad coverage of the surface to provide a sufficient sampling of the planet's surface to permit general statements about surface characteristics. Furthermore, on top of the need for high resolution, stereo pairs, and broad surface coverage, a spacecraft for a mapping mission must measure magnetic fields, meteoroid fluxes, charged particle fluxes, and carry planetary sensors to complement the photos. This just begins to suggest the scope of planetary mapping missions, which present many interesting techniques involving hardware, operations, data retrieval, and data analysis. For those of us who are still afflicted with the Buck Rogers syndrome, Sheehan holds out the right carrot. There is no reason to believe, he concludes, that our solar system is unique in the universe in possessing planets. Once having left the earth's surface, man will continue to explore and map planets in this solar system and other solar systems yet to be found. Sheehan doesn't say this, but it is a dead certainty that one of those "new" planets has got to be named Mongo.

Another paper of interest in this same issue involves the application of familiar plasma diagnostic techniques and equipment to a not so familiar aerodynamic flow problem. The paper, "Plasma Sheaths of Models in Hot-Shot Wind Tunnels," is by Jacques Dorey and Didier Compard of the Office National d'Etudes et de Recherches Aeronautiques in France.

These authors take a comprehensive look at the theoretical and experimental studies of plasma characteristics, simplified by the use of nitrogen gas, in an electrical-discharge-driven wind tunnel. They combine the electron densities, electron–neutral particle collision frequencies, dielectric approximations, and hot-shot tunnel characteristics to show a good correlation between theory and experiment. They use electrostatic probes and VHF microwave reflectometry for diagnosis of the plasma sheath.

The authors describe the experimental apparatus and the results in nitrogen. They say that the ionization is not homogeneous during the shot, a result that seems to confirm the assumption that the plasma flow is utilizable only after a delay of more than ten milliseconds following the shock formation period. In their conclusions, the authors say that the hot-shot tunnel appears a useful facility for the testing and improvement of plasma diagnostic methods, with a view toward applying it to full-scale experiments.

Among other papers that readers may find interesting is "A Laser Device for Remote Vibration Measurement," by J. V. Foster—it involves the application of a laser to a new field. (*IEEE Trans. on Aerospace and Electronic Systems*, March 1967.)

Systems and Their Users. The current issue of the IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT contains a paper that opens an area that has not received a great deal of attention in this journal or in most management-oriented journals. It has to do with the effects of introducing new information-processing systems and taking the necessary management steps to assure that the user is thoroughly indoctrinated in the operation of the system, and that he can employ it and act on it with the highest degree of confidence.

The paper, authored by R. O. McManus, describes the management techniques employed by the U.S. Air Force to indoctrinate and prepare using organizations for the operation of the Ballistic Missile Early Warning System. The system is extremely large and complex and has many novel aspects to it with which only limited members of the engineering community were familiar and extremely few of the military operational community. Thus, an organized approach by engineering management was essential, McManus says, during the acquisition period to assure thorough user understanding. This approach consisted of requiring specific designer products or joint user–designer products or activities of some kind at close periodic intervals on key aspects of the system design and implementation throughout the entire cycle of acquisition. The most important of these, which are discussed in detail by McManus, are: engineering plan; performance specifications; test specifications; test scenarios; computer program descriptions; engineering studies; operations analysis program; incident analyses; pre-operational data briefings; and test teams.

These joint products or activities served as keystones in the program. In addition, they caused the designers to understand the prospective operators' viewpoints and the operators to understand the problems of design. In the end, McManus asserts, this rapport served to provide a final system product that optimized service to the customers or operator as well as meeting the letter of the requirement and at the same time minimizing the design problems. (R. O. McManus, "Engineering Management Techniques to Prepare a User for a New Electronic Information Processing System," *IEEE Trans. on Engineering Management*, December 1966.)

Laser Bibliography. Part IV of K. Tomiyasu's laser bibliography, covering the period from January to June 1966, has been published. It contains 734 references divided into 27 categories and listed chronologically. (K. Tomiyasu, "Laser Bibliography IV," *IEEE Journal of Quantum Electronics*, November 1966.)

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. 5
IEEE Transactions on	
Electron Devices	Vol. ED-14, no. 5
Industry and General Applications	Vol. IGA-3, no. 2
Microwave Theory and Techniques	Vol. MTT-15, no. 5
Power Apparatus and Systems	Vol. PAS-86, no. 4 and no. 5
IEEE Journal of Quantum Electronics	Vol. QE-3, no. 5
IEEE Journal of Solid-State Circuits	Vol. SC-2, no. 1

Proceedings of the IEEE

Vol. 55, no. 5, May 1967

Frequency-Domain Instability Criteria for Time-Varying and Nonlinear Systems, *R. W. Brockett, H. B. Lee*—Recent research has produced a number of frequency-domain stability criteria applicable to linear systems having nonlinear and/or time varying feedback. One of the more interesting of these stability criteria is the so-called "circle criterion," which represents a generalization of the familiar result of Nyquist. A basis for generating instability counterparts of most of the available frequency-domain stability criteria is provided. The procedure is described in detail for the circle criterion. Once the general pattern is established, it becomes a simple matter to generate instability counterparts of other similar stability criteria. Several worked examples are included to illustrate the theory.

Communication-System Blackout During Re-entry of Large Vehicles, *F. H. Mitchell, Jr.*—Much of the theoretical research on re-entry blackout is in a format difficult for the communications design engineer to use in his system analysis. Simplified equations are derived for the average sheath power loss that may be added (in decibels) to the usual space loss to obtain an approximate total propagation loss. The plasma and sheath properties are discussed in detail but largely without supporting mathematics, in order to give the design engineer a better understanding of the overall problem. For the same reason and to provide insight into the final results, the average radiated power is found, using both intuitive and rigorous techniques. Several graphs of plasma properties are included in the development as an aid to numerical computations, and results are compared with the work of other authors.

Doppler and Acceleration Tolerances of High-Gain, Wide-Band Linear FM Correlation Sonars, *S. A. Kramer*—An analysis is given of the decorrelation effects of target velocity and acceleration on high-gain, wide-band linear FM correlation sonars that match the received signal against a family of velocity reference functions, each of which is a different time compressed or expanded replica of the transmitted signal. Such sonars are shown to have velocity (i.e., Doppler) and acceleration tolerances far different from that predicted by narrow-band radar theory. Unlike the narrow-band case, the wide-band velocity tolerance may be quite small and is approximately independent of the carrier frequency and inversely proportional to the time–bandwidth product (TW). Narrow-band radar-type calculations of velocity tolerance can give erroneous results far in excess of the true value, because the narrow-band velocity tolerance is derived entirely on the basis of temporal overlap loss, whereas the actual tolerance depends primarily on the slope difference between the frequency–time sweeps of the received and reference signals. High acceleration tolerance, without separate acceleration processing channels, can be achieved by cross-correlating the acceleration return with a "best match" velocity reference function. The resultant wide-band acceleration tolerance is approximately inversely proportional to WT^2 and better than the narrow-band tolerance by a factor of 12 Q (Q = carrier frequency/bandwidth). This improvement arises because the wide-band reference functions are able partially to compensate for the nonlinearity imparted to the transmitted frequency–time sweep by an accelerating target, whereas such compensation is not possible in narrow-band systems in which carrier-shifted reference functions are employed.

CIRCAL: On-Line Circuit Design, *M. L. Dertouzos*—On-line circuit design involves interaction between a designer who initiates circuit modifications on the basis of circuit performance, and a digital computer that calculates the performance resulting from such modifications. Besides network analysis, the flexibility of an on-line utility makes possible a variety of other services such as on-line definition and modeling of new circuit elements, whereas graphical input and display devices facilitate man–machine communication, requiring no programming knowledge of the user. Compared with conventional design or batch-computer design, the on-line approach includes advantages such as savings in design time and cost, and progressive accumulation of diverse and accurate knowledge about expected circuit behavior, before actual construction is undertaken. A family of on-line nonlinear circuit-design systems known as CIRCAL, in terms of features visible to a user, internal structure, supporting theory, experience, and future plans is discussed.

The Equivalent Circuit Model in Solid-State Electrons—Part I: The Single-Energy-Level Defect Centers, *C. T. Sah*—The equivalent circuit model is developed in this series and applied to solid-state junction devices. In Part I, the exact equivalent circuit of a single-energy-level defect center in a semiconductor is developed based on the Shockley–Read–Hall model. It is then applied to the calculation of the steady-state lifetimes of electrons and holes and to the transient decay time constants. The transient decay time constants are obtained for arbitrary nonequilibrium, but steady-state, conditions and are presented as a function of the steady-state electron and hole concentrations by means of contour maps. Simple examples and gold in silicon are used for the construction of these maps. The general criteria of trapping, recombination, and generation are also obtained using the single-energy-level defect center model, which divides the carrier concentration plane $\log_{10}N$ vs. $\log_{10}P$ into four quadrants centered at the equality carrier concentrations p^* and n^*. At this equality point, the four rates of electron or hole capture or emission at the defect center are equal and the four quadrants represent regions where recombination, generation, electron trapping, or hole trapping dominates.

The Equivalent Circuit Model in Solid-State Electronics—Part II: The Multiple-Energy-Level Impurity Centers, *C. T. Sah*—The equivalent circuit of a defect center with multiple energy levels in a semiconductor is formulated and applied to the calculation of the characteristic time constants of the multiple-energy-level system. A detailed numerical example of gold-doped silicon is given, including the constant characteristic time constant contour maps. The steady-state charge distribution ratio $R_N = N_{s+1}/N_s$ (s = charge state of the center) and recombination rate ratio $R_R(s) = R_{SS}(s + \frac{1}{2})/R_{SS}(s - \frac{1}{2})$ diagrams are developed and applied to the numerical calculations of the steady-state recombination and generation rate of electrons and holes in gold-doped silicon.

Proceedings Letters

Because letters are published in PROCEEDINGS as soon as possible after receipt, necessitating a late closing date, we are unable to include a list here of the letters in the May issue of PROCEEDINGS. The list will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 55, no. 4, April 1967.

Electromagnetics and Plasmas

Modifications on the Axial-Mode Helical Antenna, *D. J. Angelakos, D. Kaifez*

The Helicone—A Circularly Polarized Antenna with Low Sidelobe Level, *K. R. Carver*

Meteorological Factors Associated with Severe Signal Strength Depressions on 4-GHz Radio Paths Over a Coastal Plain, *M. H. Van Dijk*

Abnormal Signal Strength Depressions on 4-GHz Radio Paths Over a Coastal Plain, *G. F. Jenkinson*

Influence of a Thin Inhomogeneous Surface Layer on Electromagnetic Ground Wave Propagation, *J. R. Wait*

Some Remarks on Radio-Frequency Holography, *G. A. Deschamps*

The Induced Voltage for Conducting Ring Interaction with Axially Symmetric Magnetic Fields, *A. D. Poularikas, M. J. McCutcheon, D. O. Akhurst*

On the Polarization and the Convection Current Models, *M. Koyama, B. R. Chawla, H. Unz*

Field Distribution in a Waveguide Loaded with a Thin Plate of n-InSb, *M. Toda*

Comment on "Digital Computation of the Field of an Electromagnet for Magnetohydrodynamic Research," *A. A. Fouad, R. L. Fuller*

Variations of Space-Diversity Performance on Line-of-Sight Links, *A. Vigants*
Plane-Wave Shielding Effectiveness Studies of Thin Films, *R. A. Weck, C. J. Lump*

Circuit and System Theory

A Physical Representation for Scattering Matrices Employing Complex Normalization, *J. Carlstein*
A Simple Proof of the Unimodular Property for the Basic Loop Matrix, *R. S. Wilkov*
On Generalized Nonuniform Lines, *M. N. S. Swamy, B. B. Bhattacharyya*

Electronic Circuits and Design

Synthesizing Transfer Functions with Two Grounded Pentodes, *P. I. Richards*
On the Realizability of Traditors, *K. J. Schmidt-Tiedemann*
A Voltage-Controlled Tunable Active Filter, *M. Reshef*
Null Network Oscillators, *U. S. Ganguly*

Electronic Devices

Anomalous Radiation Effect in *p*-Channel MOSFETs Under Electron Irradiation, *P. A. Newman, H. Wannemacher*
A Distributed MOS Attenuator, *A. Bilotti*
A Proposed Ultrasensitive Miniature Temperature Sensor, *F. T. Wooten*
Practical Analysis of the Overdriver Varactor Multiplier with a Single Idler, *J. I. Smith*
Logic and Memory Elements Using Two-Valley Semiconductors, *J. A. Copeland, T. Hayashi, M. Uenohara*
The Dependence of Collector Capacitance on Collector Current, *H. C. Josephs*
A Continuous Film Memory Driven by Multiple Coincident Pulses, *K. Goser, H. Kirchner*
A Frequency-Selective Limiter Using Magnetoelastic Instability, *A. J. Giarola, D. R. Jackson, R. W. Orth, W. P. Robbins*

Optics and Quantum Electronics

Automatic Tuning of Hydrogen Masers, *H. Hellwig, E. Pannaci*
Temporal Line Shift of Pulsed $GaAs_{1-x}P_x$ Injection Laser Diodes, *C. J. Magee*
High-Power, High-Efficiency Silicon Avalanche Diodes at Ultrahigh Frequencies, *H. J. Prager, K. K. N. Chang, S. Weisbrod*
The Effect of Multiple Zinc Diffusions on the Threshold and CW Output Power of GaAs Laser, *K. M. Hergenrother, J. E. Ludman*
A Computer Algorithm for the Synthesis of Spatial Frequency Filter, *J. J. Burch*

Communication Theory

The Autocorrelation Function of the Output of a Randomly Phase-Modulated Oscillator with a Nonlinear Modulation Characteristic, *B. D. Nelin*
Achievement of Rate-Distortion Bound Over Additive White Noise Channel Utilizing a Noiseless Feedback Channel, *T. J. Cruise*
Statistical Aspects of Ideal Radar Targets, *P. H. R. Scholefield*
A Note on the Wiener-Khintchine Theorem for Autocorrelation, *A. K. Fung*
Correction to "Numerical Calculation of the Incomplete Toronto Function," *H. Sagon*

Control Systems and Cybernetics

A Cascade Relation for Orthonormal Functions, *P. J. Tu, M. L. Moe*

Miscellaneous

Comments on "Phase Locking on Pulsed Gunn Oscillators," *R. W. Cushman*
Measuring the Delay of Subnanosecond Circuits, *A. S. Farber, J. J. DeCillo*
Stress Dependence of the Frequency of Quartz Plates, *R. W. Keyes, F. W. Blair*
Comments on "The Effect of Frequency on the Conductivity of Sea Water," *C. Bowden*
Chebyshev Coefficients for Piecewise Linear Functions, *J. Vlach*
A Useful Recursive Form for Obtaining Inverse *z*-Transforms, *L. B. Jenkins, Jr.*
On the Transfer Function of a Phase-Lock Loop, *F. Tinta*
On the Trapped-Wave Criterion for AT-Cut Quartz Resonators with Coated Electrodes, *W. H. Horton, R. C. Smythe*

IEEE Transactions on Electron Devices

Vol. ED-14, no. 5, May 1967

Device Modeling, *J. J. Sparkes*—Models of electronic devices have to express the physical structure of the device, represent its significant properties, and lead to useful equivalent circuits for circuit analysis. The criteria by which a model can be said to achieve each of these three functions are explored and it is shown, with particular reference to transistors, that the demands of each function are so different that no previously proposed model is wholly satisfactory. The wisdom of trying to achieve a general theory of modeling is consequently questioned, and it is suggested that a deliberate separation might be preferable.

A Model of the Avalanche Photodiode, *J. R. Biard, W. N. Shaunfield*—A general model for the avalanche photodiode is presented. It is shown that the diode consists of four regions: (1) guard ring, (2) uniform avalanche region, (3) high-field absorption region, (4) zero-field absorption region. Expressions are given for the ac quantum efficiency, the dc quantum efficiency, and the transit time cutoff frequency. Material requirements are discussed. Based on an entire detector system, an expression is derived for the signal-to-noise ratio. An example is given with the result that a NEP of 10^{-12} W/Hz$^{1/2}$ is obtained with an optimum avalanche gain of approximately 23.

An Optimized Avalanche Photodiode, *H. W. Ruegg*—The feasibility of a fast, high-gain photodetector based on the phenomenon of avalanche multiplication in semiconductors has been investigated. Based on the process of carrier multiplication in a high electric field, criteria for the design of an optimized avalanche photodiode and for the choice of the best semiconductor material are developed. The device theory of an optimized, realizable avalanche photodiode is presented. A practical silicon device optimized for the detection of light with a wavelength of 9000 Å is suggested and design parameters are presented. Details of the fabrication process are given and the performance of experimental devices is compared with the device theory presented. The results of the study indicate that it is possible to achieve a silicon photomultiplier with a quantum efficiency–bandwidth product of the order of 100 GHz for the detection of light up to a wavelength of over 9000 Å.

Parametric Effects in a Microwave Read Avalanche Diode, *Y. Fukatsu*—The parametric effects in the microwave Read avalanche diode are studied using a simplified one-dimensional model. The signals of frequencies ω_1 and ω_2 interact each other via the pumping wave of frequency $\omega_0 = \omega_1 + \omega_2$, through the nonlinearity in avalanche. The range in which the microwave Read avalanche diode has the parametric negative resistance is shown. Some typical values of impedance matrix elements of the microwave Read avalanche diode are given, and the small-signal impedance locus of the microwave Read avalanche diode on a Smith chart is shown to coincide approximately with Kita's experimental results.

Thermal Properties of High-Power Transistors, *R. H. Winkler*—The temperature of a transistor can be determined from the emitter-base voltage versus collector-current characteristic. This characteristic was used for studying the stability of parallel pairs of high-frequency high-power transistors. The thermal effect may cause the incremental emitter-base resistance to assume a negative value. This, in turn, will cause the current flow in a pair of transistors to be asymmetrical. The transition from symmetrical to asymmetrical current flow occurs at a power level that is determined by the nonshared thermal and electrical resistances. Stability to a higher current level can be obtained by increasing the nonshared emitter or base resistances or reducing the collector voltage. Higher currents can also be obtained by reducing the nonshared thermal resistances, which indicates close thermal coupling between the two units.

Electron-Optical Analog Study of Image Tubes with Different Types of Cathodes, *W. Harth, D. Steffen, W. Dittmar*—Electron trajectory analog measurements for image tubes show that the serious aberrations of distortion and curvature of the image field, inherent in flat unipotential photocathodes, can be reduced by using a flat gradient cathode. Similar potential distributions as with curved cathodes are thus established. The resulting curvatures of the equipotential surfaces in the vicinity of the flat gradient cathode can be changed within a relatively wide range by varying the potentials at the gradient-cathode terminals. Pincushion distortion rapidly vanishes and even becomes barrel-shaped with increasing cathode center potential. Adequate reduction of the image-field defect can be achieved only at the cost of introducing barrel-shaped distortion.

High-Current-Density Operation of Oxide Cathodes, *R. Dominguez, H. D. Doolittle, P. F. Varadi*—Oxide-coated cathodes have been used widely in electron tubes due to their high emission efficiency at low operating temperatures. The maximum limit for dc emission of oxide cathodes has been considered at 0.5 A/cm² due to limitations of sparking or overheating due to Joule effect. Oxide cathodes have been tested successfully at operating temperatures of 1000°K at current levels from 1.0 to 4.0 A/cm² with considerable life. Different types of oxide cathodes were tested in planar diodes and triodes. It was found that the operation limitations of an oxide cathode in a triode are far more severe than that in a diode. Diode testing at high density direct current was performed, and triode testing at dc, RF, and pulse conditions were carried out. Experimenting with high-current-density oxide cathodes in diodes indicated some limitations in the presently used cathode materials only above 4.0 A/cm². In triodes where the limitation was found at present at 2.0 A/cm², several interesting effects occurred. Grid overloading and beaming effects due to the closely spaced grids produced intrusions on the anode face and poisoning on the cathode. Various grid materials have been tested and results are compared. Triodes in high-power RF oscillators have been tested at about 1.0 A/cm² average current density. In this mode of operation, the limiting factor is the grid design and its materials. Evaporation of the grid materials may cause sudden and catastrophic failure of the tube. Evaporated grid materials deposited on the insulators result in cracking the structure during RF operation. Experiments are discussed that showed that this effect can be avoided by the proper selection of materials.

The Beam-Loading Admittance of Gridless Klystron Gaps, *E. J. Craig*—Expressions for the beam-loading conductance for an electron beam have been derived by Branch and Vlasov. The beam-loading susceptance is shown to be the Hilbert transform of the conductance. The expressions for the admittance of the ideal gridded gap and the gridless gap are derived. In particular, curves of G/G_0 and B/G_0 are presented for gridless gaps with different gap lengths and with different beam sizes.

Correspondence

The Velocity Fluctuation Noise in Field Emission Devices, *P. J. Pushpavati, A. van der Ziel*

An Integrated Unijunction Structure, *E. Harlow*

IEEE Transactions on Industry and General Applications

Vol. IGA-3, no. 2, March/April 1967

Reducing Electrical Noise, *B. Klipec*—The use of computers and other sensitive electronic equipment in process instrumentation systems has demanded that more attention be given to electrical noise pickup in instrument circuits. The results of tests conducted on ways of reducing the four types of noise encountered in electronic instrument circuits are presented. The superior performance of aluminum-Mylar tape shields in comparison with copper braid and copper-served wire shields for static noise rejection is described. The effect of twisting wires to cancel magnetic noise is compared with that of various shielding materials. Twisting the wires is shown to be the most effective practical way of reducing magnetic noise. The control of common mode noise by proper grounding of shields in thermocouple circuits is shown. The use of single grounding points in shield circuits grounded at the couple is recommended. Multipair cables with individual isolated pair shields are recommended. Comparative results on crosstalk elimination in multipair cables are presented. Individually shielded pairs are recommended as the most practical means of crosstalk rejection in instrument circuits.

Procedure for Determining Maximum Short Values in Electrical Distribution Systems, *R. Ohlson*—Written to be easily understood, this straightforward comprehensive procedure for short-circuit calculation presents familiar concepts in clear pictorial instructions supported with pertinent explanations. The system one-line diagram and circuit data are used directly without conversion to unfamiliar abstract terms. Simple arithmetic produces readily evaluated results. Typical circuit data are offered for reference and an example demonstrates the complete procedure.

Selection of Driver Systems for Large Compressors, *W. B. Wilson*—With the large horsepowers required for centrifugal compressors in the process industry today, driver selection has an important effect on overall plant profitability. Some general application considerations are discussed and price and performance data for electric motors, gas turbines, and steam turbines are presented. These data will assist the process plant designer in selecting economic alternatives to be considered in a driver system study. For instance, cost data included compare different motor enclosures, motor voltages, and types of motors. Curves are provided that can be used to estimate voltage dip when starting different motors with a range of different electrical supply systems. Gas-turbine and steam-turbine data indicate performance, low-fuel-cost by-product power available, fuel chargeable to power, and the availability of heat for process or other power uses.

Dynamic Equilibrium Cycling in Discontinuously Controlled Electric Process Heating, *W. Roots, F. Walker*—Open- and closed-loop discontinuously controlled electric process heating and similar electrothermal processes are represented by analog, equation, and block diagram. Dynamic equilibrium cycling and its performance indexes are studied. The error due to process transit delay is corrected by integral feedback or by a new feedforward technique. Temperature differential is reduced by auxiliary feedback from the electric heating apparatus or from a new simple first-derivative transducer. Portions of the dynamic equilibrium cycle can be prolonged by using a new simple second-derivative transducer.

High-Voltage Solid-State Torque Control for Long Reversing Conveyor, *C. Sanborn*—Large bulk-material-handling facilities have been and are being built today in which the belt conveyor has an important part. A motor control system for an improved method of accelerating long belt conveyors is described. The application of the drive motor and its control system can have significant effect on belt life and initial cost of the control, motor, and drive equipment. In the motor control system static power amplifiers control the magnitude of the voltage supplied to an ac motor. Motor torque is proportional to applied motor voltage. Therefore, controlled torque acceleration of the belt is accomplished by using a regulated system with a ramp function generator for a reference signal and a speed feedback signal. The system can be used to control either low- or high-voltage ac squirrel-cage or wound-rotor motors. Application is ideal for any belt conveyor drive with single or tandem motors, reversing or nonreversing.

Recent Developments in Machine Vibration Monitoring, *G. B. Foster*—Electronic vibration-monitoring devices are spreading to a wide variety of industrial machinery applications. It is pointed out that present monitor designs are capable of predictive signaling of impending mechanical problems in many classes of prime movers and loads. The established limits of allowable vibration are in the process of change, both in units of measurement, as well as values. Velocity measurement is gaining acceptance over mils and *g* units. Manufacturers of machinery are incorporating vibration levels into their warranty conditions. Noncontact devices for measuring shaft vibration are undergoing rapid development. Their need is well established in large journal bearing machines and hold promise for additional applications in axial turbine designs. Initial experience is being gained with computer trend monitoring. Coupled with procedures of mechanical impedance analysis, these data give promise of achieving a greatly improved reliability factor in industrial process machinery, as well as permitting closer design of future equipment.

In-Line Gasoline Blending at Suntide Refining, *J. D. Johnson, C. Q. Williamson*—An in-line gasoline blender installed at the Suntide Refinery, Corpus Christi, Tex. is discussed. The blender will produce blended gasoline at a maximum rate of 6000 barrels per hour. Up to 11 component streams are controlled to give the final gasoline blend. Each stream is controlled by a digital control system to maintain that component as a fixed percentage of the total blend. A new digital trim control system on two of the component streams receives feedback from on-stream analyzers to maintain the vapor pressure and octane number of the blend within close tolerances. The control system utilizes advanced electronic hardware to maintain high accuracy and reliability. The use of this new blending system has resulted in faster and more accurate gasoline blending.

Thyristor Adjustable-Frequency Power Supplies for Hot Strip Mill Run-Out Tables, *R. A. Hamilton, G. R. Lezan*—An application of thyristor power supplies used to generate adjustable 13–0–13 Hz directly from the 60-Hz system, controlling both frequency and voltage to power the reversing run-out table motors for a hot strip mill, is discussed. A description of the equipment used to perform this required function, its characteristics, and performance, as well as an evaluation and analysis of the results are included. Finally, the advantages, disadvantages, and applications to other jobs and future potential are discussed.

An SCR Inverter with Good Regulation and Sine-Wave Output, *N. Mapham*—SCR inverters of the sine-wave type are well known. Some have the disadvantages of poor regulation, very high component voltages when operating under heavy load, and an inability to operate with no load. The SCR inverter described overcomes these disadvantages without losing the advantages possessed by sine-wave inverters of good output waveform, low SCR switching losses, and sure-fire operation. This inverter has optimum performance over a frequency of 400 Hz to above 25 kHz. The results of a computer analysis are given, leading to complete design data including the specifications needed by the SCR. Practical variations on the basic circuit are discussed, such as center-tapped load and bridge configurations, load-coupling methods, and short-circuit-proof circuits.

Trends in Subsurface Distribution, *F. McKenna*—The Subserf system described was specifically designed with the safety and problems of the utility engineer and lineman in mind. It is believed to be the first real attempt to provide standardization of components for submersible underground systems. No longer need the lineman be concerned with complicated circuitry or lack of means to properly handle shielded systems. Purchasing and stores functions are simplified through a minimum number of standardized plug-in components. Utility design engineers have at their disposal a complete line of coordinated components to simplify their application problems. Subserf systems are available today to serve the needs of residential subdivisions. The Subserf philosophy is rapidly being expanded to include main line switching, both single and three-phase, and automatic sectionalizing devices necessary to serve the growing trend to complete underground systems.

Electric Drilling Rig Developments, *M. Rizzone*—The electrification of oil-field drilling equipment has for the most part taken place on offshore installations and mobile units. Other applications of oil-field drilling equipment have generally not utilized available electric transmissions because of factors not readily recognized. An attempt is made to review the design engineer's considerations for drilling equipment design and important environmental and logistic factors. Some observations are made that should assist the electric equipment manufacturer in broadening his field of application in this market by proper consideration of the factors.

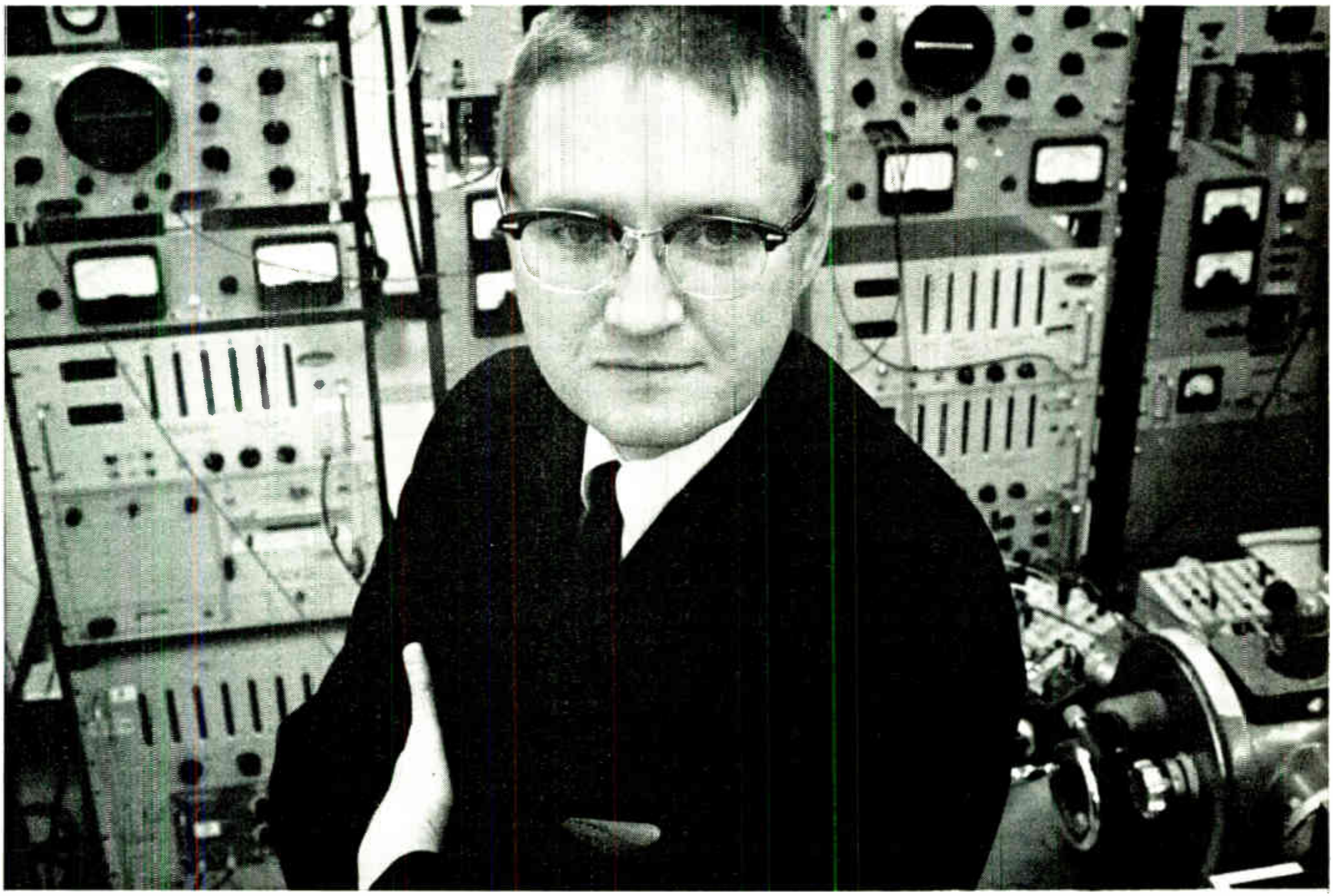
IEEE Transactions on Microwave Theory and Techniques

Vol. MTT-15, no. 5, May 1967

Propagation in the Off-Center E-Plane Dielectrically Loaded Waveguide, *N. Eberhardt*—Rectangular waveguides containing a full-height lossless dielectric slab in arbitrary positions are theoretically treated. Numerical data about the cutoff frequencies of the three lowest TE modes in the case of loading with alumina are presented. A graphical method is developed to determine cutoff frequencies for other dielectric constants as well. Graphs are given to determine the propagation constant and its frequency dependence. Figures of some characteristic mode patterns are added. A possible application to dissipative filters and frequency separators is discussed.

Stabilization of the Gain Versus Frequency Characteristics of Parametric Amplifiers at

TRW is Bill Tallon testing a guidance system prototype



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High Input Signal Levels, *H. E. Brenner*—Decreasing the negative bias voltage of varactor diodes in a parametric amplifier causes the gain versus frequency characteristic of the amplifier to shift to the higher frequency side, resulting in a so-called "positive slope" at the signal center frequency. The same happens when the pump power is increased or when the signal power is increased, but in the latter case only when the idler circuit load resistance is below a certain value. It is pointed out that the slope of the gain characteristic can be partially or completely compensated by detuning the signal-circuit characteristic relative to the gain versus frequency characteristic in such a way that the latter is located on a certain point of the left or right slope of the signal-circuit characteristic, or by resistive loading of the idler circuit. Complete cancellation was achieved in the range from −30 to −20 dBm signal input power by using both methods simultaneously on a practical model of a parametric amplifier operating at a signal center frequency of 3.95 GHz and a pump frequency of 11.76 GHz. The loading of the idler circuit was done by drawing a little rectified diode current. The necessary increase in pump power in order to maintain the same gain as with both signal and idler circuits tuned to resonance was less than 3 dB, the increase in noise figure a few tenths of a decibel from a typical value of about 3 dB.

Design of Composite Magnetic Circuits for Temperature Stabilization of Microwave Ferrite Devices, *E. Stern, W. J. Ince*—The magnetic flux density of unsaturated microwave ferrites can be made almost constant although microwave ferrite saturation magnetization, coercive force, and hysteresis loop shapes change substantially. Temperature stabilization of flux is achieved by a composite series magnetic circuit consisting of microwave, driver, and flux-limiter ferrites, and a control coil. The flux limiter constrains the circuit flux to an almost constant level throughout the operating temperature range, despite large changes in the size and shape of the microwave ferrite hysteresis loop. The driver ferrite supplies the MMF necessary to sustain the flux. Current impulses in the control coil energize and switch the circuit flux. Estimates of the required lengths and cross-sectional areas of the circuit elements and of the required switching field and energy for a waveguide remanence phase shifter are given, along with the effects of leakage and fringing fluxes. Composite circuit techniques have been applied to an experimental remanence phase shifter. Unstabilized, a 16 percent loss of phase shift was incurred as a result of an 80°C rise in temperature. By applying composite circuit techniques, this value was reduced to less than 2½ percent for the same temperature range.

A Unilateral Parametric Amplifier, *H. E. Brenner*—A theoretical investigation of a unilateral parametric amplifier using two varactor diodes indicates an improvement of unilateral stability over already existing types. A circuit is suggested that uses lower sideband idler energy for achieving forward gain and upper sideband energy to obtain substantial reverse loss. The phases of the applied signals and of the pump at the two varactors have to be 90° out of phase to achieve unilateral operation. Numerical evaluation of the theoretical results for a signal frequency at 4.0 GHz and a pump frequency at 12.0 GHz, assuming a diode junction capacitance of $C_j = 0.4$ pF and a bulk resistance of $R_s = 2$ ohms, was done for several pump power levels. For 14-dB maximum forward gain, the 3-dB bandwidth of the gain versus frequency characteristic of the unilateral amplifier is about 18 percent smaller than that of the reflection-type amplifier. The maximum reverse loss for those conditions is 7.3 dB. For lower forward gain the backward loss increases relatively until for very low gain values (about 1 dB) the amplifier is unconditionally stable, i.e., the backward loss is larger than the forward gain. The theoretical noise figure is about 1.95 dB at signal center frequency for 14-dB forward gain and, for ±80 MHz from the center frequency, only 0.1 dB higher than for the reflection-type amplifier.

The Digital Elliptic Filter—A Composite Sharp-Cutoff Design for Wide Stopband or Bandpass Requirements, *M. C. Horton, R. J. Wenzel*—Detailed design procedures are presented for a practical elliptic-function filter form capable of achieving high selectivity in a very compact configuration. This filter form, called the digital elliptic because of its digital construction and elliptic function response, can provide either bandpass or bandstop characteristics. Examples are given to illustrate typical design procedures for both bandpass and bandstop applications. Experimental results are presented for an octave bandstop design.

On the Node Correspondence Between Circular and Square Multimode Tapered Waveguides, *C. C. H. Tang*—In an axially straight multimode circular waveguide taper excited with a pure TE°_{11} dominant mode, the first and only converted mode at and near cutoff is the TM°_{11} mode. It is shown that in an axially straight multimode square waveguide taper excited with a pure $TE^{\square}_{10}$ dominant mode, the $TM^{\square}_{12}$ mode corresponding to the TM°_{11} mode in circular case is not the only first converted mode at and near cutoff. The overall behavior or coupling mechanism of waveguides is similar whether the waveguide is rectangular, square, circular, or elliptical; i.e., the overall coupling coefficient at cutoff of a converted mode or modes approaches an infinity of the order $0^{-\frac{1}{4}}$.

Correspondence

Theory of Unidirectionality and Conjugate Matching in Three-Port Time-Varying Reactance Circuits, *A. E. Fantom*

Acoustic Gas Lenses for Light, *J. Kerdiles, J. R. Whinnery*

The Resonant Frequency of Interdigital Filter Elements, *D. D. Khandelwal*

Simplifying Maxwell's Equations in Gyrotropic Media, *C. F. Vasile*

A Wideband Microwave Solid-State FM Deviator, *W. J. Clemetson*

Comments on "Longitudinal Waves in Hot Nonuniform Plasma," *D. Kalluri, H. Unz, K. E. Lonngren*

IEEE Transactions on Power Apparatus and Systems

Vol. PAS-86, no. 4, April 1967

Evaluation of Sodium Conductor Power Cable, *A. E. Ruprecht, P. H. Ware*—The suitability of the newly developed polyethylene-insulated sodium conductor for use in electrical power cables was evaluated electrically and mechanically. Polyethylene-insulated sodium conductors are shown to lend themselves to a wide range of constructions manufactured on standard cable-fabricating equipment.

The Application of Relaying on an EHV System, *H. J. Sutton*—An outline is presented of the EHV relaying to be used for the 500-kV lines in the southern branch of SCEC system involving the Mississippi Power and Light Company, Louisiana Power and Light Company, Gulf States Utilities Company, and Central Louisiana Electric Company. Some of the problem areas are pointed out and how they affected the selection of the relaying is then described.

Mechanized Calculation of Unbalanced Load Flow on Radial Distribution Circuits, *R. Berg, Jr., E. S. Hawkins, W. W. Pleines*—A computerized method of calculating unbalanced load flow or fault currents on multigrounded radial distribution circuits is described. The basic concept employed is that the electrical characteristics of any portion of an unbalanced three-phase circuit can be represented by a six-element Y-delta network. An operating program that can accommodate up to 750 circuit branches has been written for the IBM 7094 computer. Program input consists of power and coincidence factors, source voltage, wire size, and length of branches, and loads of transformers. Program outputs can be any or all of the following: phase-to-neutral voltages, phase and neutral amperes, phase angles, real and reactive line losses, and such quantities as kVA, kvar, and kW flow. An appendix presents mathematical justification for the use of certain simplifying approximations in calculating neutral return impedance.

Load Tap Changing with Vacuum Interrupters, *H. A. Fohrhaltz*—A comparison between the four common types of conventional load-tap-changing mechanisms for use on power transformers and the introduction of a new mechanism using vacuum interrupters for the arcing function are presented. Design parameters for the present and new equipment are discussed along with an understanding of some new problems associated with operating speeds, interrupter life, and voltage transients. The advantages from both the manufacturer's and user's point of view of load tap changing using vacuum interrupters are identified. These include increased life, smaller size, fewer inspections and less servicing, and fewer equipment types.

Series Gaps in Air Break Switches, *P. C. Mayo*—The electrical characteristics of series gaps used in power switching equipment are discussed. The dielectric strength of the series gap for 60-Hz, impulse, and switching surge voltages is considered and curves are included of the results for gaps of dimensions from 44 inches to 139 inches. The ability to isolate two circuits and maintain a minimum of disturbance on one circuit when voltage transients occur on the other circuit is discussed. Also included are discussions of the potential of the floating blade and the effect of a grounded plane near the floating blade on the series gap strength and the insulator dielectric strength.

Damping of System Oscillations with a Hydrogenerating Unit, *F. R. Schleif, G. E. Martin, R. R. Angell*—Under discussion is stabilization of the initial interconnection across Utah and Arizona between the northwest and southwest power systems, which has been aided by damping torques generated through special control of a unit in Grand Coulee Power plant in Washington. The special control is derived from local frequency, using the phase advance of the first derivative to offset the inherent lags of the hydro unit. The scheme is proving capable in augmenting the stabilizing effort from the limited amount of suitable fast response steam capacity available.

Nonlinear Hydro Governing Model and Improved Calculation for Determining Temporary Droop, *J. M. Undrill, J. L. Woodward*—A digital computer model, which simulates the dynamic performance of an isolated hydroelectric generating set, is described. The model is based on the work of L. M. Hovey, but it eliminates several limitations inherent in Hovey's governing model. The model described extends Hovey's work by considering the finite gain of the combined pilot valve and servovalve, the constraints on the gate servomotor velocity and position, and the variation of turbine characteristics with turbine operating point. Hovey's method of determining the temporary droop of a governor from a closed dashpot step response test is reconsidered. It is demonstrated that his method is erroneous and a correct method of calculation is presented. Simulations of the response of a 28-MW generating set in the Ohakuri Power Station of the New Zealand Electricity Department are compared with actual test results for both small and large signal conditions.

Allegheny Power System Design of 500-kV Towers, *G. B. Hoffman, J. R. Arena*—The philosophy pertaining to the design of the 500-kV towers is outlined, starting with the economic studies to determine conductor type and size, phase spacing, insulator arrangement, span length, and loading. Particular attention is given to a discussion of unbalanced ice loading as well as realistic summertime wind loading. The analysis of the tower as a space frame structure by the STAIR computer program is described. Full-scale electrical and structural tests of the tower are discussed and a comparison is presented of the tower deflections as observed and predicted by the STAIR computer program. Foundations of both concrete and grillage types are discussed.

Induction Motor with Free-Rotating DC Excitation, *J. K. Sedivy*—An induction motor that has an additional dc field on the shaft is described. The dc field is free to rotate inside an independently rotating squirrel cage and it serves the purpose of improving the input power factor. The performance equations are derived, steady-state conditions discussed, and test data presented.

An Analog and Analysis of Induction Servomotors, *B. V. Jayawant, G. Williams*—The development of solid-state frequency converters or inverters makes the induction motor a possible machine for the final drive of a position control system, especially in power sizes. An analysis of the transient behavior of induction motors under conditions of changing supply frequency is presented. The analysis is achieved by considering the squirrel cage as a two-coil rotor and it is shown that this representation is exact. This model enables a simple simulator to be built and effects of rotor time constant and inertia can be studied with relative ease.

Medical Evaluation of Man Working in AC Electric Fields, *W. B. Kouwenhoven, G. G. Knickerbocker, M. L. Singewald, O. R. Langworthy*—An investigation of the effects of HV 60-Hz ac fields on human beings is covered. Experimental results are presented of the intensity of the electric fields to which linemen are subjected when doing maintenance work on energized HV lines. The protection offered by Faraday screens is discussed. The results of a series of physiological examinations that were carried out on 11 linemen, some of whom used conventional hot stick methods and others worked bare-handed from an aerial bucket connected to an energized conductor, are presented. The examinations were conducted by members of the staff of The Johns Hopkins Hospital, Baltimore, Md., and extended over a 30-month period.

Exposure of Mice to a Strong AC Electric Field—An Experimental Study, *G. G. Knickerbocker, W. B. Kouwenhoven, R. C. Barnes*—Twenty-two male mice were exposed to a 60-Hz ac electric field by placing them, in cages, between parallel plates, energized to create a field, initially unperturbed, of 4 kV/in. In the course of 10½ months, each animal had an accumulated exposure time of nearly 1500 hours. These animals, and a parallel control group (essentially identically handled but receiving no exposure to electric fields), were repeatedly bred and observed to determine whether there were any effects, harmful or beneficial, as a result of the exposure. The overall condition of the exposed mice, their ability to reproduce, and pathological changes, as well as growth patterns in their offspring, were observed. No observable changes in the primary group of males were detected, and there was no effect upon their ability to reproduce. There is evidence of modified growth of male progeny. Further studies are suggested.

The Measurement of Electric Fields in Live-Line Working, *C. J. Miller, Jr.*—Several devices are described that have been used recently in studying electric currents induced by 60-Hz electric fields in the bodies of linemen working on energized power lines using both the conventional hot stick method and the bare-hand method. These devices include (1) the gradient meter, used to measure the intensity of electric fields impinging on different areas on the lineman's body; (2) the icosahedron, used to demonstrate that total body current is the summation of unit area charging currents resulting from the electric field impinging on unit areas over the entire body; and (3) the dipole, used to measure the magnitude of electric currents flowing in an isolated conducting body located in an electric field. Typical measurements obtained with each of these devices are included.

Rational Analysis of Electric Fields in Live-Line Working, *H. C. Barnes, A. J. McElroy, J. H. Charkow*—As voltages of electrical transmission system increase, live-line maintenance by the bare-hand method becomes increasingly necessary to meet the requirements of system reliability; but of more importance is its value to the workman in permitting him to use power and hand tools without the strains that would be encountered with the long, heavy hot line tools required at these voltages. Protection of the workman from exposure to high-voltage gradients and body currents is easily attained through Faraday-cage-type shielding, as has been proved by an extensive test program. A method of predicting voltage gradients and body currents utilizing both analytical and numerical techniques in the solution of Laplace's equation is developed. The results are compared with field measurements and excellent agreement is obtained. The method described can therefore be used to predict both currents and gradients for both new and existing designs and voltage levels.

IEEE Transactions on Power Apparatus and Systems

Vol. PAS-86, no. 5, May 1967

The Adaptive Reliability Control System, *T. E. Dy Liacco*—Necessary considerations for the design of a total control system for the improved reliability of the generation-transmission are discussed. The control system is made up of automatic functions, human participation, and an information system. First, the framework of the design and the basic overall strategy for maintaining reliability are described, followed by details of the work being done at Cleveland Electric Illuminating Company for the practical implementation of the design concepts on the CEI system. The approach is as comprehensive as possible even though all the solutions have not yet been formulated. In the process of describing how the requirements may be met, major difficulties are pointed out to aid in identifying areas where research in depth would be of value.

Design of the First 500-kV Substations on the Southern California Edison Company System, *P. R. Dolan, A. J. Peat*—The design of two new 500-kV substations has been completed and is outlined. A description of the design of the 500-kV grid of transmission lines and substations that will serve as a support for the existing 200-kV system is followed by a discussion of the substation design criteria. The areas covered are insulation coordination, line and bus arrangement, bus conductor selection, and equipment requirements. A description of the stations is also included.

Transmission Line Uprating 115-kV to 230-kV Electrical and Structural Design, *E. L. C. Larson, M. Broschat, R. L. Thomson*—The Otter Tail Power Company plans to convert a 90-mile section of 115-kV wood-pole transmission line to 230 kV. The electrical and structural analysis upon which final selection of the uprated design was based is described.

Extra-High-Voltage Line Outages, *IEEE-EEI Committee Report*—The placing in operation of transmission lines of 345 kV and higher made it desirable to update previous reports on transmission-line operation. Information on EHV transmission lines was obtained from operating companies and correlations were attempted between design characteristics and operating results. The wealth of information obtained was sorted out, and is presented in tabular form that should be of value to transmission-line designers and operators and system planners.

A New High-Pass Coupling Network for Power-Line Carrier Operation—Field Test Report, *R. W. Brown, G. L. Kopischke*—Field tests of a new high-pass coupling network for power-line carrier operation are discussed. The tests pointed out several weaknesses in the coupling system as originally designed and installed. Redesign of coupling units and installation of auxiliary capacitors on the substation bus improved the attenuation characteristics and low-frequency cutoff point of the networks, resulting in satisfactory operation. Results of field test measurements are shown for the original system and for the modified system.

Integrity of C_2F_6 in Gas-Cooled Sealed Dry-Type Transformer, *G. G. Posner, J. A. Philosophos, J. P. Manion*—Gas-filled dry-type transformers after three years of service were checked for evidence of corona. The C_2F_6 was found to be better than 96 percent pure and no evidence of corona was found. Laboratory experiments have shown that CF_4 is the major corona and arc decomposition product of C_2F_6. Differences in the types of minor and trace decomposition gases exist and can be used to distinguish between corona and arc faults. Analyses of the gases are presented that were carried out by mass spectrometry and gas chromatography.

Very-High-Voltage, Heavily Loaded Underground Cables, *C. T. W. Sutton*—The problems associated with the use of high-voltage heavily loaded underground cables in Great Britain are reviewed. A major aspect of this situation is the effective control of the thermal environment. Details of unsuccessful solutions are given. Methods of artificial cooling, the possibilities of control of the cooling by monitoring the external surface temperature of an underground cable, the techniques required for the laying and joining of these large cables, the sphere of usefulness of steel-pipe compression cable and the possible substitution of a plastic in place of the orthodox impregnated paper dielectric, together with the adoption of dc circuits, are assessed.

Characteristics of Mechanically Damaged Single-Core Oil-filled Cable, *T. Takagi, S. Takahashi, T. Tabata, K. Kikuchi*—Underground power transmissione lines of 60 kV and over, now in use in Japan, are mostly OF cables. Particularly, use of 140-kV OF cable has been sharply increasing of late. This cable is liable to various kinds of mechanical damage (excluding mechanical fatigue phenomena), some of which are considered to affect its performance adversely. In this research, 140-kV singlo-core cable was used, and various kinds of mechanical damage were inflicted on it; the kinds and degree of damage done were studied, and experiments are reported that were performed to ascertain the relationship between possible damage to the cable and its electrical properties.

Laboratory and Service Aging Tests of Paper-Insulated, Three-Conductor Cables for 12-kV Service, *H. A. Adler, H. Halperin*—Forty three-conductor cables for 12-kV service were subjected to stability studies in laboratory aging tests and/or in experimental service operation. The main purpose was the determination (1) of the difference between the stability of shielded and of belted cables, (2) of minimum safe insulation thickness for shielded cables, and (3) of maximum permissible temperatures for normal and emergency operation. The results, which showed superiority of shielded cables and marked effects of insulation thickness and temperatures upon stability, are reported.

400-kV Cable Development in Great Britain, *F. J. Miranda, H. W. Holdup, P. G. S. Wood*—Reasons for the selection and development of low-pressure oil-filled 400-kV cable systems in Great Britain are discussed. Factors such as the limited size of the transmission area, thermal requirements, installation problems, test procedures, and results are described. British underground cable systems are dealt with in detail.

Some Factors Affecting the Static Resistance of Electric Contacts, *K. P. P. Pillai*—The variations of the contact resistance and temperature distribution in the vicinity of an electric contact are shown for different types of right-circular conicoid contacts. The limiting cases of such a contact geometry are the circle and the hemisphere. The ways in which the resistance and temperature distribution are relatively affected by the conception of a simplified geometric shape for the contact area are shown. To determine the effect of the elongation of an area on the contact resistance, new form-factor curves are given that are applicable for all contact materials, pressures, and temperatures. Graphs are also given showing the relation between the maximum temperature and the interface temperature in various bimetal contacts that are in common use.

Moisture Dependency of Silver-Graphite Brushes in Air, Nitrogen, Helium, and Carbon Dioxide, *R. P. Pardee*—Wear tests were conducted on silver-graphite brushes sliding against copper slip rings. It is reported that the brushes would not dust in carbon dioxide at the lowest attainable moisture concentration of 9–10 PPM, whereas critical moisture levels were found for the other three gases. The order of increasing moisture dependence for prevention of dusting was as follows: carbon dioxide, air, helium, and nitrogen. Wear rate, contact resistance, and coefficient of friction characteristics were also revealed by the study.

A Dynamic Model of a Drum-Type Boiler System, *F. T. Thompson*—A dynamic model of a drum-type electric utility boiler, which is suitable for use in designing and evaluating a multivariable controller, is described. State-space matrix equations are used in making the model. Unique iterative methods are developed for obtaining accurate steady-state profiles of the superheater and water-wall sections. Constants for the dynamic model are derived using these profiles. An original superheater model provides the transient response of steam temperature, pressure, enthalpy, and mass flow rate. Transient responses were obtained on the digital computer for a number of plant input disturbances. These responses are compared with experimental responses obtained from an actual plant. This comparison serves to verify the model and provides insight into the behavior of the plant.

Response of Bus Bars on Elastic Supports Subjected to a Suddenly Applied Force, *N. S. Attri, J. N. Edgar*—The dynamic response of a bus bar subjected to a suddenly applied fault current has been determined by means of a mathematical model. The theoretical response was in good agreement with experimental results obtained with a small-scale bus-bar model. This theoretical technique permits the dynamic response of any bus-bar system to be predicted for any fault current.

Guide for Welding Aluminum in Substations, *Working Group Subcommittee Report*—The Working Group on Project 63.2 of the Transmission Substations Subcommittee of the IEEE Substations Committee has prepared a guide for welding aluminum in substations. The final report on this work covers the many unique properties of aluminum with respect to welding. Recommendations are made relative to the choice of welding methods, welding techniques, and selection of materials. Evaluations are presented on the chemical and physical properties of materials, on welder qualification, weld evaluation, safety, and preparation of joints.

IEEE Journal of Quantum Electronics

Vol. QE-3, no. 5, May 1967

Modulation and Mode Locking of the Continuous Ruby Laser, *K. Gurs*—The continuous ruby laser is operated with an external mirror; a modulating crystal (KDP) and a Brewster plate as polarization switch are used in the inner beam path. Coupling of the axial laser modes occurs if the frequency of a voltage applied to the KDP crystal equals $c/2L$ (=30 MHz). Instead of assuming equal mode intensities, these intensities are calculated from the condition of a minimum of the total losses in the resonator. It is found that these intensities differ largely in their magnitudes. A curve calculated for six locked modes corresponds exactly to the measured emission curve. If a modulating frequency other than the frequency separation $c/2L$ between adjacent longitudinal modes is chosen, the effect of the modulation on the stored energy within the laser averages out. Nevertheless, the intensity coupled out at the Brewster plate is modulated according to the term $(\varphi_1 + \varphi_0 \cos \omega t)^2$. Some results of this coupling modulation are presented.

Preliminary Measurements of Laser Short-Term Frequency Fluctuations, *A. E. Siegman, B. Daino, K. R. Manes*—Preliminary but relatively detailed measurements have been made of the short-term frequency or phase fluctuations of two short stable single-frequency 6328 Å He-Ne lasers. Both lasers were essentially free-running in a quiet stable environment, with no frequency-stabilization or temperature-control loops except for a slow AFC loop (one-half-second response time), which kept one laser frequency at a nominal 30-MHz spacing from the other by piezoelectric tuning. The random frequency fluctuations of the 30-MHz beat note between the lasers were measured in three ways. The results, which are all qualitatively compatible, and quantitatively in agreement to within better than a factor of two, indicate random Gaussian perturbation of the laser's instantaneous frequency by internal or environmental disturbances (plasma noise, acoustic noise, etc.) that have not yet been clearly identified. By improving these characteristics somewhat, and operating one laser at a very much lower power level in order to enhance its quantum phase fluctuations, it appears feasible to measure the ultimate quantum frequency fluctuations caused by random walk of the oscillator phase under the influence of spontaneous emission.

Observations of Spontaneous Phase Locking of TEM_{00q} Modes at 0.63 μm, *F. R. Nash*—Two types of spontaneous phase locking of the TEM_{00q} modes at 0.63 μm have been observed for a mixed isotope tube (Ne^{20}, Ne^{22}). In both cases the mode-locked laser output consisted of pulses that were less than 1 ns in duration. The pulse repetition frequencies were $c/2L$ and c/L for the two types. Adjacent mode competition appears to play a role in determining which type occurs. The persistence of the self-locking was adversely affected by simultaneous 3.39 μm oscillation. The mode power spectra for the self-locked configuration revealed a dip close to the center of the gain curve. The mode power spectra for the self-locked and the free-running situations were shifted to the high-frequency side of the gain profile, and for a mixed isotope tube this can be accounted for by an asymmetric gain curve. For a pure isotope tube (Ne^{20}) only one type of self-locking was observed, and the power spectra for the self-locked and free-running configurations were shifted to the low-frequency side of the gain curve. On the basis of the experiments performed, it proved possible to calculate the magnitude of the third-order nonlinear susceptibility of the active medium at 0.63 μm, which, it is believed, was responsible for the spontaneous mode locking. The possibility of employing nonlinear crystals as passive mode-locking devices was examined and it was found that the effect required for locking for a piece of deuterated KDP 3 cm in length and placed within the optical cavity was ~ six orders of magnitude too small.

Controlled Stimulated Raman Amplification and Oscillation in Hydrogen Gas, *N. Bloembergen, G. Bret, P. Lallemand, A. Pine, P. Simova*—The gain of the $Q(1)$ vibrational stokes line of H_2 has been measured as a function of pressure in a Raman amplifier cell of variable length. The threshold power for stimulated emission of the $Q(1)$ vibrational and $S(1)$ rotational stokes line of H_2 has been measured in a transverse resonator as a function of pressure. Both geometries give results in good agreement with theory, without invoking any other nonlinear instabilities.

Correspondence

Frequency Modulation and Demodulation of a Gallium Arsenide Injection Laser Using Ultrasonic Waves, *J. E. Ripper, C. G. Whitney*

Stability Measurements of CO_2-N-He Lasers at 10.6-μm Wavelength, *C. Freed*

Note on Excitation Cross Section of Some of the States of Ne II, Ar II, Kr II by Electron Collision, *S. H. Koozekanani*

Threshold of Phase-Locked Parametric Oscillators, *S. E. Harris*

IEEE Journal of Solid-State Circuits

Vol. SC-2, no. 1, March 1967

An Integrated 4-GHz Balanced Transistor Amplifier, *T. E. Saunders, P. D. Stark*—Performance data and design information on a broadband 4-GHz balanced transistor amplifier being developed for possible use in microwave radio relay systems are presented. The balanced stripline circuitry and passive components are integrally fabricated on a 1.5-inch-square alumina substrate using thin-film technology. A comprehensive description is presented of the circuit design, mechanical fabrication techniques, and long-term stability tests. Three-stage amplifiers give 15 dB of gain at 4 GHz with a 3-dB bandwidth of 1000 MHz. Input and output VSWRs were below 1.05 with a noise figure of 7 dB. A mean time to failure of more than 10^6 hours has been indicated for a complete three-stage device by data obtained on accelerated component aging tests.

Study of Transistor Switching Circuit Stability in the Avalanche Region, *J. S. T. Huang*—In the common-emitter transistor switching application, there are occasions on which the collector supply voltage exceeds the transistor sustain voltage. Consequently, the load line could intersect the negative resistance characteristic of the device in the I_C–V_{CE} plane, resulting in a possible unstable or latch-up condition. The avalanche region characteristics and their implications for transistor switching applications are studied analytically. First, the derivation of the direct current–voltage relation that, when viewed from the output terminal, represents a negative resistance is studied. The characteristic of this negative resistance depends on the base-emitter circuit condition. Second, the ac terminal behavior is treated; consideration of the frequency dependence of alpha leads to an equivalent circuit consisting of an inductance in series with a negative resistance. Both elements are nonlinear as well as frequency dependent. With an external load connected to this nonlinear circuit, a technique of nonlinear analysis is employed to investigate the circuit stability. From this analysis, latch-up and oscillation phenomena in the transistor switching circuit can be predicted. Since the second breakdown involves additional mechanisms besides avalanche multiplication, it is not discussed.

A Method for Realizing the Negative-Impedance Inverter, *K. L. Su*—A negative-impedance inverter (NIV) can be used to realize the negative dual of any driving-point function. A scheme by which two controlled sources are connected in series to realize the NIV, is described and the basic principle involved is delineated. The feasibility of such a scheme is demonstrated by using, in place of each controlled source, a transistor amplifier that uses a common-base stage and a common-collector stage in cascade. The transistor amplifier requires only one power supply and is readily adaptable for integrated-circuit applications. Experimental results showing the realizability of the negative resistance, the negative capacitance, and the negative inductance by this NIV circuit are presented.

A Practical Tantalum Thin-Film Single-Sideband Demodulator Using RC Time-Varying and Active Networks, *R. K. P. Galpin, P. L. Hawkes, W. Saraga, F. G. Tarbin*—The thin-film circuit described is equivalent to a demodulator circuit containing an extremely selective filter ("sideband" filter). Such a filter would, in conventional form, require very high Q inductors or, as the Q requirement increases, the use of crystal or mechanical filters. At the frequency of operation of this circuit (1 MHz), demodulation with conventional filters would have to be accomplished in two or more stages so that the selectivity requirement can be decreased for each filter. Thin-film techniques restrict us to circuits using only resistors (R), capacitors (C), and added semiconductor devices (thin-film inductors are not considered since their inductance values are too small). The current trend is to realize frequency-selective networks (conventionally in LC form) as active RC networks. However, although the circuit described incorporates such a network, the main selectivity requirement cannot be met by present-day active network techniques. The solution is found in the use of time-varying RC networks, i.e., by combining passive RC thin-film phase-shift networks with miniature transistors, used as electronic switches, in the form of so-called quadrature modulation circuits. The phase-shift networks, which in principle can be passive thin-film RC circuits, are in practice more easily realized as combinations of much simpler RC circuits with buffer amplifiers.

Correspondence

Equivalent Inductance and Q of a Capacitor-Loaded Gyrator, *R. W. Newcomb, T. N. Rao, P. Gary*

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 Technica, 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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*Electrical and electronics engineers and scientists who have a knowledge of Russian or Japanese and who are willing to translate on a free-lance basis for Scripta Technica should apply to the IEEE Special Subscription Department.

Approximate Calculation of a Dissipated Field Based on Its Phase Structure, *Yu. A. Erukhimovich*

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A Method of Designing Nonlinear Transitions in the High-Frequency Channel of a Multichannel Radio Relay System, *S. V. Borodich*

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Part II—Radio Engineering

Vol. 22, no. 1, January 1967

Integral Method of Investigating Parametric Systems, *S. I. Viglin* (e.g., those of the antenna aperture) as well. The space–time noise correlation function $K(t_1 - t_2, \vec{r}_1 - \vec{r}_2)$ is derived for the case of isotropic noise whose power density spectrum is uniformly distributed in time frequency and angle from the receiving array. It is also shown that even when the noise sources are uncorrelated in time the resultant noise field in the antenna aperture is correlated in both time and space. The difficulties in solving the integral equation for the optimum filter impulse response are indicated, but then the author quickly narrows the discussion to include only a narrow-band signal arriving from a particular direction. Implicity he assumed that the noise field can be similarly restricted (constant time-frequency spectrum and constant space-frequency spectrum throughout the signal band) without investigating the conditions of the restriction. Accepting the restriction, the noise correlation function can be expressed as a product of time and space delta functions, and the integral equation can then be solved readily for the optimum filter impulse response. The exact equations are derived for the cases of a linear array and a circular area array, both of whose dimensions are large compared with λ. The author's development would have been helped by an explicit statement that the restriction on the noise field is achieved by perfect time-frequency filtering (conventional filtering) and space-frequency filtering (beam forming).

The mathematical presentation is terse and correct throughout, and the initial approach to optimum space–time filtering from a decision theory point of view is admirably broad. Moreover, restricting the subsequent treatment to one of detecting a narrow-band signal propagating from a single direction suits the author's purpose in setting up the equations for optimum processing in a direction finder. Although it is not hard to surmise that time- and space-uncorrelated noise fields can be assumed under these conditions, the derivations actually show why the assumptions are reasonable. If one is tempted to add that a great deal more can be said upon the subject, it is in no way a criticism of that portion of the subject the author chose to treat. As an example, it would be interesting to apply these decision criteria to the cases where antenna sidelobe patterns are important, to the use of steerable nulls for suppressing off-axis noise, and to those cases in which the wavelength is comparable to the spacing of elements in an array. With regard to the last, much recent work has been done in the field of acoustic signal detection with many receiving elements properly phased to achieve a "supergain" performance.—*Ross Williams*

Toward Design of a Laser With Passive Shutter, *A. L. Mikaelyan, V. G. Savel'yev, Yu. G. Turkov*—The evolution of a giant pulse in a laser is calculated assuming that Q-switching is performed with a bleachable absorber. The calculation consists of a numerical solution of three nonlinear differential equations linking the photon flux in the laser with population inversion in the active material and in the absorber. These equations occur in an earlier work of the senior author and the Western literature as well. The only new material in the present paper is a graph obtained as a result of numerical integration. The graph is applicable to the case when the variables of the problem (laser size, losses, excitation) are selected as chosen by the authors and relatively little is said about the effect of the variation of these parameters on the result.

The authors were apparently unaware of the work of Szabó and Stein,[1] which carried the solution of this problem much further and which was published shortly before they submitted their manuscript.—*B. Lengyel*

1. Szabó, A., and Stein, R. A., *J. Appl. Phys.*, vol. 36, p. 1562, 1965.

Vol. 11, no. 6, June 1966

Sequential Detection in the Presence of Many Independent Reception Channels with Noise, *G. S. Tyslyatskiy*—This paper analyzes a sequential multichannel detection problem. The author makes an approximate analysis of the average number of trial stages necessary, which shows that the power loss due to the presence of many channels has a logarithmic behavior. A computer simulation was done and several curves are given. The assumptions the author uses to obtain answers to this problem seem so restrictive that the results are primarily of mathematical rather than practical interest.—*H. J. Scudder, III*

Carrier Power of Oscillations with Random Phase in the Presence of Different Probability Density of Phase Distribution, *B. D. Sergiyevskiy, L. G. Oganes'yants*—This brief communication is concerned with the relative power at the carrier frequency of an oscillation $\cos(\omega_0 t + \theta)$, where θ is a random phase (not necessarily normally distributed). Expressions are derived for relative powers at the carrier frequency as a function of dispersion of random phase for different phase distributions. See chapter 14 of Middleton's *An Introduction to Statistical Communication Theory* for more detailed treatment.—*G. S. Glinski*

Envelope Distribution of a Signal-Plus-Noise Mixture with Random Angle Modulation, *V. V. Bykov, A. N. Fedoseyev*—This brief communication is concerned with the analysis of statistical properties of a signal-plus-noise envelope undergoing angle modulation by noise. Three cases are considered. The first two cases are not new and have been previously discussed, by authors referenced in the article. The third case is concerned with a Rayleigh distribution of signal amplitude fluctuation, uniformly distributed signal phase, and the noise phase with an arbitrary distribution. For this case the authors show that the conditional distribution of the envelope has the form of a generalized Rayleigh law. See chapter 14 of Middleton's *An Introduction to Statistical Communication Theory* for a good introduction.—*G. S. Glinski*

Vol. 11, no. 7, July 1966

Possibility of Cascaded Frequency Doublers Without Interstage Tunnel-Diode Amplifiers, *Y. U. L. Simonov, A. I. Fayner*—The translated title is somewhat misleading and should read: "Possibility of Cascading Tunnel-Diode Frequency Doublers Without Additional Amplification."

The presented analysis of the static characteristics of a tunnel diode reveals the possibility of obtaining significant second-harmonic power, while dissipating little or no fundamental power. The design makes use of the large quadratic content and nearly even voltage symmetry of these characteristics, in the vicinity of the current peak. Since no fundamental power is dissipated, the authors conclude that a number of stages can be cascaded without the need for additional amplification. A simple experiment, performed at 50 kHz, is also described.

Unfortunately, it is left to the reader to determine the relative merits of the proposed scheme. Several important points that were omitted are: (1) overall efficiency, (2) stability, (3) effects of parasitic elements, and, most important, (4) available power output levels. A comparison with transistor doublers would also have been desirable.—*C. F. Vasile*

A Traveling-Wave Maser Amplifier Using Chromium-Doped Rutile and Placed in a Magnet with Superconducting Coils, *Ye. Solov'yev, Yu. V. Abazadze, S. K. Isayev, Ye. G. Stepanova, I. B. Krynetskiy*—This brief paper describes the design of an L-band maser using TiO_2 (Cr^{3+}) in a slow-wave structure. The operating temperature is 4.2°K. The net gain was 15 to 20 dB, and the bandwidth was 10 to 12 MHz; pump power was of the order of 100 MW.

While not particularly new, such details as are given may be of interest to those involved in the construction of such devices.—*W. A. Miller*

Telecommunications and Radio Engineering Part I—Telecommunications

Vol. 20, no. 5, May 1966

A Method of Improving Protection of Data Transmission Channels Against Pulse Noise and Route Disruptions, *L. K. Kiselev, A. A. Meshkov*—The method described in this article is identical to that suggested in the United States by Lerner[1] and Wainwright[2] in 1960. It employs an all-pass filter structure with quadratic phase-frequency characteristic or a time-delay characteristic ascending linearly with frequency within the band of interest at the sending end. A filter, having complementary descending delay-frequency characteristics, is used at the receiving data reception terminal. Signals, therefore, pass through the chain without distortion end to end. In between, however, signal energy is dispersed by the unequal time displacement of the various components of the spectrum. Impulsive noise spikes entering the system over the transmission medium go through the receiving-end filter only and hopefully get "smeared" to the degree that they will no longer cause serious interference.

A minimum ratio of improvement is derived for the effective amplitude reduction of a single impulse, which is shown to be proportional to the delay difference and to the square root of the bandwidth utilized (2.7 kHz for a standard voice channel and 5-ms smear-filter delay variation). A limited amount of experimental data is offered within the article, but the only significant contribution to the art is the derivation of the noise amplitude reduction ratio.—*A. B. Bodony*

1. Lerner, R. M., "Modulation and signal selection for digital data systems," *Proc. Nat'l Electron Conf.*, vol. 16, pp. 2–15, 1960.

2. Wainwright, R., "Overcoming impulse noise interference to narrow band data communication systems by a sophisticated filter technique," Rixon Eng. Bull. No. 70, July 1960.

Subscription rates for these translated journals for 1967 are as follows:

Electrical Engineering in Japan	$75.00
Electronics and Communications in Japan	75.00
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The following listing includes titles of recently issued Special Publications available from IEEE for the prices quoted; M for members, N for nonmembers. Members may purchase one copy at the member rate; additional copies purchased are chargeable at the nonmember rate. Orders should be addressed to: The Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017. Shipment will be made promptly on receipt of order and payment. Publication titles shown in boldface are listed for the first time.

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S-135	Power Cable Ampacities, Volumes I and II (Sold in sets only)—1962	15.00	15.00
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3 C 38	International Symposium on Antennas & Propagation—Dec. 5–7, 1966	4.00	6.00
7 C 50	1967 Symposium on Reliability—Jan. 10–12	8.00	8.00
10 C 19	MIL-E-CON 9—1965 IEEE Conference on Military Electronics—Sept. 22–24	6.00	12.00
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
15 C 41	Thermionic Conversion Specialists Conference—Nov. 3–4, 1966	10.00	15.00
17 C 32	1966 International Symposium on Microwave Theory & Techniques—May 16–19	3.00	6.00
19 C 30	1966 International Communications Conference—June 15–17 (Digest)	10.00	15.00
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
33 C 4	INTERMAG, International Conference on Nonlinear Magnetics—April 21–23, 1965	10.00	10.00
	1966 Conference on Electrical Applications for the Textile Industry —April 14–15	1.00	2.00
34 C 36	Industry & General Applications Group Annual Meeting—Oct. 3–6, 1966	10.00	16.00
F 17	Canadian Electronics Conference—Oct. 4–6, 1965	3.00	3.00
F 62	Third Annual Rocky Mountain Bioengineering Symposium—May 2–3, 1966	6.00	6.00
	MAECON, Mid American Electronics Conference—Nov. 18–19, 1965	7.50	7.50
	Conference Record, Region 3 Meeting—April 11–13, 1966	5.00	10.00
	Conference Record, Region 6 Conference—April 26–28, 1966 (Order from 1966 IEEE Region 6 Conference Record, Box 12826, Tucson, Ariz.)	10.00	20.00
F 63	7th Annual New York Electronic Reliability Conference—May 20, 1966	8.00	12.00
	8th Cement Industry Technical Conference—May 17–19, 1966	10.00	15.00
F 67	5th Annual Symposium on Microelectronics—July 18–20, 1966	8.00	12.00
F 70	Northeast Electronics Research and Engineering Meeting (NEREM) —Nov. 2–4, 1966	7.50	7.50
	8th Conference on Tube Techniques—Sept. 20–22, 1966	1.00	2.00
	8th Electromagnetic Compatibility Symposium—July 11–13, 1966	3.00	5.00
	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
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	1965 Thermionic Conversion Specialist Conference—Oct. 25–27	10.00	15.00
	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
6 C 64	**Vehicular Communications Conference Record—Dec. 1–2, 1966**	**2.50**	**5.00**
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	1966 Electron Devices Meeting—Oct. 26–28 (Abstracts)	**2.00**	**2.00**

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Book reviews

Characteristics and Limitations of Transistors (Vol. 4), R. D. Thornton, D. DeWitt, P. E. Gray, and E. R. Chenette—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 177 pages, illus., $4.50; $2.65 pprbk.* This book is the fourth in a series by the Semiconductor Electronics Education Committee (SEEC). It is intended to augment a good basic knowledge of transistor physics and modeling, such as presented in earlier books of the SEEC set. In its brief length, the volume considers the effects of high-current and high-voltage operation, thermal consideration, bandwidth limiting factors, and noise.

In the first section relating to operation at high current densities, the homogeneous base, step junction transistor is analyzed. Although this simplified model is readily treated, it is quite possible for the reader not familiar with double diffused devices to draw the wrong conclusions. In particular, the point is emphasized that minority carrier transport through the base region is enhanced at current levels, thus providing a higher effective diffusion constant. For graded base structures that are most commonly encountered in the art, however, the effect of high current densities through the base region is just the opposite to that which is cited. Although this point is conceded in the book, it is quite easy to overlook.

The section relating to thermal considerations is quite concise and well written. This should prove to be quite useful to designers of high-power low-frequency systems. Unfortunately, little space has been devoted to the treatment of second breakdown. It is quite apparent that certain compromises must be made in the material to be presented in a volume of this size. The section relating to speed limitations is also well written. It is felt, however, that reference should have included the scattering parameter model, since this is proving to be of most value at frequencies in excess of 1 GHz. This was treated in the literature as early as 1963. The section devoted to noise is a good basis of noise in junctions, but again the treatment is far too brief. It is felt that this section should have been presented separately, or in another volume.

To summarize, this is a volume that should receive considerable usage by practicing engineers. However, it would be of far more value had the authors included a more comprehensive bibliography, or referred to the many articles that do include such a bibliography.

David F. Hibiber
Hewlett-Packard Company
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Electromagnetodynamics of Fluids, W. F. Hughes and F. J. Young—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 616 pages, illus., $17.50.* This book, despite its ponderous size and lumbering style, makes a useful, if somewhat limited, contribution to the magnetohydrodynamics literature. The authors' attention is restricted throughout to continuum hydromagnetics with scalar dissipation. Listing the titles of the chapters will give some idea of the topics covered: Principles of Special Relativity, The Electrodynamics of Moving Media, The Electromagnetic Body Force, The Fluid Equations—Basic Ideas of Viscous Flow in Magnetohydrodynamics, The Fluid Equations—Energy and Thermodynamics, The Fluid Equations—Magnetohydrodynamic Approximations, Equations, and Parameters, Incompressible Viscous Magnetohydrodynamic Flow, Plane Waves in Fluids, Transient and Alternating Incompressible Viscous MHD Flow, Discontinuities and Shock Waves, One-Dimensional Compressible Flow, Magnetoaerodynamics, and Waves in Bounded Media; Appendices: Tables of Properties and Constants, Relativistic Formulation of Magnetohydrodynamics. Where possible, they illustrate their discussion with examples of MHD engineering devices—MHD generators, MHD viscous couplers, and the like.

The first six chapters are an extended and leisurely discussion of the foundations of magnetohydrodynamics. More compact treatments can be found elsewhere, however. The final chapters, a "handbuch" of MHD flow problems, are radically different in content and style. Mathematical solutions are written out in exhaustive detail with many intermediate manipulations shown. Instead of illustrating a class of MHD problems by one of the members, the authors have tended to solve many, if not all, problems in the class with an emphasis on a step-by-step presentation of complete mathematical solutions, progressing from simple to complex cases through the progressive relaxation of simplifying assumptions. An especially attractive feature in this regard is the liberal sprinkling throughout of diagrams illustrating numerical solutions of the various problems under discussion. In general, the figures and appearance of the book are of high quality.

The leisurely pace, prolixity, and exhaustiveness of *Electromagnetodynamics of Fluids* could make it unsuitable for teaching, where many topics must be covered briefly. On the other hand, it should be useful for those research men who need a reference that summarizes, both through exposition of the mathematical manipulations and through many fine graphs, detailed solutions of many MHD flow problems.

Charles F. Kennel
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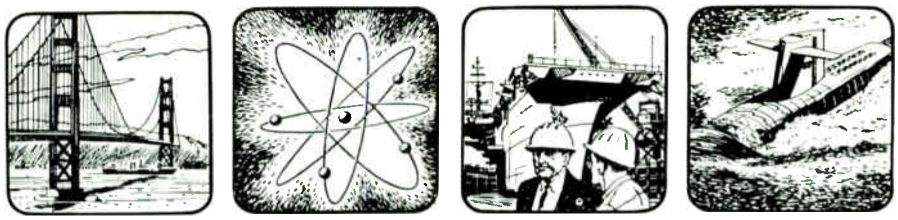
Magnetic Domains and Techniques for Their Observation, R. Cary and E. D. Isaac—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 154 pages, illus., $8.50.* This is an excellent book for prospective research workers in ferromagnetic domain theory. The study of domains and domain walls in ferromagnetic material and their influence on the hysteresis loop and coercive force has expanded rapidly in the past several years. In particular, the use of the magnetooptical Faraday and Kerr effects, starting in the early 1950s, and of electron microscopy in the late 1950s–early 1960s, has resulted in the publication of a considerable amount of new information. The authors have critically examined these results, with emphasis on the experimental techniques.

The initial three chapters are a review of the basic static and dynamic mechanisms of magnetization in ferromagnetic materials. The theory is used mostly as a tool to help elucidate the physical processes involved in domain and domain wall formation and motion. The subsequent four chapters describe the current techniques and present status of research using colloidal suspensions, the Faraday and Kerr optical techniques, electron microscopy methods, and the Hall and Permalloy probes. The last chapter reviews the basic domain configurations and the experimental observations thereof for uniaxial and cubic



crystals, polycrystalline materials, and thin films.

Practically all of the statements made in this book are documented by reference to the literature through an extensive bibliography of approximately 210 listings given in the back. Of these, over 120 are in the post-1955 period, and approximately half of these refer to literature published in the 1960s. Thus, the information is very much up to date.

This is not a book intended to give a complete treatment of the subject. The elementary theoretical analysis presented is very elementary, its purpose being to provide a vehicle for understanding the experimental phenomena and their importance. The book does, however, present an incisive description of what each experimental technique is capable of doing, and includes photographs of results obtained using these techniques.

David I. Paul
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New York, N.Y.

Introduction to Electron Microscopy, Cecil E. Hall—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1966; 378 pages, illus., $17.50.* This is the second edition of a textbook that first appeared in 1953 and has played a leading role in training electron microscopists since that time. Although new material is included at a number of points, the book has actually been shortened through the entirely appropriate elimination of chapters on commercial electron microscopes and on applications; at this time, a survey of either field would demand an amount of space out of proportion to its value to the average reader.

The book is fairly evenly divided into two halves, the first constituting an introduction to electron optics and the second treating problems peculiar to electron microscopy.

The second half should prove particularly valuable to the student. It treats the interaction of the beam with the specimen and its effects on the image in considerable detail. The discussion of questions of instrument alignment, specimen preparation, and image interpretation benefits from the wealth of experience that the author gathered in nearly two decades of practicing and teaching electron microscopy.

The introduction to electron optics in the first half of the book is for the most part simply and clearly presented. However, there are occasional lapses: there is no inconsistency between the sine condition and the "tangent condition" (page 54) since the latter is valid only in the paraxial approximation; much of the discussion on page 61 of the general solution of the ray equation is meaningless, although the correct results are given; on page 72 we find the statement that electrons leaving the cathode with zero velocity would move always normal to the equipotentials (they do not); and on page 116 we are told that "octopole lenses are also possible" (octopole fields act only as correcting elements, not as lenses). Such occasional blemishes may be regretted, but they should not prevent the book from continuing to serve as a valuable guide to the incipient electron microscopist.

E. G. Ramberg
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Princeton, N.J.

The Challenge of the Computer Utility, Douglas F. Parkhill—*Addison-Wesley Publishing Co., Inc., Reading, Mass., 1966; 182 pages, illus., $7.95.* The author states that "no matter how one struggles to keep abreast of current technology the rate of change is so rapid compared with the mechanics of book production that what is 'current' to the writer is almost certain to be 'ancient history' to the reader." The difficulty of describing technological "progress" was largely circumvented by the author by devoting very little discussion to current developments in the field. Instead, the book is mainly a historical work, with some future predictions added for interest. As such, it is of more than passing interest.

With current development within the field, more people are concerned with the feasibility, both economic and technical, of general-purpose time-sharing systems, at least in the very near future. The author has presented an "overview" and is not concerned with how we get from where we are to where we will be in the future. While the technics of time sharing, both operationally and functionally, are not sufficiently present in the book, its philosophy and desirability are clearly represented. Hence, the book could serve as an introduction to, rather than a technical presentation of, the computer utility concept.

The last four chapters are of particular interest. The economic, legal, and social implications of a computer utility are excellently presented.

Richard Auerbach
Computer Usage Company
New York, N.Y.

Communicating Technical Information, R. R. Rathbone—*Addison-Wesley Publishing Co., Inc., Reading, Mass., 1966; 91 pages, illus., $1.95 pprbk.* The author's stated purpose in adding this thin paperback to the mountain of "how to write" books is to provide "an inexpensive self-improvement guide for engineers and scientists, whether on the job or in the classroom." He has—in a matter of hours the reader can acquire or renew a familiarity with the bothersome points of writing reports, texts, and articles. The book presents these points in a well-organized manner. Then too, it is thoroughly indexed and should serve as a handy desk-top reference.

It begins *at the beginning* by counseling the reader to improve his approach to any writing task. He must then establish his basic thesis, based on the intent of the document, depth of coverage, and emphasis. The introduction must build the bridge or establish the common interest between the writer and the reader.

The author has included a discussion of style and format as they affect organization. He also treats pace, or density of information, an often-neglected aspect of good communication. This section includes tips on how to control pace and to vary it. He discusses "noise" in the sense of signal/noise ratio. Semantic noise is introduced by choice, placement, and combinations of words; mechanical noise—by format, structure, and faulty proofreading or printing. One section covers certain pitfalls—often thought of as artful dodges by writers but seldom by readers. Sections on writing titles and abstracts, as well as an important one on editing, round out the book.

Professor Rathbone opens his book with, "Let's begin by being realistic." The pervading sense of realism places this book high on the mountain of "how to write" books. It's an incisive tool for the real world where technical information is written.

John J. Gillespie
Radio Corporation of America
Camden, N.J.

Physical Principles of Magnetism, F. Brailsford—*D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N.J., 1966; 255 pages, illus., $9.75.* This book is a compact and readable account of the theory and practice of magnetism. The treatment is intermediate between theories of magnetism and engineering properties. Having material of both, it should be of interest both to physicists and engineers. The book is inexpensive and available also as a paperback. It would require a strong will and some dedication for a self-study course, but the problems

with answers, suggested reading, and extensive references make it suitable for this purpose. The book is also attractive for classroom use but would require at least a half year of study on a graduate level to do it justice. Some items, such as Fermi–Dirac statistics, Fermi energy, etc., are not adequately developed and will require additional classroom time if the student has not otherwise been exposed.

F. Brailsford, who is a professor of electrical engineering at the University of London, is to be commended for making a clean break with past practices and writing completely in rationalized MKS units. A few other authors have made similar breaks. I am encouraged to believe the trend may continue, and the past horrible mess of magnetic units "cleaned up." In addition to MKS units, Brailsford also defines the material magnetization M in units of B and magnetic dipoles in units of magnetic "charge" (webers) × separation. I employ both definitions in my classes although I have to excuse the usage as not conforming with texts. I do take exception with Brailsford in labeling μ/μ_0 as μ_R. He properly calls this ratio the relative permeability, but as a nondimensional quantity it would, I believe, more properly be designated by a letter other than μ. I generally prefer K_μ. He compounds the confusion by using K to designate the material susceptibility as a dimensioned quantity. A more significant and basic difference is the designation of magnetic potential I as having units of amperes and consequently H with units of ampere *turns*/meter. It is better, I believe, to consider and use I as the magnetic potential/turn (amperes/turn) in which case NI is the magnetic potential (amperes) and H has the conventional units of magnetic field (amperes/meter). Certainly, it is difficult to visualize coil turns as associated with magnetic fields at a point in free space. Because of many problems with units and dimensions, a table with conversion values would have been very useful.

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Annual Review of Information Science and Technology, Vol. 1, Carlos A. Cuadra, ed.—*John Wiley & Sons, Inc., New York, N.Y., 1966; 351 pages, $12.50.* The chapters of this ADI-sponsored volume cover a dozen major topics in the information sciences and related technology. Each chapter is a short, self-contained review of the literature written and the progress made in some portion of the field during 1965. Since this is the first such "annual" review, some pre-1965 background introduces each topic—scarcely enough to orient the nonspecialist, but sufficient to help someone searching at the periphery of his own interests.

The subject coverage ranges from professional development to national information trends, stopping along the way to inspect indexing methods and systems, language processing, hardware, man–machine interactions, library automation, and specialized information centers. Characteristically, an art touching on many disciplines has undefined and nearly indefinable boundaries. Faced with a nearly impossible choice, the editor and his advisors have wisely selected for treatment all the more important areas of present concern to the information sciences community.

Authors of individual chapters have referenced the voluminous literature selectively; even so, they cite 1106 papers. The subject organization and the comprehensive indexing, however, make it relatively easy to obtain access to this formidable information store—the review is itself a good example of the documentalist's art.

Reviewers manage to remain mostly disinterested—rarely is partisanship discernible, a notable achievement in a controversy-ridden area. No less striking is the readability that distinguishes the review, a characteristic not evident in many of the original papers, which often seem to be written in an unknown tongue.

If later volumes in this series succeed as well as this one, much credit will be due the outstanding start made by the first.

Louis M. Cole, Jr.
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Transistor Bandpass Amplifiers, W. Th. H. Hetterscheid—*Springer-Verlag New York Inc., 175 Fifth Ave., New York, N.Y., 1964; 312 pages, illus., $11.40.* This is the only book listed under the topic transistor amplifiers in the *Subject Guide to Books in Print, 1966.* It has a companion volume entitled *Designing Transistor I.F. Amplifiers.* The pair deal almost exclusively with synchronously tuned bandpass transistor amplifiers. Related books spend only a few chapters on bandpass amplifiers, both synchronously tuned and stagger tuned.

The foundation of the book is developed in chapter 2. A stability analysis is made of a single-stage transistor amplifier with single tuned input and output bandpass filters. A complex variable is chosen that is a function of the frequency deviations of the input and output tuned circuits. The plane of this complex variable is divided into a region of stable amplifier operation and unstable operation by a stability parabola. Analytical and geometrical arguments using this stability parabola lead to a significant portion of the results found in the rest of the book.

Three basic tuning methods and the frequency and phase responses of the basic single-stage bandpass amplifiers are also developed in chapter 2. Chapter 3 is concerned with neutralization and unilateralization. Chapter 4 deals with the optimization of power gain.

The various combinations of single-stage and multistage amplifiers with single-tuned and double-tuned circuits are analyzed in chapters 5, 6, 7, and 8. Spreads in transistor amplifier parameters and effects of nonideal coupling transformers are treated in chapters 11 and 12.

Chapters 9 and 10 were not described until this point because they can be used to underline two areas of the book that could be improved. First, the index is less than two pages long. This is too brief to allow access to even the more important material. For example, double-tuned circuits with complex coupling coefficients and their use to achieve symmetrical response curves are treated in chapter 9. Yet, symmetrical response is not mentioned in the index. Another problem is the superficial treatment of stagger tuning. Chapter 10 is two pages long and is entitled "Stagger Tuning in Transistor Bandpass Amplifiers." It says, in essence, that stagger tuning yields less gain than synchronous tuning. However, as Ghausi[1] points out, stagger tuning increases selectivity at the price of gain.

In summary, this book and its companion volume go deeply into synchronously tuned transistor bandpass amplifiers. They perform the necessary and useful function of unifying previously widespread material into a readable whole.

R. D. Brooks
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Allentown, Pa.

1. Ghausi, M. S., *Principles and Design of Linear Active Circuits.* New York: McGraw-Hill, p. 463, 1965.

Microwave Breakdown in Gases, A. D. MacDonald—*John Wiley & Sons, Inc.,* *605 Third Ave., New York, N.Y., 1966; 196 pages, illus., $7.95.* A valuable service is generally rendered by the researcher who pauses to compile coherently the knowledge that he and his colleagues have accumulated in their field of specialization. Review articles and monographs that make a specialized subject accessible and digestible for workers in related fields are always welcome and timely, despite, and often because of, any loose ends that may remain.

This volume represents such a compilation, bridging the gap between research article and textbook, in the area of RF breakdown in gases. The complex phenomena it treats are relevant to gas tube design, microwave antennas, and communication with high-flying vehicles. Experimental and theoretical developments are traced and correlated with impressive success.

Somewhat extravagantly, the introduction includes a derivation of the basic theorem of dimensional analysis, formally justifying the convenience and adequacy of the odd combinations of variables used to describe breakdown conditions. Electron collision phenomena are then briefly reviewed and kinetic theory introduced, although with only slight attention to rigor and fundamental assumptions. The main theoretical development follows, beginning with expansions of the distribution function in spherical harmonics, to second order. A careful delineation of the limits of validity of diffusion theory is included. A master differential equation is then shown to predict breakdown conditions, to within experimental accuracy, for both constant and energy-dependent collision frequencies. Nonuniform electric fields and magnetic effects are discussed and experimental methods described. Finally, the intractable but highly practical case of breakdown in air is treated on a phenomenological basis.

The sketchy presentation of background material on collision processes and kinetic theory is in marked contrast to the elaborate development of the theory to fit experimental results. The derivations are presented in exhaustive—and exhausting—detail, culminating, however, in remarkably successful predictions. The student and unwary novice should be warned of misprints in some equations, many instances of references to the wrong figures or equations, and even missing lines of text. These can be readily overlooked by workers concerned with gases subjected to high-frequency fields, who will find a wealth of experimental information presented in an eminently practical manner, together with guidelines for formulating reliable theoretical predictions of microwave breakdown in many types of gases.

This work constitutes neither a textbook nor a handbook but does present a useful summary of current experimental knowledge and theoretical understanding of microwave breakdown, which makes it a valuable addition to the literature of the field.

Paul Diament
Columbia University
New York, N.Y.

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.

Advances in Computers, Vol. 7, Franz L. Alt and Morris Rubinoff, eds.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 303 pages, $14.00.* This volume presents a comprehensive critical review of programming language processors, a detailed review and evaluation of hardware systems with multiple cooperating digital and/or analog processing units, and a description of computer-drive displays and their use in real-time on-line man-machine problem solving. Recent advances in computer applications are represented in this volume by two articles on copy editing and typesetting. The emphasis is on principles, techniques, and methods for preparing computer output for publication. There is an overall subject index to the six sections, and the contents of the previous six volumes are listed.

American Men of Science, L–O (11th Edition), Jacques Cattell Press, ed.—*R. R. Bowker Company, 1180 Ave.*

of the Americas, New York, N.Y., 1966; 1064 pages, $25.00 (Set of six volumes: $150.00). American Men of Science gives condensed biographical data, including education, positions held, research activities, and special fields of interest. The eleventh edition, when completed, will cover the physical and biological sciences in six volumes containing some 130 000 entries in all. Using a broad interpretation of the physical sciences, the entries range from aerospace researchers to zoologists and include engineers of all kinds—an extensive and highly useful listing of scientists who have reached a certain level of achievement.

Concatenated Codes (M.I.T. Research Monograph no. 37), G. David Forney, Jr.—*M.I.T. Press, 50 Ames St., Cambridge, Mass., 1966; 147 pages, $8.50.* Some sections of this monograph, those which develop the techniques of concatenated coding, should be useful to students and communications engineers with minimal knowledge of coding and an interest in deep space telemetry—the decoding of BCH codes, generalized minimum distance decoding, structure and properties of BCH codes, and derivation of the weight distribution of Reed–Solomon codes. The major emphasis, however, is on the analysis of the performance of concatenated codes, the exhibition of realizable codes capable of achieving low error probabilities, and actual computed performances of representative schemes.

Electron Dynamics of Diode Regions, Charles K. Birdsall and William B. Bridges—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 270 pages, $10.00.* This book describes the motion of charged particles in time-varying fields between two electrodes. One-dimensional versions of active microwave devices are analyzed. Detailed development of linear analyses and nonlinear computer experiments with charged sheets are given, allowing wide application. Model construction is also presented in detail. Emphasis is placed on the variational time dynamics used by Benham, Llewellyn, and others. It should be of interest to researchers and designers working with vacuum and solid-state devices having large transit angles in terms of signal, plasma, cyclotron, or relaxation frequencies.

Index of Engineering Opportunity, 1967, *Resource Publications, Inc., Box 381, Princeton, N.J., 1967; 22 paperback* *volumes, boxed; $25.00/set, $1.50/single volume.* The complete series comprises twenty-two separate publications which cover from one to six states each. Overall, it gives more than 1000 full-page descriptions of major manufacturing companies and consulting engineering firms, listing products, areas of activity, opportunities, and special features such as benefits. In each volume the firms listed are cross-referenced by type of engineering activity and city of location. Although primarily for the individual job-seeker, the information can also be useful to companies, for example, as an indication of personnel needs in various industries.

Modern Aspects of Electrochemistry, no. 4, J. O'M. Bockris, ed.—*Plenum Press, 227 West 17 St., New York, N.Y., 1966; 316 pages, $12.00.* Volume 4 of this review series reflects the most recent developments and the increasing reorientation of the entire field. The editor observes that electrochemistry is now regarded as a specialized aspect of physical chemistry with a particular interest in the study of charge transfers at phase interfaces. Thus, it is a broad interdisciplinary field having important applications in physics, chemistry, metallurgy, and biology. The papers selected for this volume present an application of the theory of irreversible thermodynamics to electrochemistry, a theoretical study of the mechanism of organic hydrocarbon oxidation which pertains directly to fuel cells, an account of anodic and electronic currents in oxide films, and a paper charting the rise of electrochemistry in economic importance in the chemical industry.

Nonlinear System Analysis, Austin Blaquière—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 392 pages, $14.50.* This monograph is devoted to the study of systems whose behavior is governed by nonlinear differential equations. Attention is focused on a few problems which play a central role in engineering and physics. Illustrative examples are discussed with applications to particle accelerators, frequency measurement, and masers. Important practical problems such as synchronization, stability of systems with periodic coefficients, and effect of random disturbances are analyzed from different viewpoints. One of the purposes of the book is to provide engineers and physicists with basic knowledge of oscillations; the subject is carefully limited as the book does not exhaustively cover the problems occurring in this field. The book will be of value to electrical and mechanical engineers, as well as to physicists and applied mathematicians.

Phasor Diagrams, M. G. Scroggie—*Iliffe Books, Ltd., Distributed in the U.S. by Transatlantic Arts, Inc., 565 Fifth Ave., New York, N.Y., 1966; 181 pages, $12.50.* The author of this book contends that the present state of the representation of alternating quantities in electrical engineering is chaotic. Notations, conventions, and even basic concepts are so diverse that there is apparently no common language between different branches or between different books and teachers. Dissatisfaction with this situation has led the author to present what he believes to be the first and only completely integrated system of dealing with ac circuits, valid in all branches of electrical engineering. The book is in three parts: chapters 2 to 6 in which the proposals are developed; chapter 7, which consists of examples of their application to a wide range of ac technologies; and chapters 8 and 9, in which the present doctrines and methods are examined and compared with them.

Printed Circuits Handbook, Clyde F. Coombs, Jr., ed.—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; various pagings, $15.00.* This detailed "how-to-do-it" guide covers the entire scope of printed circuit design, fabrication, assembly, soldering, and testing. Among the recent advances dealt with are multilayer printed circuit processing and automatic component insertion. Ten authorities, picked for their familiarity with both aspects, have contributed to the writing in order to make this sufficiently technical for engineering personnel, yet practical enough for production use. In addition to the detailed descriptions, numerous references are given to standards, specifications, and other reference works.

Radio Handbook (17th Edition), William I. Orr, ed.—*Editors and Engineers, Ltd., New Augusta, Ind., 1967; 847 pages.* This is a new edition of a standard communications manual written particularly for the advanced radio amateur and the electronics engineer. All aspects are covered, from basic dc and ac circuits to the current state of development of amplifiers, power supplies, oscillators, antennas, and other elements. Separate chapters are devoted to special topics such as transmitter keying

and control, rotary beams, low-power exciters, and mobile equipment design and installation. Electronic test equipment is described, and the necessary mathematics for radio calculations is appended. The brief chapters on computers and hi-fi equipment have, however, been omitted to allow for expansion of more pertinent topics.

Reliability of Electronic Components, C. E. Jowett—*Iliffe Books Ltd., Distributed in the U.S. by Transatlantic Arts, Inc., 565 Fifth Ave., New York, N.Y.; 165 pages, $12.25.* The introductory chapter deals with the effect of the environment on equipment, possible hazards of the environment, and some methods of protection. Following is a survey of widely differing components and processes, including soldering, crimping, resistors, capacitors, vacuum tubes, transistors, relays, cables, contacts, etc. The final chapter describes techniques used in potting components, including encapsulation.

Vacuum Sealing Techniques, A. Roth—*Pergamon Press, Inc., 44-01 21 St., Long Island City, N.Y., 1966; 845 pages, $35.00.* This comprehensive reference book discusses in detail the various techniques used in vacuum sealing. Any physicist, chemist, or engineer who has built or used a vacuum system knows that one of the major problems is to insure and to maintain the vacuum tightness at the required level. Leak hunting, plugging, and repeated testing of the vacuum system can be avoided only by careful design and construction of the constituent parts and adequate assembly of the system. The author has attempted to make a systematic and detailed classification of all the vacuum seals that have been developed. The book follows this classification and discusses the various seals in two fundamental groups: (a) basic vacuum seals, and (b) specialized vacuum seals. These groups are then divided according to the constructional features of the seals. The book includes well over a thousand references and numerous illustrations.

Recent Books

Advances in Microwaves, Leo Young, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.,* $17.50

Differential Games, Rufus Isaacs—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $15.00

Directory of Electronic Circuits, Matthew Mandl—*Prentice-Hall, Inc., Englewood Cliffs, N.J.,* $10.00

Einfuhrung in Die Anwendung Kontaktloser Schaltelemente, Hansruedi Buhler—*Druck von W. Rosch & Co., Bern, Switzerland*

Elements de Theorie des Matrices Carrees et Rectangles en Analyse Numerique, Andre Korganoff and Monica Pavel-Parvu—*Dunod, 92, Rue Bonaparte, Paris, France*

Engineering in the Practice of Medicine, Bernard L. Segal and David G. Kilpatrick, eds.—*The Williams & Wilkins Co., Baltimore, Md.,* $20.00

Grounding Electrical Distribution Systems for Safety, Eustace C. Soares—*Marsh Publishing Co., Inc., Box 630, Wayne, N.J.,* $8.00 pprbk.

Information Technology and Survival of the Firm, John McLaughlin—*Dow Jones-Irwin, Inc., Homewood, Ill.*

Introduction to Statistical Mechanics, Ronald W. Gurney—*Dover Publications, Inc., 180 Varick St., New York, N.Y.,* $2.00 pprbk.

Magnetism and Magnetic Materials: 1966 Digest, C. Warren Haas and H. S. Jarrett, eds.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.,* $11.00

Mathematics for Electronics Technicians, Paul L. Evans—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.,* $7.00

Microwave Spectroscopy, Walter Gordy, William V. Smith, and Ralph F. Trambarulo—*Dover Publications, Inc., 180 Varick St., New York, N.Y.,* $3.00 pprbk.

The Development of High-Energy Accelerators, M. Stanley Livingston—*Dover Publications, Inc., 180 Varick St., New York, N.Y.,* $2.25

The Technical Applications of Radioactivity, vol. 1, Engelbert Broda and Thomas Schonfeld—*Pergamon Press, Inc., 44-01 21 St., Long Island City, N.Y.,* £5 5s. net

Thin-Film and Semiconductor Integrated Circuitry, John Doyle—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y.,* $6.95

covered are recent advances in switching and automata theory, communications, computer graphics, solid-state electronics, nondestructive testing, and nuclear energy for the electric utilities.

The courses will range in length from three days to two weeks and tuition will range from $175 to $360. Additional information and registration forms may be obtained from the Director of Engineering Short Courses, Ohio State University, 2070 Neil Avenue, Columbus, Ohio 43210.

Stevens Institute of Technology

A number of intensive short courses will be offered this summer that are designed to meet the needs of presently employed engineers and scientists who wish to extend their knowledge in special fields. Two courses of particular interest are "Semiconductor Materials and Technology," June 5–9; and "Computer-Aided Integrated Circuit Design," September 11–15.

Further information may be obtained from the Stevens Institute of Technology, Castle Point Station, Hoboken, N.J. 07030.

Washington University

A course entitled "Statistical Detection and Estimation Theory with Application to Digital and Analog Communication, Sonar, Radar and Seismic Systems" will be presented by the Institute for Continuing Education of Washington University in St. Louis, June 12–23.

Among the topics to be covered will be the application of detection and estimation theory to digital and time-quantized communication, linear and nonlinear modulation theory, the application of ambiguity functions, and optimum array processing.

For further information, write to Dr. G. L. Esterson, Box 1048, Washington University, St. Louis, Mo. 63130.

University of Waterloo

"Modern Control Theory and Its Applications" is the title of a course to be given at the University of Waterloo, Canada, on July 31–August 5. The course will cover discrete time and sampled data techniques, systems with random variables, process modeling, steady-state optimization, dynamic optimization, computer technology, and Fortran programming. The fee will be $250.

Correspondence should be addressed to Prof. W. J. Vetter, Department of Electrical Engineering, University of Waterloo, Waterloo, Ont., Canada.

Technical correspondence

Color TV standards

I am distressed by the paragraph on color television in your editorial in the March issue of IEEE SPECTRUM in which you state: "..... PAL and SECAM are definitely superior to the U.S. System (NTSC)..... unless something radical occurs, U.S. color television broadcasting will eventually be second rate." (See Cutler, C. C., "Spectral lines: The challenge of picture transmission," p. 101, Mar. 1967.)

Neither PAL nor SECAM is superior to NTSC. They were developed to cure the effect of differential-phase distortion in equipment and microwave links. With improvement in video tape recorders, this defect no longer exists in equipment, and we leave it to AT&T to state whether it exists in microwave links. PAL and SECAM accomplished this cure at the cost of increased receiver complexity. We believe it to be fundamentally wrong to introduce receiver complexity to cure correctable errors in transmission.

The performance of PAL and NTSC are very close, but SECAM leaves much to be desired. In listing the relative advantages of the systems, the evaluation committees did not apply any weighting factors, so that two rabbits appear to outweigh one horse.

As stated in Herbstreit's paper at the end of page 110 of the same issue of SPECTRUM:

"..... That none of the three systems is technically or overwhelmingly superior to the other two is, perhaps, a pity. If one of the three showed such an advantage, it is likely that a technical body such as the CCIR would have recommended that system. Unfortunately, this was not the case, and it was obvious..... that other factors were bound to play a part in forming the opinions of many of the delegations....."

I enclose two papers that compare the three systems and whose authors conclude that NTSC is superior. One paper is by a Philips engineer and the other by a Russian. Yet, the Netherlands adopted PAL and the U.S.S.R. adopted SECAM. Since PAL is sponsored by Germany, which will start broadcasting PAL this October, we let you guess the reasons for their decisions.

The timing of your editorial is unfortunate because of impending discussions on color standards in Latin America, whose monochrome standards are almost identical to ours and who has much to lose by adopting any system other than NTSC.

Charles J. Hirsch
Princeton, N.J.

I also am distressed by the quoted paragraph. The papers[1-3] to which Mr. Hirsch refers tell the story quite well and leave little doubt about the virtues of the NTSC system, as does other material that has been called to my attention. Therefore, I have little choice but to eat my words.

It seems that the defects for which we criticize what we presently see in color television are principally due to equipment problems and operational factors that are not peculiar to the system of modulation used. We do look for improved broadcast television, but we had better concentrate on devices and operational practices if we want United States television to be first rate.

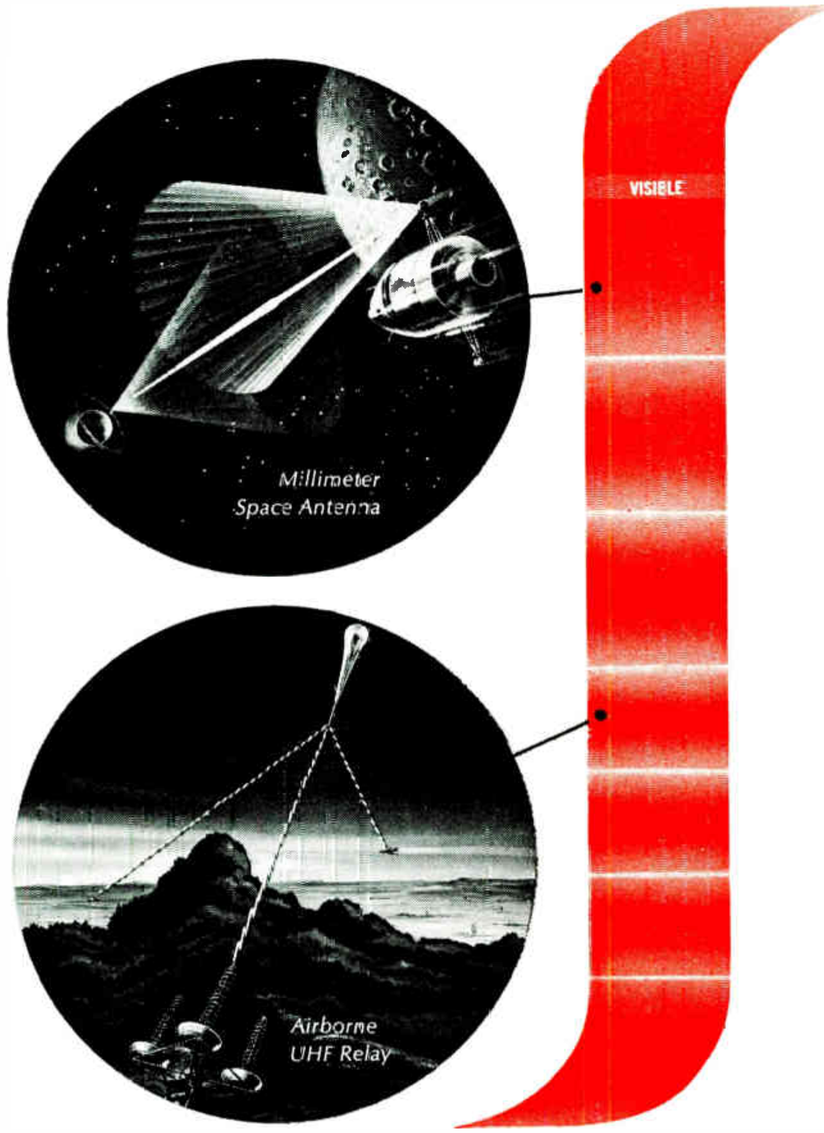
It seems that there are still some arguments about the relative weights of horse and rabbit, as is well documented in the March issue of SPECTRUM. It is clear, however, that engineering factors have ceased to be important in the choices of European color television systems. It is sad that such decisions should be made on other than a scientific and economic basis.

C. C. Culter
Editor, IEEE SPECTRUM

1. Zakharov, I. P., *et al.* "Selection of a color television system," *Tekhnika kino i televideniya* (Moscow), pp. 9–13, Sept. 1964. Translation, U.S. Dept. of Commerce, Office of Technical Services, Joint Publications Research Service, 26,844 TT:64-51101, Washington, D.C.

2. deVrijer, F. W., *Philips Tech. Rev.*, vol. 27, no. 2, 1966.

3. Herbstreit, J. W., and Pouliquen, H., "International standards for color television," *IEEE Spectrum*, vol. 4, pp. 104–111, Mar. 1967.



HIGHER AND HIGHER

AIRBORNE UHF RELAYS AND MILLIMETER SPACE ANTENNAS IN THE COMPLETE COMMUNICATIONS SPECTRUM

Recent developments at Sylvania Electronic Systems:

■ ■ Seizing the high ground in tactical UHF radio communications, Sylvania Electronic Systems has demonstrated a UHF relay that is rugged, compact and reliable enough to be borne aloft by a balloon or drone aircraft. With this airborne repeater our Armed Forces can achieve full two-way voice and teletype communications over 500-mile ranges even in the jungles and mountains of Viet Nam.

■ ■ Higher still, orbiting spacecraft must find each other swiftly and communicate enormous amounts of data. Sylvania Electronic Systems has produced a millimeter wave antenna system that will pinpoint another satellite antenna in less than a second. With 10 times the information-handling capacity of conventional lower-frequency systems, millimeter waves meet the needs of space communications.

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Revamp educational system?

This letter is more or less a rebuttal to the article, "Dilemmas of Engineering Education," by H. Brooks in the February issue of IEEE SPECTRUM (pp. 89–91).

In this article, as in almost all articles dealing with the problems of engineering education, IEEE SPECTRUM takes the position that we are today plagued by what has been termed "overspecialization." I submit that this is not the problem but rather the result of the real problem. The real problem is the inadequacy of the overall, not just engineering, educational system. It would seem to me that a general indictment of our present educational system should be based on the fact that we are training men for professions that are either in the process of being redefined out of existence or are becoming obsolete.

We are quickly approaching (if we have not already reached) the point where technology will be reshaping the sociological environment rather than providing the means for the aspirations of society as had been the case. As an example of this, I cite the "computer." The failure of our universities has been that they have not provided their graduates with the means to deal with this problem. Still in use is the antiquated system of teaching the solution to select specific problems; the university has not seen the need to provide a more general base for the solution of problems not in existence today. In 1967 we are training professionals only for 1967 without regard to the fact that most of these people will be around 40 or 50 years from now and will be required to function in the society of that time. The presumption of the university is that if we show the student the way some problem has been solved in the past, he will no doubt have the ability to generalize and be able to solve successfully any and all of the problems of the future. One can resolve this argument as invalid by simply looking at the state of the world today.

In the February 21 issue of *Look* magazine, the article on "The Future of Education" deals in part with the problem I have stated, although I have serious reservations about the solution it proposes.

I do not wish to imply that the problem Dr. Brooks has stated does not exist; rather, I wish to second his statements. Where I do not agree with

Dr. Brooks is in his analysis, for it would seem that the only way to solve the problem is to root out its cause—which I believe to be in the educational system with respect to the content rather than the makeup of the faculty, as Dr. Brooks suggests.

Michael M. Cirovic
Jackson Heights, N.Y.

Notes on radio spectrum

I have read T. L. Greenwood's article with a great deal of interest ("The Radio Spectrum Below 550 kHz," pp. 121–123, Mar. 1967). He has brought together a wealth of information as to the present use of this end of the spectrum. However, it should be noted that his paper appears to be an expansion and updating of a letter appearing in *QST* for January 1961 (p. 60) entitled "Radio Below 500 Kc," and to which no reference is made.

The reader who might be interested in current shore station activity on 500 kHz is referred to an article on that subject in the Winter 1966–67 *Bulletin of The Antique Wireless Association*, published at Holcomb, N.Y.

William B. Gould
Elberon, N.J.

To answer several inquiries as to the equipment used in receiving the low-frequency signals reported in my article, the receiver used is a World War II surplus Navy RBA-5, frequency range 15–600 kHz, three-stage TRF, detector, and BFO, bandwidth at VLF 0.3 kHz, with grounded antenna circuit. The antenna used is a single wire approximately $10^1/_2$ meters (35 feet) long.

Several typographical errors appeared in the article. On page 123, the second paragraph in the right hand column reads "SNU" where it should read "WNU." On the same page, in the next to the last paragraph in the left-hand column, "40 km" should read "240 km." The second paragraph in the right-hand column on page 122 reads "ESL" rather than the correct "WSL."

I would appreciate any information that would be helpful in identifying signals heard between 100 and 140 kHz and that appear to be from navigation systems: an FSK signal on 131.5 kHz with alternate V and B, and a variable-amplitude CW signal on 113.2 kHz, and a signal at 115.5 kHz with a complex keying sequence.

Thomas L. Greenwood
Huntsville, Ala.

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