VOLUME 4 □ NUMBER 6 JUNE 1967

IEEE spectrum

features

Departments: *please turn to the next page*

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

Primitive peoples may have been primitive technologically, but in their speech and languages (and arts) they were no less sophisticated than we are. Now, however, our technology is approaching a threshold where it may even begin to change speech itself, as discussed in the article beginning on page 75. The Bakota Tribe ancestral mask used in the cover montage and the other African masks (pages 75 and 86) are by courtesy of the Brooklyn Museum.

IEEE forum

Correspondence relating to activities and policies of the IEEE

The voice of dissent

I was very much interested in your editorial on "The Way to a More Professional Status" (IEEE SPECTRUM, p. 45, Jan. 1967). I am responding not for the purpose of offering a "Letter to the Editor," but to raise a question about editorial policy in the engineering profession at large. I have particular reference to the general "silent treatment" given to the voice of dissent. By this, I mean the type of dissent at the level of professional responsibility comparable to the great tradition of dissenting opinions observed in our highest courts.

You state: "A distinguishing mark of the professional (in the learned professions) is independence of action, personal (individual) responsibility, and the use of intellectual skills."

I know of no greater responsibility falling on an engineer in the exercise of his independence of action and use of intellectual skills than when his conscience dictates that he must record a dissenting opinion where the public interest is at stake. However, if you were to scan the engineering journals of the past decade you would have a difficult time finding published articles by, or professional recognition and support for engineers who have raised a clear and effective voice in opposition to some of the undermining influences currently at large within our profession and in the United States.

The objection (at the editorial level where the content of our professional magazines is controlled) to the publication of "controversial" articles makes a very tragic picture. I can speak from personal experience over quite a number of years. It takes a great amount of persistence and mobilizing of support among professional colleagues to get a controversial article published . . .

In the final analysis, engineering is an art and not a science. Our greatest lessons in the development of this art are learned from failures. I leave you with these questions: "To what extent has your magazine presented articles that tell in a forthright and revealing manner the various failures in engineering and in operation that have taken place thus far in atomic power plants? To what extent are engineers in the various utility companies giving an honest picture of current deficiencies in atomic power to their Boards of Directors? To what extent have our editors alerted the engineering profession to the problems of professional and business ethics in this new field of atomic power?"

Adolph J. Ackerman
Madison, Wis.

Please refer to "Spectral lines," in this issue on page 47, for the Editor's response to Mr. Ackerman.

Section membership confusion

A resounding "amen!" to the letter of R. H. Dilworth in the March issue regarding Section membership confusion. Like him, I work in one Section, live in another, and, for personal reasons, prefer to have my IEEE mail come to my home address.

As a result, I am classified as a member of the New Jersey Section, in which I have absolutely no interest. I have never attended one of their meetings and in all probability will never do so. I receive their Newsletter, which naturally gives prominent coverage to the New Jersey activities and much smaller coverage to the New York activities—in which I do at times participate. I can scarcely think of a publication I care less to receive.

Before the merger there was one AIEE Section for the entire New York area. When the New Jersey Section was created no one asked me with which Section I wished to be affiliated and, unlike Mr. Dilworth, I did not become a Section officer so I did not have to change my address to please "the great white father" at IEEE headquarters.

Perhaps only 28 members asked to change Section membership, but had the question been asked, I am sure that many more than that in the New York, Long Island, and New Jersey area also would have changed.

In this local case, I would suggest that we go back to an all-encompassing New York Section.

Robert N. Weller
Leonia, N.J.

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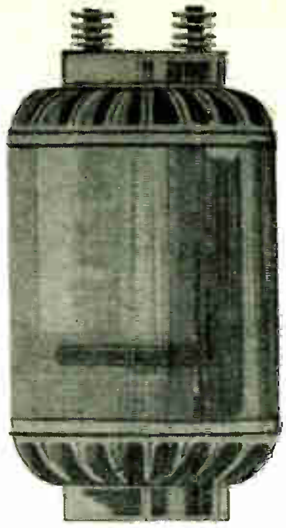

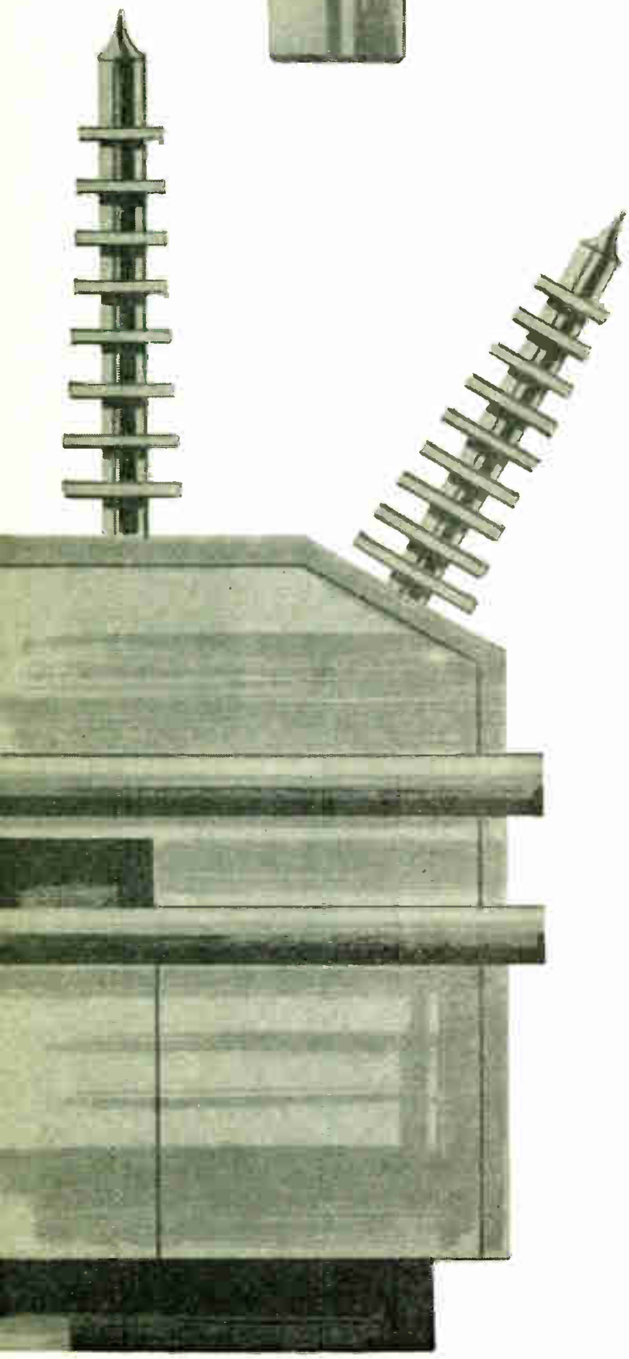

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From time to time we have been asked to list a member residing in one Section as a member of a different Section. This situation usually arises because an individual is employed in one area and lives some distance from his place of employment. Since most of his professional contacts are associated with his place of employment, he desires to belong to that Section having jurisdiction over the geographical area in which he is employed.

Until recently, it was difficult to provide this kind of service through our necessarily complex member file system. Now, however, through the development of new techniques, we are able to offer this option to all our members.

If any member wishes to take advantage of this option, he should write to The Membership Service Department at the New York office; thereafter, he will be listed as a member of the Section of his choice.

Donald G. Fink
General Manager

Professionalism—one more time

At last! Somebody has had the courage to call a spade a spade. I am referring to the letter by Gary Blake Jordan in the "Technical correspondence" section of the January issue of SPECTRUM. There is no doubt that a vast majority of engineers cannot be considered "professional people" in the same sense as most doctors or lawyers. But I do not think that the problem—or even one of the problems—is the fact that engineers sometimes perform "menial" tasks . . .

In my opinion, a pragmatic criterion for a "professional" would be that he is self-employed; that he opens an office and waits for his clients instead of having to find a job with a company. By this criterion, the owner of a grocery store is a professional.

I do not think that the opportunity to charge high prices or to choose one's work is automatically associated with "professionalism." After all, a brand-new doctor really can charge whatever fee he wishes. The question is, will he get it? We have to remember that there are other doctors and ones who, being older, are better known. The first thing a new doctor must do is to find patients. Once he acquires them and convinces them that he is good, he can charge very high fees, but, unless he is really outstanding, those fees cannot be very different from fees usually prevailing in similar cases. A doctor may earn more than an engineer; yet, he cannot charge at will, so it is only a problem of degree.

As to the question of choice, if a doctor is interested in surgery, for instance, he will not refuse a case of appendicitis because he would rather operate on a gall bladder. Of course, here also, if he is at the very top he will specialize in some more restricted subject—such as surgery of the heart. In this case he will probably be connected with an institution in much the same way as an engineer might specialize in some specific area of information theory. And this engineer, of course, would have specialized in this particular subject because he found it interesting, or had some natural aptitude useful in studying it, or because it was a subject under study at the company when he joined it, or for any other reason.

Here we come to the general subject of freedom of choice, which is truly a philosophical one. We might accept the fact that we are characters in a Greek tragedy and that our destiny is being shaped by strange and unyielding forces over which we have absolutely no control. Nevertheless, in everyday life we have some leeway in our decisions. After all, nobody is really being forced to work in military areas, for example. So, whereas I agree in general that our lives are never wholly under our control and probably even less so in these modern times, I do not think that this situation differs greatly for "professional people" or for engineers. Why aren't engineers "professional people" in the sense described? I think that this question is related directly to the present structure of our technology.

The technical projects of today, from automobiles to aerospace vehicles, are very complex and, in general, can only be designed and built by large organizations; these need engineers very much, but the engineers are of necessity cogs in a wheel. It is my opinion that unless the present trend in industrial organization is reversed—which does not seem very likely—the engineer is not going to be a "true professional."

The question arises then: "So what?" Why does an engineer have to be a professional? The answer is, because what we all want for our profession is status—and "professionalism" is usually associated with status. But I think that we can more easily fight for status than we can convince ourselves and others that engineers are like doctors. The two professions (in the larger sense) are different and just cannot be made to fit the same patterns—unless it is to make doctors

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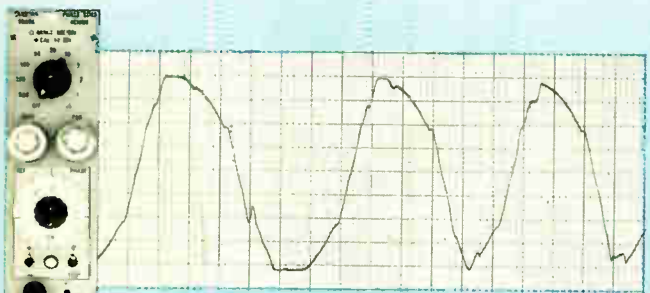

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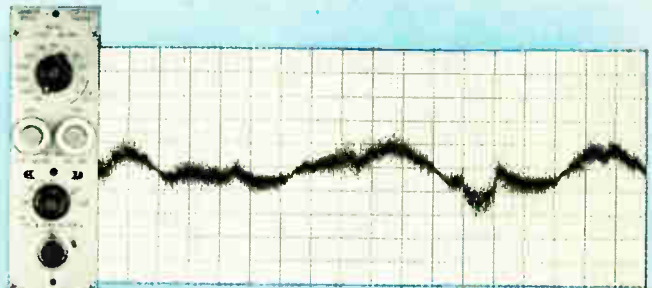

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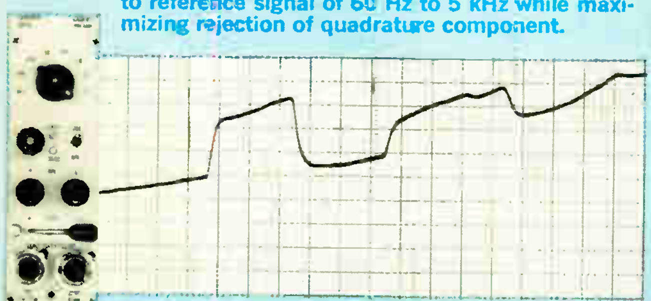

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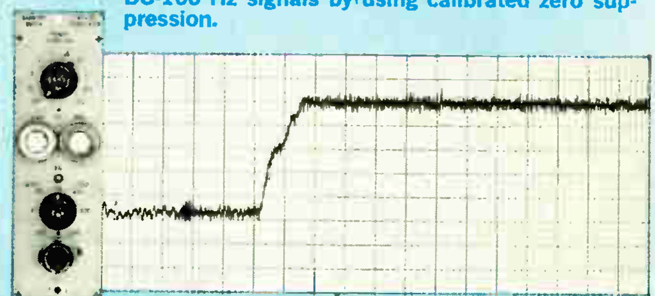

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less professional," which will solve nothing.

Management people, who usually possess high social status, are also not "professionals." They are actually hired to perform their work.

In Brazil, engineers have a social status equal to that of doctors. This is true partly because the traditional concept of engineer involves the civil engineer who has an office, is self-employed, and waits for clients who contract him to build houses—although the modern industrial organization is taking over here also and engineers are becoming less and less "professional." Nevertheless, in Brazil the word "engineer" has a special meaning: it signifies a man who works toward the development of the country. It is felt that he performs a useful and even glamorous function. And nobody is going to call a locomotive driver an "engineer" or a plumber a "sanitary engineer." In addition, there are laws that require industrial and engineering organizations to have engineers in responsible management positions. Thus, it seems to me, that organizations such as IEEE should fight for status, not necessarily for "professionalism." They should do a thorough public relations job of explaining the work of all kinds of engineers, and they should fight in order to obtain a legal definition of who can and who cannot bear the title of "engineer."

In the meantime, those who would rather be "professional people" should not become engineers. They should study medicine or law or they should sell bananas from their own pushcarts—unless they can make it on their own in their profession as consulting engineers, architects, and so on.

Jerzy Lepecki
Belém, Brazil

As I understand it, the primary function of a union is to give the individual member a means whereby he can bargain with his employer from a position of strength. Perhaps some unions concern themselves to a degree with standards of performance and behavior for their members, but I doubt that this is a high-priority objective.

Those learned callings that have firmly achieved professional status in their own eyes and in the eyes of the public—that is, medicine and law—are characterized by the discipline to which their practitioners are subject, both from themselves and from the law. The degree to which this discipline is self-imposed is what determines the calling's right to regard itself as professional. This discipline applies to both competence and morality.

For the most part, engineers are employed by organizations rather than by individual clients. This, perhaps, leads to the fear that a stronger organization for engineers would resemble a union. Perhaps this is true. If unionism, as the word is commonly understood, is the inevitable result of organizing more strongly, then it is possibly, but only possibly, a trend to be avoided. If unionism alone would result, we would have to abandon any pretensions to professional status.

But, if professional status is a desirable goal, engineers themselves will have to attempt to restrict their number to those who meet and maintain reasonably well-defined standards of competence and to those who are conversant with and practice in accordance with a reasonably well-defined standard of professional ethics.

What percentage of engineering schools teach the morality and ethics of the practice of engineering?

How many engineers have ever been disciplined by the members of their own calling, as distinguished from their employers, for malpractice?

Witness the disgrace of those of us employed by the automobile manufacturers who for years abdicated their duty to protect human life and limb in the design of their products. Professionals?

Were the business managers of the utilities solely responsible for "the great Northeast blackout?" Was there no malpractice there? Did anyone even ask? Do we even know how to define what acts or omissions might have constituted such malpractice? Do we dare to ask or define?

If professional societies such as the IEEE take a stronger stand in setting standards for engineering practice, then perhaps the engineer may indeed eventually be able to bargain from a position of strength. If he bargains only for his own personal gain, this will certainly represent a step backward from professionalism. If, however, he bargains for the health, welfare, and safety of his clients, his fellow humans, we will have something altogether different.

The question is, do engineers really want professional status, are they willing to assume its responsibilities, and are they willing to pay the price? The nature of the responsibility would be unique by the very fact that engineers are largely employees of organizations. Are engineers capable of defining and developing that unique kind of responsibility? Perhaps not, and perhaps the fears of unionism are well founded.

On the other hand, if engineers are ready to reach for professional stature, and the engineering societies are not, then the change will probably come under different leadership. When and if that happens, we will be unable to distinguish between the IEEE and all of the other highly competent technical publishing firms.

Public image is *not* quite another matter. Public image is *exactly* what professional status is. Professional status must be *earned* by the whole calling. We must earn it from the public. If we do not choose to earn professional status, why don't we admit the truth to ourselves, refer to our engineering societies as *technical* societies, and end the debate at that point?

Gilbert H. Friedman
Torrance, Calif.

Dues concessions

We have read with interest the correspondence of Rama Rao, which is entitled "Fairness to foreign members" and which deals with the payment of annual dues by foreign members. (See IEEE forum, SPECTRUM, p. 10, Dec. 1966.) In regard to this situation may I point out that with the devaluation of the Indian rupee the subscription price for an Indian member has increased from Rs. 75 to Rs. 192, which means an increase of more than 100 percent, whereas for a U.S. member, the percentage of increase is much lower. The severity of such a high rate for the Indian members has already been recognized by other professional bodies such as the Institution of Electrical Engineers, London. In a recent communication to each Indian member, the Institution has given two main concessions: (1) the annual dues for the next three years may be remitted at the old rate of exchange prevailing before devaluation of the Indian rupee, and (2) the dues may be remitted in rupees to the Indian representative of IEE, London, stationed at Calcutta.

We hope that the Special Service Committee of the IEEE, which has been established in order to deal, country by country, with the specific problems of members in Regions 8, 9, and 10, will look into the difficulties of the Indian members sympathetically and will not lag behind the IEE, London, in extending similar concessions to them.

M. R. Krishnamurthy
Kharagpur, India

Spectral lines

Duty to dissent. Of the many letters that come to this office, none have been more thought provoking than a letter appearing in this issue (see IEEE forum), in which Adolph J. Ackerman reproves professional journals for avoiding controversial issues, for giving the "silent treatment" to the voice of dissent.

Is it true, as he states, that editorial space for presentation of an unpopular viewpoint is virtually impossible to obtain in a reputable technical journal? Alas, it is true—although not because editors are necessarily contrary or stupid, or even timid. Our very methods of refereeing (i.e., having submitted papers judged by peers) militate against publication of articles about which there is substantial disagreement, as does the natural inclination of editors to publish that which they believe subscribers want to read. Dissenting opinions are likely to be unpopular. The strong desire of technical and scientific people to advance their profession and avoid political controversy is another deterrent. But perhaps the greatest hindrance to such publication is provided by the wish to present what is true, logical, and authoritative—and the voice of dissent seldom fulfills this requirement.

The editorial staff of any journal faces a difficult task in selecting papers. It is inevitable that some good papers will be rejected; that some bad ones will be published. However, recognizing the natural prejudice against unpopular causes, and their possible importance, editors should try very hard to give "equal time" to the dissenting voice. The challenge to recognize virtue in a dissenting viewpoint, to differentiate between prophet and crank, is a formidable one. The voice of dissent should be heard, however, and not only through correspondence columns.

A more serious, and even more basic, fault is the reluctance of most individuals to express their convictions publicly, and thus do their part as the conscience for our profession. The main reason that we don't hear much of the unpopular viewpoint is that dissent is seldom available in publishable form. Few will make the effort that Mr. Ackerman has made, to warn, publicly, of what is believed to be dangerous practice. It is not enough to grumble to our colleagues, or to write anonymous letters, as many do. What is required is clear, logical exposition, loaded with *facts* and backed by character. What we need most is the individual motivation to take the personal responsibility, as does Mr. Ackerman, to "record a dissenting opinion where the public interest is at stake."

It was not engineers who mounted the assault on pollution, but surely it was engineers who first knew what was happening to our water and to our air. It was not engineers who forced the program of safety in automobile design; but who was more aware of the problem? Who better than the engineers involved knew of the dangers in the Apollo spacecraft design and could have issued more effective warnings? Who can better police extravagant proposals for government contracts than the engineers,[1] and indeed, who can better tell us of the deficiencies and dangers in atomic power plants than the engineers who design them?[2]

Engineers have a responsibility that goes far beyond the building of machines and systems. We cannot leave it to the technical illiterates, or even to literate and overloaded technical administrators, to decide what is safe and for the public good. We must tell what we know, first through normal administrative channels, but when these fail, through whatever avenues we can find.

Many claim that it is disloyal to protest. Sometimes the penalty—disapproval, loss of status, even vilification—can be severe. The penalty for neglect of this duty, however, can be much more severe. Ackerman, in a published article,[3] quotes from Herbert Hoover[4]: "Our greatest danger is not from invasion by foreign armies. Our dangers are that we may commit suicide from within by complaisance with evil. Or by Public tolerance of scandalous behavior. Or by cynical acceptance of dishonor. These evils have defeated nations many times in human history. The redemption of mankind by America will depend upon our ability to cope with these evils here at home." Ackerman concludes: "Today we need more critical pronouncements and published declarations by engineers in high professional responsibilities. In some instances such criticism must be severe if we are properly to serve mankind and preserve our freedom. Hence it is of utmost importance that we maintain our freedom of communication in the engineering profession and to the public. The decades ahead are bound to be a critical and difficult period, and there will be occasions for sharp dissent and strong words if we are to meet our responsibilities."

C. C. Cutler

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Authors

Comparing MOS and bipolar integrated circuits (page 50)

R. M. Warner, Jr. (SM) holds the B.S. degree in physics from Carnegie Institute of Technology and the M.S. and Ph.D. degrees in physics from Case Institute of Technology. He has been manager of the MOS program at Texas Instruments' Semiconductor Division for the past 1½ years. Previously he was director of engineering, Motorola Semiconductor Products Division. His earlier work at Motorola, Bell Telephone Laboratories, and Corning Glass Works involved silicon controlled rectifiers, epitaxial four-layer diodes, field-effect devices, glass dielectric capacitors, and many other electronic devices. Dr. Warner holds eight patents and is the author or coauthor of 24 technical papers. He is editor of the recent McGraw-Hill book, *Integrated Circuits; Design Principles and Fabrication.*

MHD power generators in central stations (page 59)

T. C. Tsu received the B.S. degree from Chiao Tung University, China, and the M.A.Sc. degree from the University of Toronto, both in mechanical engineering, and the Sc.D. degree in aeronautical engineering from the Massachusetts Institute of Technology. After a short time with the Sloan Engineering Laboratory of M.I.T., he joined the Baldwin-Lima-Hamilton Corporation as a consulting engineer, where he helped develop free-piston engines and compressors. In 1947 he moved to Pennsylvania State University, becoming an associate professor of mechanical engineering and engineering research. He has been with Westinghouse since 1952, first at the Aviation Gas Turbine Division in Philadelphia and then at the Research Laboratories in Pittsburgh, where he is now an advisory engineer in thermodynamics, energy conversion, and other interdisciplinary areas.

Applied lasers (page 66)

James Vollmer (SM) received the B.S. degree in general science from Union College in 1945 and the M.S. and Ph.D. degrees in physics from Temple University in 1951 and 1956, respectively. His research interests, publications, and patents have covered a wide variety of fields, ranging from infrared properties of materials to plasma physics to quantum electronics. His professional experience includes five years of teaching at Temple University, eight years of supervising a research group at Honeywell Inc., and seven years of research supervision at the Radio Corporation of America. Currently Dr. Vollmer is manager of RCA's Applied Research, a group charged with translating the recent advances in basic research into useful techniques and devices. Typical areas include microwave physics, lasers, and electrooptics.

Solid-state microwave delay lines (page 87)

Richard W. Damon (SM) received the B.S. degree in physics and the M.A. and Ph.D. degrees in applied physics from Harvard University, where he was also a Teaching Fellow in applied physics. From 1943 to 1946 he served in the U.S. Navy and in 1948–49 was employed by Raytheon Company. From 1951 to 1960 he was a research associate at the General Electric Research Laboratory, working on television camera tubes and magnetic resonance. As head of the Solid State Control Device Department at Microwave Associates, Inc., from 1960 to 1962, he was responsible for the development of microwave semiconductor and ferrite devices. In 1962 he joined the Sperry Rand Research Center, where he is now head of the Quantum Electronics Department and associate manager of the Solid State Sciences Laboratory.

A message from your President

W. K. MacAdam *President IEEE*

Whether or not to maintain one's membership in a professional engineering society is a decision that is re-examined annually by hundreds of thousands of engineers and engineering managers. Unfortunately, a conclusion is not often easily reached. First, membership requires, as a minimum, a significant financial commitment in the face of strong competition from other worthwhile investments. Beyond this, for many it also entails a contribution of valuable time and energy in support of active participation in professional affairs. The decision obviously has a first-order negative bias. The fact that each year more than 150 000 members of IEEE find overriding motivations in favor of continued membership in their professional technical society invites a careful look at some of the positive factors that control these selections. Such an analysis is vital to all of us, if we are to keep our Institute responsive to changing membership needs.

Some benefits, of course, are direct and easily visible. They come with the membership package and do not entail a wait for investment maturity. These first-order advantages consist of a subscription to an outstanding core publication providing broad interdisciplinary coverage, combined with the identification, recognition, and personal satisfaction that derive from membership in a society representing one's profession. For many engineers and engineering managers, this combination provides good and sufficient reasons for joining the Institute. To them, the higher-order factors are a bonus.

For probably a much larger segment of Institute membership, however, the indirect, not so obvious, returns become an important, and in many cases controlling, factor in their decision. These higher-order effects are many and varied—the individual advantages have a different value for each member. They are a cafeteria display from which he can make a choice to suit his taste and appetite in relation to what he is willing to invest. But despite their variety, all these supplementary advantages have one basic characteristic: They require a further investment in time, energy, and interest in order to release their reward. The motivation for the investment is often indirect but, because of its importance, it deserves careful analysis and understanding by all who are interested in the future of our Institute.

Consider, for example, the benefits that lie beyond passive IEEE membership for the engineer or scientist in a research laboratory or for one engaged in exploratory product development. For him, and for the success of the institution or company with which he is associated, it is vital to be in constant communication with the changing technology and in contact with others working in his own or related fields. In view of the fact that our Institute publishes about one tenth of the world's primary technical papers in the electrical field, currently in 42 journals, his need for careful study of selected articles in the appropriate Group Transactions is the key to professional effectiveness and advancement. This is almost his only sure way of riding the crest of the technological wave. The publications and conferences of the Institute also bring this member another substantial value—the opportunity to report his own findings and, equally important, to test them in a worldwide forum of his colleagues.

Another, and probably far larger, category of members includes those engineers concerned with design for manufacture, with operations, or with systems planning. For them, the investment in conference attendance and selective perusal of Institute publications offers opportunities that they critically need to keep up to date on a wide front. For many there is a requirement for broad technical awareness. Those in the management, design, and operation of industries sensitive to technological progress run the risk of failing to recognize the changes taking place. Technological name dropping in the new environment is not enough; broader comprehension is needed by the practicing engineer and engineering executive. They, also, need contact with the changing scene. Through the medium of their professional society publications and activities they can step beyond the walls of their company or industrial environment and view the panorama in broad perspective.

That which is of value to the engineer, scientist, educator, or engineering manager is correspondingly beneficial to the organization with which he is associated. An alert management of an institution or organization dependent on generating, disseminating, or making important use of modern technology will encourage engineering search beyond company walls, beyond immediate associates, and even beyond the field of direct interest or engineering discipline. Indeed, there is good evidence that the most progressive institutions and organizations do just that. This is not a matter of paying off past obligations to those authors and professional publications that helped produce the technological expansion. Rather, it is a matter of making sure the industry maintains a high standard of competence in an expanding and changing technology.

This year your Institute is taking an even closer and more well-informed look into the needs and desires of the engineering profession in all its fields and at all its levels of management. A carefully planned survey is being made of member interest, readership, and personal participation. It is being carried out under the guidance of the Board of Directors by a competent and experienced organization that specializes in such undertakings. A sufficiently large sample will be taken to obtain a reliable comparison between the various major industry, government, or educationally oriented groups. In this way, we will be exploring ways to make the Institute of even greater value to all our members.

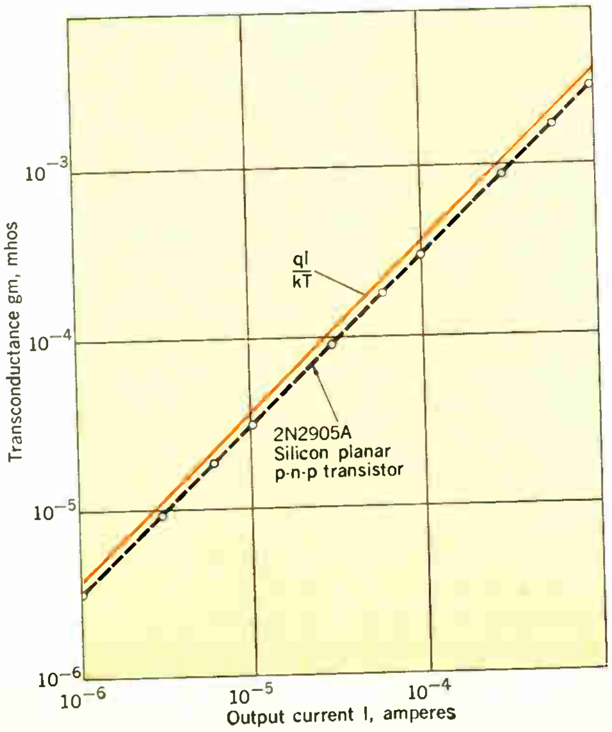
What is Institute membership worth? To the alert and progressive scientist, engineer, educator, or technical manager, it can represent a compound investment in himself, in his company, in industry, and in society. It can serve as a coupling link with the outside world. But its value is not obvious. The motivation for increasing the coupling factor through enlightened self-interest is more subtle—and its realization thus more rewarding.

Comparing MOS and bipolar integrated circuits

Where speed is not of paramount importance, metal-oxide-semiconductor integrated circuits have distinct advantages over bipolar integrated circuits. These include greater functional density, fewer processing steps, and lower cost

R. M. Warner, Jr. *Texas Instruments Incorporated*

In terms of speed and speed/power performance, bipolar integrated circuits are superior to metal-oxide-semiconductor integrated circuits. This superiority is based on the high transconductance inherent in bipolar transistors and is technology-independent. For the MOS case, transconductance is highly technology-dependent, and hence the performance difference will probably diminish in the future. Comparisons of the two technologies in their mid-1966 forms are made; the bipolar performance advantage in most cases is between 10 and 100. MOS integrated circuits have an area-per-function advantage ratio of about 5 for equivalent-function circuits, but a ratio of between 5 and 10 when circuits exploiting the unique MOS properties are considered. In addition, MOS processing is simpler than bipolar processing by approximately 40 percent.



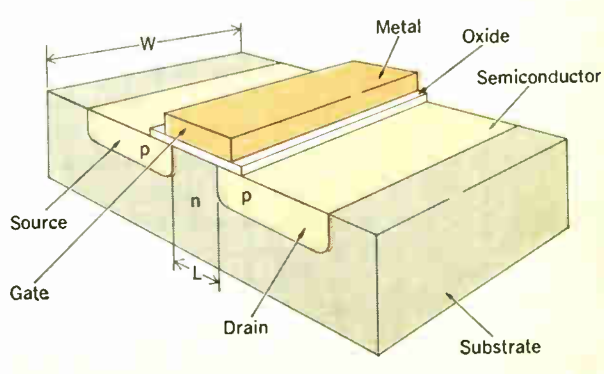
Integrated circuit technology is evolving so rapidly that even a period as short as six months can produce a significant change in the quantitative results of comparisons such as those made in this article. Hence it is probably desirable to pinpoint the time for which these comparisons apply; in this vein, let us consider that these are based on "mid-1966." To simplify the comparison process, the following restrictions are imposed:

1. Only digital circuit examples are discussed.
2. Only monolithic integrated circuits are compared.
3. Only fixed-interconnect-pattern (FIP) integrated circuits are considered. For purposes of this specific discussion we rule out both the discretionary interconnection of "cells" on a single piece of silicon and discretionary connections within a cell to alter its function.
4. Only a single level of metal is allowed in the circuits being compared.

Several of the developments thus ruled out of consideration here have potentially far-reaching consequences. Undoubtedly, in the near future they will be the subjects of comparisons similar to the present one.

FIGURE 1. Transconductance versus output current for a bipolar transistor. Theoretical curve is shown in color.

FIGURE 2. Schematic diagram of a MOSFET.



Factors affecting active-device speed

In an integrated-circuit-type bipolar transistor, frequency response or speed can be analyzed in terms of five delay times and time constants.[1] These are:

1. The emitter time constant involving its parasitic resistance and capacitance.
2. The minority carrier transit time through the base.
3. The carrier transit time through the collector depletion layer.
4. The collector time constant involving parasitic resistance in the collector and the sum of the collector and substrate junction capacitances.
5. The delay connected with the storage of minority carriers in the base and collector when the transistor is operated in "saturation," or with its collector junction forward-biased.

The last-named delay is controlled by gold doping the silicon to reduce carrier lifetime, and by avoiding saturated operation. In order to estimate a bipolar performance limit that is independent of operation mode, let us omit this delay time from consideration, even though it can be a dominant mechanism when it does enter. Collector depletion layer transit time (item 3) can be neglected because it is typically about 10 percent of base transit time (item 2). The sum of the emitter and collector time constants (items 1 and 4) is about equal to the base transit time, with the collector time constant being the dominant one. In a typical integrated circuit, important additional parasitic capacitance associated with the interconnection from transistor to load occurs in parallel with substrate-junction capacitance. Thus capacitance charging times can easily be larger than base transit times, and hence have a primary part in fixing bipolar speed.

In the MOS field-effect transistor (MOSFET), there are no important transit-time delays. In addition, transconductance values are generally lower than in bipolar transistors. Consequently, MOS integrated circuits are almost purely "*RC* limited" insofar as speed is concerned.

Since the charging of parasitic capacitance is a dominant consideration in both technologies, it is appropriate to employ a figure of merit involving the transconductance g_m of the active device and the capacitance C that the device must charge. Let us begin by examining the transconductances of the two active devices. The bipolar transistor is the principal element in bipolar integrated circuits. The MOSFET is the principal element—and indeed, essentially the only element—in MOS integrated circuits.

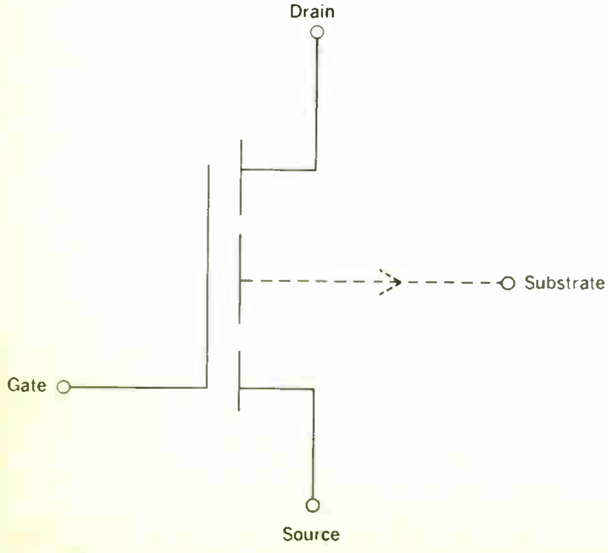
Performance comparison in terms of transconductance. Bipolar transconductance is a consequence of modulating the voltage barrier in a junction, and is found by differentiating the "law of the junction." The result is proportional to current ($g_m \approx qI/kT$) and independent of carrier type, independent of which semiconductor material is used, and over wide current ranges is independent of junction area. Figure 1 shows transconductance vs. current and compares measured points for a silicon planar transistor with the foregoing expression.

Let us now turn to the MOSFET; Fig. 2 shows schematically the physical structure of the MOSFET and identifies its principal features and terminals. This is the p-channel "enchancement-mode" device used in most MOS integrated circuits. With sufficient negative bias on the gate, a p-type inversion layer or "channel" is established, connecting source and drain.

Figure 3 shows the symbol for the MOSFET and identifies its four terminals. The position of the gate terminal identifies the source-terminal end of the device for the numerous cases in which a preference exists. The device is inherently bilateral and there are important cases (an example is given later) where it is so used. The arrow on the substrate lead informs us that the substrate is n-type. This lead is often omitted, since all MOSFET's in a monolithic circuit have a common substrate.

Transconductance in the MOSFET for a given device geometry varies as $\sqrt{I}$. For a given value of current, transconductance varies as $\sqrt{W}$ (see Fig. 2 for the defini-

FIGURE 3. Schematic symbol for the p-channel enhancement-mode MOSFET. (Substrate lead is often omitted.)



tion of W), and hence approximately as the square root of device area once the other device dimensions have been fixed at the minimum values associated with a particular state of the technology. Representative mid-1966 MOS technology has led to the relation $\sqrt{(0.014)WI}$ for g_m, where the units for W, I, and g_m are centimeter, ampere, and mho, respectively. It is noteworthy that attainable g_m in the MOSFET is tied directly to the state of the art, whereas g_m in the bipolar device is essentially fixed by nature.

The MOSFET has a parasitic output capacitance C primarily associated with the drain–substrate junction. It clearly increases in proportion to device area, or in proportion to W, once again assuming that the other dimensions have been fixed at minimum values. For recent commercial practice, C in picofarads is approximately 13 W, where W is in centimeters.

An often-used figure of merit is g_m/C, which has frequency dimensions. A related figure of merit is $g_m/\sqrt{C}$; although it cannot be interpreted directly in terms of frequency, it does have an advantage in this discussion because it is independent of MOSFET size (W), thus facilitating comparisons. This relationship is plotted (solid line) for a range of currents in Fig. 4.

To effect a comparison, several integrated-circuit-type bipolar transistors[2] and discrete transistors[3] have been spotted (plotted points) on the same diagram. For each device, the value of current yielding peak current gain was determined. For this current value, transconductance was calculated from the expression cited above; then $g_m/\sqrt{C}$ was calculated by using for C the junction contribution to C_{ob}. Figure 4 shows that the bipolar transistor has an advantage of about 65 with respect to this figure of merit. It should be noted again that both base transit delay and minority carrier storage delay have been neglected in the bipolar case.

As indicated earlier, bipolar transconductance can be considered technology-independent. In the MOSFET case, however, achievable transconductance depends on our ability to obtain and reproduce small dimensions, to realize ever-higher carrier mobilities, and to exploit insulators of increasing dielectric constant and breakdown strength. In short, MOSFET transconductance is highly technology-dependent. Thus we can expect to see the bipolar-MOS transconductance gap diminish in the future.

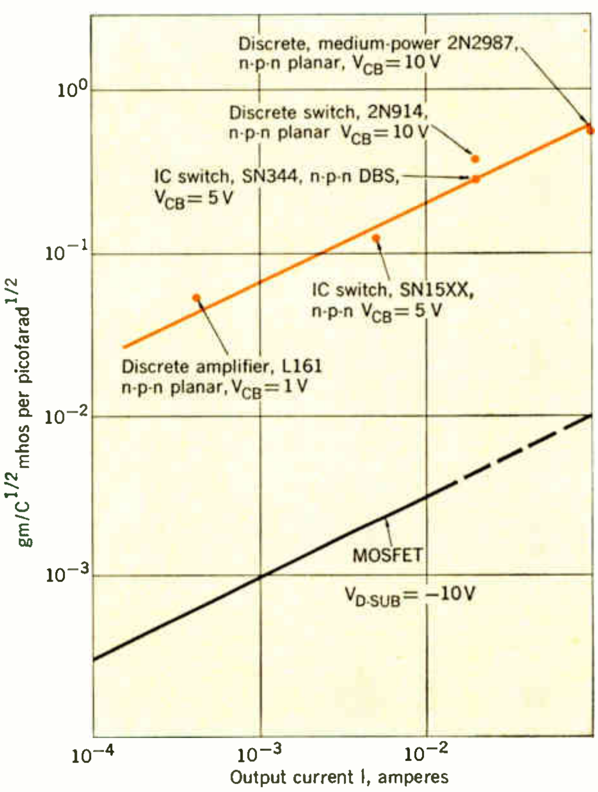
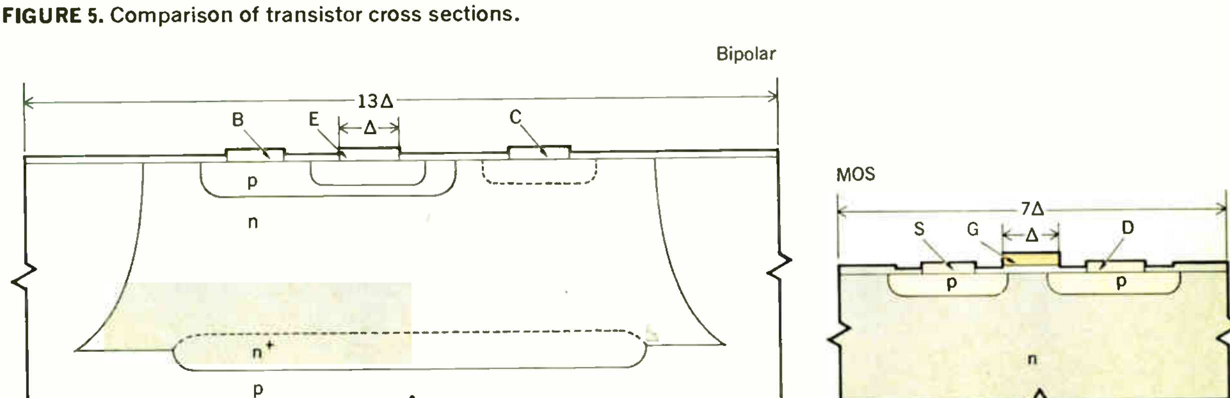


FIGURE 4. Curves of $g_m/\sqrt{C}$ vs. I for silicon bipolar transistors (color) and MOS transistors (black).

I. Performance-ratio comparison

Circuits Compared	Performance ratios, Bipolar/MOS: Speed (f_{max})	Performance ratios, Bipolar/MOS: Speed/Static Power
Bipolar static shift-register bit/ MOS dynamic shift-register bit	1.5	2
Bipolar static shift-register bit/ MOS static shift-register bit	6	17
Bipolar static J-K flip-flop/ MOS static J-K flip-flop	20	36
Bipolar BCD decade counter/ MOS BCD decade counter	150	75

FIGURE 5. Comparison of transistor cross sections.



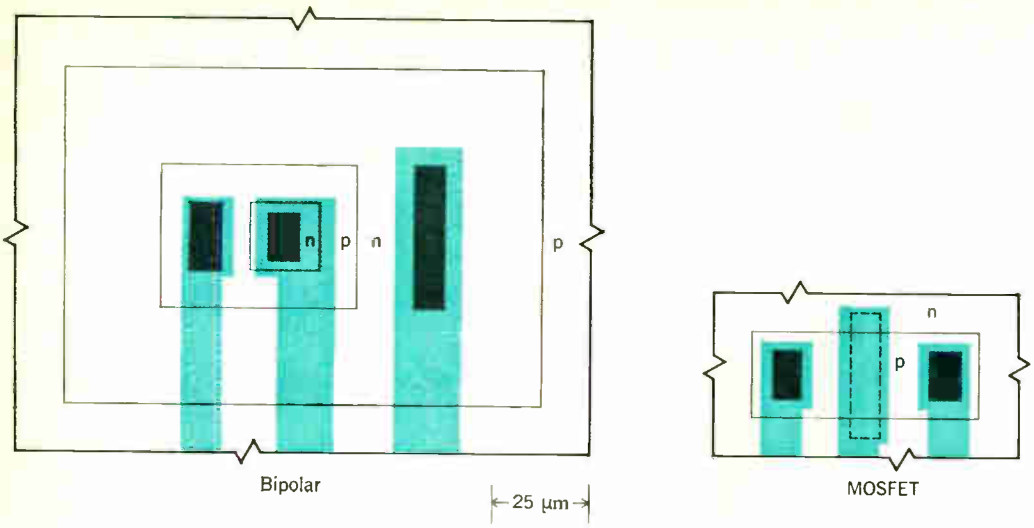


FIGURE 6. Layout comparison of a bipolar transistor and a MOSFET, both for integrated circuits.

Performance comparison in terms of speed and power. Even though discrete-device transconductance is fundamental to the subject of integrated-circuit performance, it does not tell the whole story. Additional factors enter when one makes a transition from discrete-device to integrated-circuit analysis. These can be handled once more through an appropriate figure of merit, though additional assumptions are required. A recent treatment of the problem by Josephs[4] employs the product of signal propagation delay and average static power per stage as a figure of merit. The reciprocal of this product can, with consistency, be called a speed/power figure of merit. He found a speed/power advantage of about 15 for bipolar transistor-transistor logic and direct-coupled transistor logic circuits over MOS digital circuits.

Still another approach is a one-to-one comparison of actual circuits on an empirical basis. Table I compares four pairs of circuits in terms of speed and speed/power, where maximum operating frequency and typical static power are the basic data employed. Circuits are listed in order of increasing complexity and the numbers suggest that the bipolar performance advantage increases with complexity, which may be a reflection of bipolar superiority at "capacity driving," or rapid charging of circuit capacitance.

All of the circuits, except the MOS dynamic shift-register bit, have a lower frequency limit of zero, which the word "static" is intended to convey. Dynamic operation in MOS circuits is discussed in the next section; as Table I indicates, it is an important means of improving MOS performance. Dynamic operation is also applicable in a number of other circuits where dc operation is not essential, although it is especially important in the shift-register case.

Generalizing on the subject of performance is difficult because the quantitative comparisons cited range very widely (for example, in Table I alone a two-decade range occurs). Perhaps a fair summary statement is that the median bipolar performance advantage factor falls in the 10-to-100 range insofar as all of the foregoing quantitative performance comparisons are concerned. Hence, where speed/power performance is vital, bipolar circuits are strongly indicated.

Functional-density advantage

For numerous applications in which speed/power performance is not paramount, MOS circuits have advantages. Their most important advantage is economy, a factor that should become evident in a year or so. One of the major factors from which MOS economy stems is its high functional density (for example, gates per square centimeter). This factor has a favorable effect on yield, which is intimately related to cost.

Fundamental-device size comparison. Let us attempt a quantitative comparison of the functional densities achievable in these two technologies, assuming that the processing capabilities (photomasking, diffusion, etc.) brought to bear on the two are equally refined. Once more a reasonable starting point is a comparison of a single bipolar transistor and a single MOSFET.

Figure 5 shows integrated-circuit versions of these two devices in cross section, with vertical dimensions exaggerated for clarity by a factor of two as compared with the lateral dimensions. Consider that the narrowest acceptable line, either as an opening in the oxide or as a metal conductor, has a width Δ. Consider further that we can space such a line a distance $\Delta/2$ away from another edge.[5] Thus, one could position a contact of width Δ within a diffusion-mask opening of width 2Δ. It can be seen (Fig. 5) in the MOS case that the metal spacing is less than Δ, but this is common practice in MOS technology. In defining the outer boundaries in each case, enough clearance is allowed to permit the joining of one device directly to another without mutual interference. It is clear that the large isolation junction (outer junction) in the bipolar device costs considerable space, especially since the deep diffusion required has a sizable lateral component. This feature is obviated in the MOS case because either a junction or an insulator lies between each terminal and substrate, and one never needs to forward-bias a junction. Isolating junction aside, it is also clear in Fig. 5 that bipolar topology requires more space than that of the MOSFET. Considering all these factors, there is nearly a two-to-one difference in overall device lengths.

Next examine the top-view diagrams of a bipolar transistor and a MOSFET, as shown in Fig. 6. On the basis

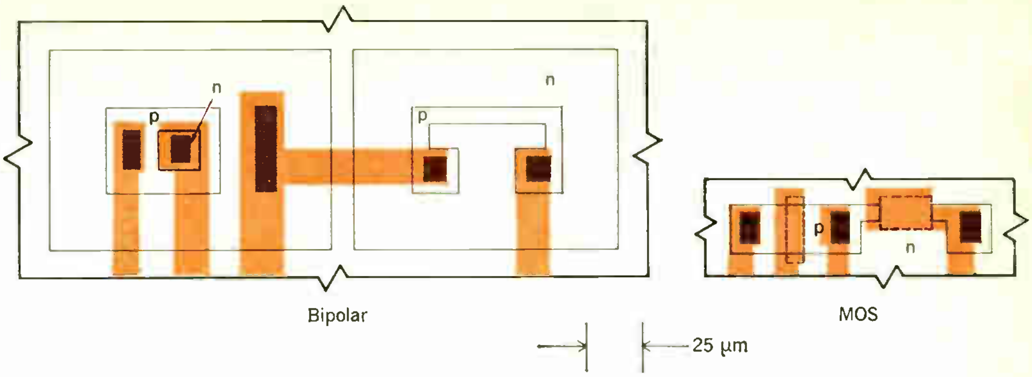


FIGURE 7. Layout comparison of bipolar and MOS integrated inverters.

of comparatively conservative layout rules, the MOSFET shown here measures 43 by 79 μm. The smallest permissible contact has been used for the bipolar emitter; the other bipolar contacts are made larger because no saving is achieved by giving them minimum size. In the MOSFET, both contacts are of minimum size. Thus, using consistent layout criteria, the ratio of the overall areas of these two basic devices is five to one.

Inverter area comparison. For further insight, area comparisons have been made for several additional entities, each progressively more complex. All of these have been chosen because they perform identical functions. The second item is a transistor and load combination, or inverter. This is depicted for each technology in Fig. 7; the bipolar-to-MOS area ratio is 5.5 to 1. In the bipolar case it is customary to form a resistor by employing a base-type diffusion (as depicted in Fig. 7) having a sheet resistance in the neighborhood of 200 ohms per square. Doing so yields a reasonable compromise between the high value desired for resistor fabrication and an acceptably low value of temperature coefficient of resistance. In the MOS case, on the other hand, an inversion layer is employed and it may have sheet resistance as high as 40 000 ohms per square. Such resistors exhibit appreciable temperature coefficients of resistance but are still very usable because the channel of the "driver" transistor has the same behavior with respect to temperature. The resulting compensation is an advantage of having but one basic kind of element in the MOS integrated circuit.

For these reasons the two load resistors depicted in Fig. 7 would have values of approximately 2×10^3 ohms and 10^5 ohms, respectively, even though the MOS resistor is much smaller. It follows that low-current and low-power MOS circuits are quite feasible. In summary, the high sheet resistance in the MOS load resistor is significant in permitting compact devices and functions, and in keeping power dissipation at a low level consistent with the high MOS functional density.

Other functional-density comparisons. It is interesting to make similar comparisons farther up the complexity scale. The static shift registers mentioned in Table I constitute an appropriate equivalent-function pair. The dimensions of these are 360 by 480 μm and 108 by 300 μm for the bipolar and MOS cases, respectively, yielding an area ratio of 5.3 to 1. The static J-K flip-flops are another convenient pair. These measure 1040 by 1040 μm and 375 by 565 μm, respectively, for a ratio of 5.1 to 1.

II. Area ratios for bipolar and MOS integrated-circuit building blocks

Circuit	Area Ratios: MOS Circuit to Single MOSFET	Area Ratios: Bipolar to MOS
Transistor	1.0	5.0
Inverter	1.7	5.5
Static shift-register bit	9.5	5.3
Static J-K flip-flop	62.2	5.1

All four entities and their comparisons are summarized in Table II. The center column gives the ratio of the size of each successive MOS circuit to the size of the MOSFET, as an indication of the range of sizes and complexities considered here. The right-hand column, then, gives the bipolar-to-MOS area ratios just cited. There may be some degree of coincidence in the fact that these area ratios are so nearly equal, as subsequent comparisons of these same circuits will suggest. But nonetheless, this exercise does indicate a genuine MOS size advantage and does impart a feeling for its magnitude.

Part of the MOS size advantage is derived from the fact that a number of functions can be achieved with fewer elements in the MOS case than in the bipolar case. This is illustrated in Fig. 8, in which the ratios of element counts are plotted. The number of elements in the MOS member is taken as an independent variable that indicates circuit complexity. It can be seen here that the simplicity advantage in MOS static shift registers is exceptional. Aside from the shift-register case, the MOS advantage increases monotonically with circuit complexity. To extend the comparison, a point is added for a BCD (binary-coded-decimal) decade counter having 102 elements in its MOS form.

Another indicator of complexity is the number of metal–silicon contacts required to implement a circuit. MOS integrated circuits require fewer per element than do bipolars, and hence require substantially fewer per function. The structural differences that contribute here are particularly evident in Fig. 7. This is a further factor in the MOS size advantage and may contribute intrinsically to a fabrication yield advantage as well. In Fig. 9 the ratios of the numbers of contacts for the two technologies are plotted for the same circuit examples as before, with number of MOS elements as the independent variable again. We see the MOS advantage increasing

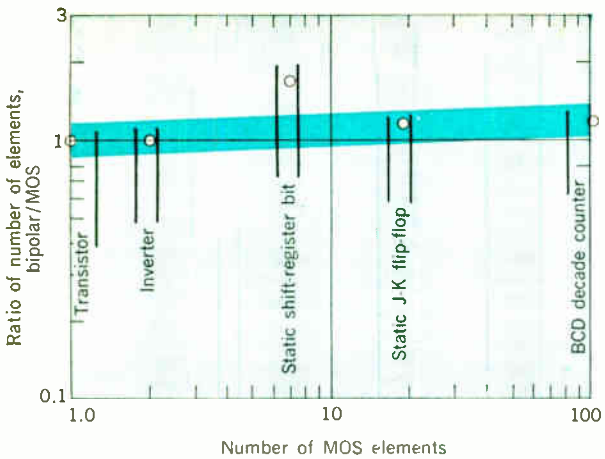


FIGURE 8. Ratios of the numbers of elements required for various functions vs. the number required in the MOS case.

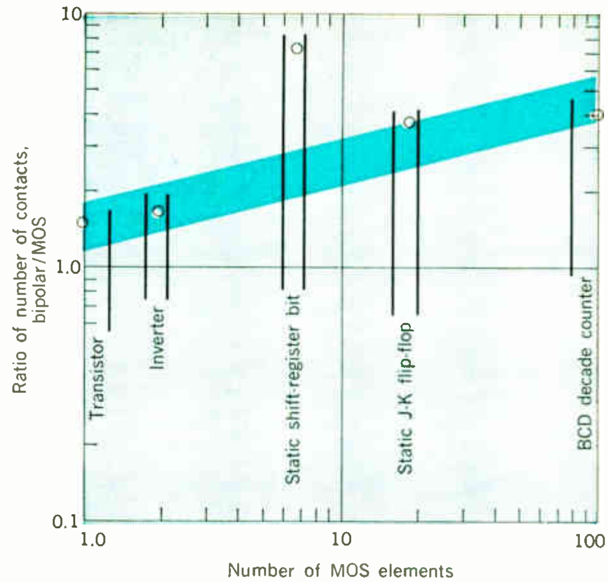
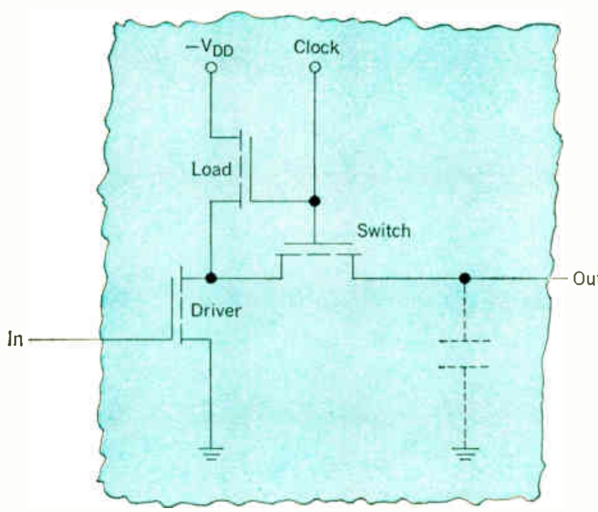


FIGURE 9. Ratios of the numbers of contacts required for various functions vs. number of MOS elements required.

monotonically with complexity, except for the particularly advantageous MOS shift-register case, where the ratio is seven to one.

FIGURE 10. Schematic representation of half a dynamic MOS shift-register bit.



Exploiting unique MOSFET properties

Thus far the comparisons have been made in terms of circuits performing the same functions. Further simplification is possible in MOS circuits by employing the unique properties of the MOSFET. The dynamic-storage mode of operation provides a good example here. Because the MOSFET gate structure constitutes a high-quality capacitor, a temporary charge can readily be stored on it. An application of this principle is shown in Fig. 10, which depicts half a dynamic shift-register bit.[6] This circuit section is followed by an identical section.

The capacitor indicated consists of three components:

1. Junction capacitance associated with one terminal of the MOSFET labeled switch.
2. MOS capacitance of the metal lead connecting that terminal with the subsequent device.
3. MOS capacitance of the gate itself in the subsequent device.

It is the junction leakage that places an upper limit on charge-storage time and hence a lower limit on operating frequency in the dynamic mode. Representative values of these limits are 100 μs and 10 kHz, respectively.

The circuit's operation is as follows: If a logical ZERO in the form of a zero-voltage bias is applied to the input, the driver is off. When a clock pulse is applied at the indicated terminal, both the load and switch turn on and the capacitor receives a negative charge (or a logical ONE) from V_{DD}. If on the next cycle a ONE is presented to the input, the capacitor is discharged through the driver during clocking or a ZERO is stored on it. Clocking of the load and switch does not interfere with the ZERO state because the load is a higher resistance device than the driver. The two halves of the bit are clocked with alternate and nonoverlapping pulses, and thus a signal is shifted to the right, with capacitor storage maintaining a "state" on a gate while the gate is isolated by a switch.

Note that the source and drain of the switch interchange roles, depending on whether it is called upon to charge or discharge the capacitor. This bilateral property is another unique feature that is exploited in this mode of operation.

The dynamic shift-register bit has six elements instead of the seven required by its static counterpart. The area economy resulting from this fact and from its simpler topology is illustrated in Fig. 11 by comparing it with the other two shift-register examples considered previously. Evidently the size advantage of the MOS dynamic shift register over the bipolar static shift register amounts to a ratio of 7.2 to 1. Data quoted by other workers suggest that a factor of ten is a reasonably representative value for area ratio on the basis of similar bipolar-to-dynamic-MOS comparisons.[7,8] Thus there are advantages to be gained by using properties peculiar to the MOSFET and it is safe to predict that the future holds a great deal more of this.

Interconnection factors

The area comparisons made have considered only "active" areas of an integrated circuit. In other words, they have ignored the problem of interconnecting the various functions on a single monolithic circuit, and also the problem of connecting the monolithic circuit with its environment. Let us consider the latter problem: A connection from an integrated circuit to the outside world is accomplished by bonding a small wire to a metallized "pad" provided near an edge of the monolithic block. For circuits of low complexity, the area requirements of these pads dominate so completely that both the bipolar and MOS technologies require about the same area. This is illustrated in the upper portion of Fig. 12 for a single static shift-register bit (taking some liberties with shape but preserving the proper area relationship). The lower portion, then, compares monolithic blocks, each containing ten static shift-register bits. It is clear that pad area diminishes in importance as complexity increases.

Figure 13 presents more fully the manner in which bipolar-to-MOS area ratio varies as a function of the number of static shift-register bits. As the number of bits increases, the full area-advantage factor of about five is rapidly approached, with approximately four bits marking the mid-transition point. Again it is necessary to comment that the shift-register case is a special one, with its fanout and fan-in of one; indeed, for a simple shift register, the number of external leads required is independent of the number of bits. However, the principle concerning bonding pads shown here with static shift registers could also be illustrated with other circuits, although the transition would occur at a higher level of complexity. This problem has been considered before,[8] though primarily by comparing complex MOS circuits and gate-level bipolar circuits, which of course emphasizes the differences.

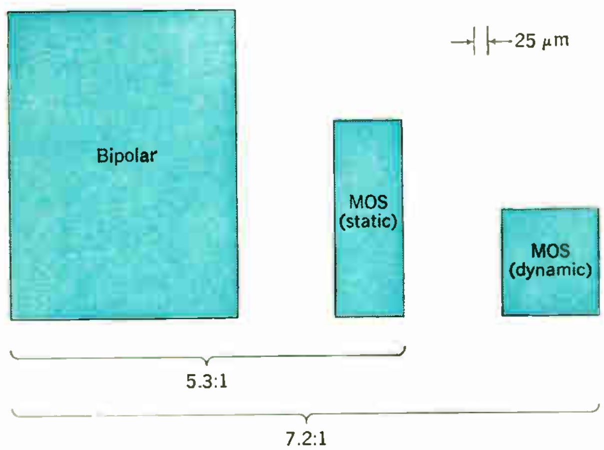
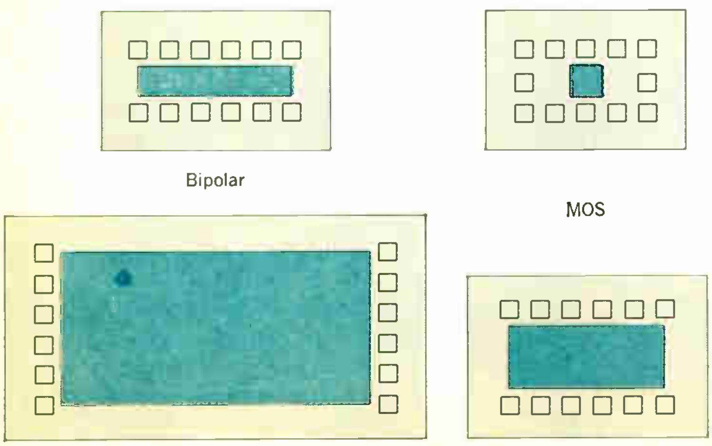


FIGURE 11. Comparison of the area requirements for three different shift-register bits.

FIGURE 12. A comparison of bipolar-to-MOS total area ratios for a low-complexity circuit (top) and a high-complexity circuit (bottom).



The problem of interconnecting the various functions within a monolithic circuit places an upper limit on functional density.[9] (We have limited ourselves to the case of a single level of metallization.) Even reducing device area to zero cannot enable one to diminish the area of a particular function below the area required for the interconnections associated with that particular function. This area limitation is of course less stringent in a low-fanout serial-logic situation than in high-fanout random-logic cases, and in memory arrays requiring access to each bit. Regardless, the existence of such limit tends to dilute the MOS density advantage as both technologies progress; in the end it would eliminate the advantage if both technologies had identical interconnection requirements. However, their requirements are not identical; because MOS circuits operate at four or so times the voltage of bipolar circuits and their current levels are often lower, they can employ narrower metal interconnections. Therefore, the relative area allocation for leads is smaller in the MOS case.

Another factor of even greater significance favors the MOS circuit. It is common practice in MOS technology to extend a source or drain-diffused region into a diffused "bus," even though such a conductor has a relatively high sheet resistance. This technique is permissible because of the current and voltage considerations just cited. Furthermore, it is frequently permissible to run a metal conductor right across such a diffused conductor, with the intervening oxide as insulation. In other words, crossovers are extensively used in MOS circuits. Thus the interconnection flexibility open to the designer approximates that existing in the design of a two-sided printed-circuit board. In the design of bipolar integrated circuits, on the other hand, the use of crossovers (or "diffused tunnels") is discouraged because the resulting parasitic resistance leads to intolerable "debiasing." The bipolar case, therefore, has a design flexibility more nearly approximating that of a one-sided printed circuit board. The matter of interconnection design flexibility is also very important in automatic circuit design. For the single-level-metal case, MOS circuits lend themselves much more readily to automatic design than do bipolar circuits.

In the original development of integrated circuits, a primary motivation was a desire to reduce the number of connections that had to be made by bonding, soldering, welding, etc.; the interconnection of related functions on a single monolithic block, by means of diffused or deposited-metal conductors, is simpler, more economical and more reliable than bonding wires from block to block. It is evident from the foregoing discussion that the

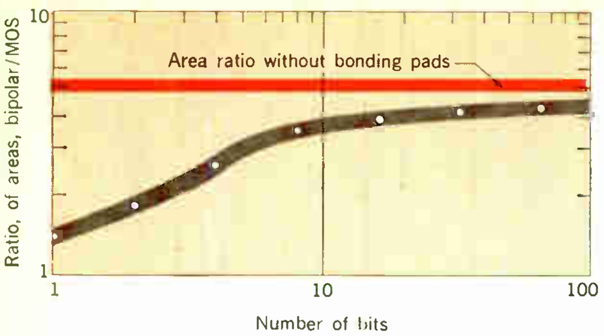


FIGURE 13. Ratios of the overall areas required for bipolar and MOS static shift registers vs. the number of bits in the register. Bonding-pad area is taken into account.

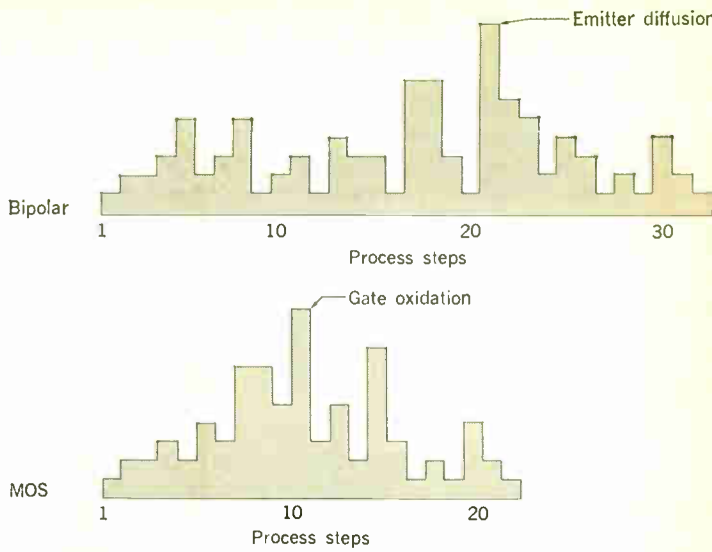


FIGURE 14. A comparison of process difficulty for bipolar and MOS integrated circuit technologies.

functional-density advantage of MOS technology enables one to move well up the monolithic-complexity scale.

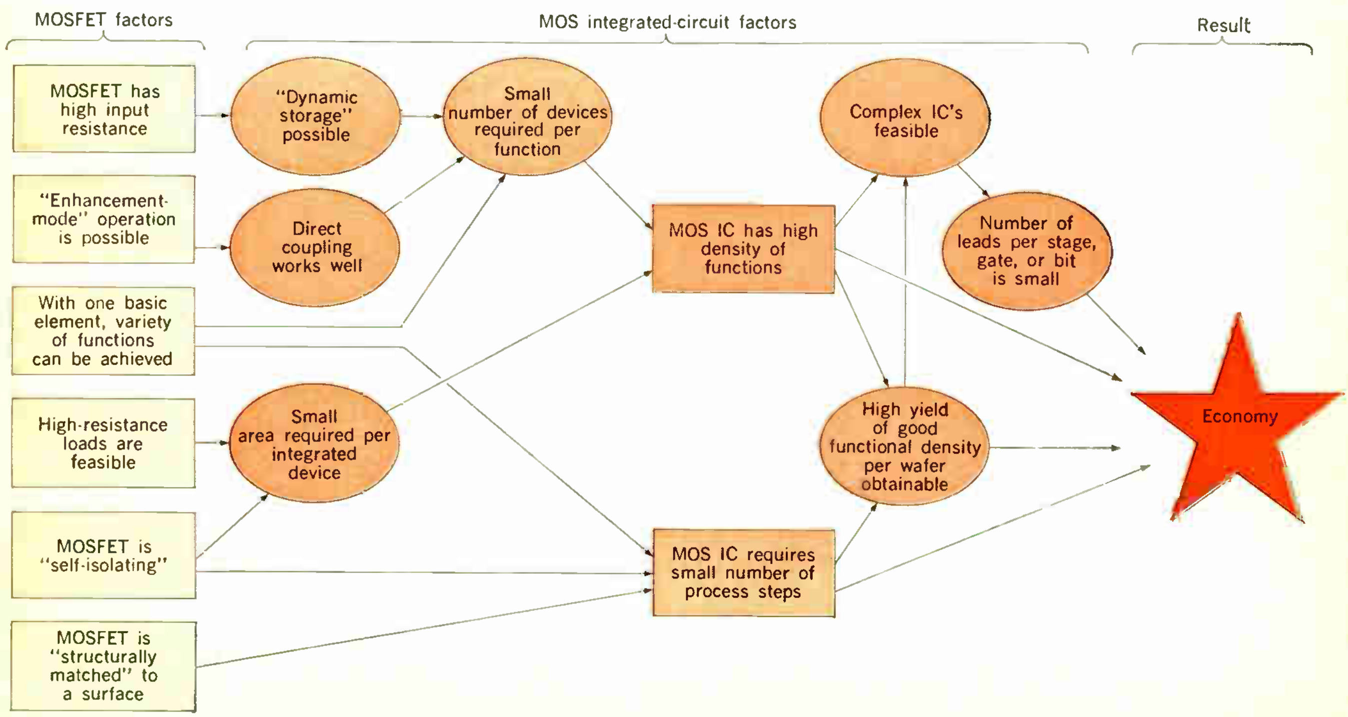
A process comparison

An additional factor favoring MOS economy is process simplicity. MOS integrated circuits require fewer process steps than bipolar integrated circuits; this has a favorable effect on yield, which, as noted previously, is closely related to cost.

If one simply enumerates the major process steps required to produce an integrated circuit of each type, he finds that the numbers are approximately 32 for the bipolar case and 22 for the MOS case. Examples of "major" steps (as the term is used here) are epitaxial growth, base deposition, base diffusion, photoresist removal and cleaning, metal evaporation etc. This suggests that the bipolar is about 45 percent more difficult than the MOS process. An attempt at the admittedly somewhat subjective matter of assigning "difficulty weights" to the various steps gives a result like that shown in Fig. 14. Comparing the areas in the two cases suggests about a 30 percent margin of difficulty for the bipolar case.

It is not as easy to be quantitative in this matter as in the matter of functional density. "Difficulty" is of course a time-dependent quantity; the assessment represented

FIGURE 15. Some of the MOS factors that contribute to economy.



in Fig. 14 is an attempt to represent a particular state of the art.

Factors underlying MOS process simplicity and functional density

It is instructive to consider the interrelationship of the factors that make for functional density and process simplicity. Most of these have been mentioned in the foregoing discussion. Figure 15 endeavors to put these factors into perspective. In this diagram, comparison with the bipolar case is implied where adjectives such as "high" or "small" are used. In Fig. 15, six unique or distinguishing MOS properties are enumerated at the left:

1. High input resistance, which was mentioned in the discussion of capacitor storage.
2. Enhancement-mode operation, which was used in all of the MOS circuits mentioned.
3. Three different MOSFET applications—driver, load, and coupling switch. These are depicted in Fig. 10.
4. The fact that high sheet resistances can be employed, which was treated in the discussion of the inverter.
5. The "self-isolation" feature of the MOSFET, which is best seen in Figs. 6 and 7.
6. "Structural matching," which refers to the fact that major currents in the MOSFET flow parallel to the surface upon which the devices are formed. (In the bipolar case the "natural" current direction is normal to the surface.)

The unique properties enumerated have consequences shown in the successive boxes to the right (Fig. 15) and terminate in the two major factors that were the subject of most of the foregoing discussion; high functional density and simple processing. As the diagram conveys, both factors contribute directly to economy; here, it is savings in material and labor that are involved. Also, the feasibility of making complex monolithic functions means that the task of assembling systems can be made easier.[9]

As also noted in Fig. 15, the high-density factor leads to economy mainly because it serves to improve fabrication yield. High density is helpful because there is an inverse correlation between device size and yield over a considerable range of sizes, an effect based on the fact that the probability of incidence of certain defects increases with area. The following is an example of this effect. Suppose a given rectangular piece of silicon contains a point defect of a nature that is fatal to an integrated circuit. If we fabricate an integrated circuit that consumes the entire area, there will be a zero yield. If it is possible to place two equivalent-function circuits in this area, we will have a 50 percent yield (considering yield losses only from this particular cause). With five circuits in the same area we will have an 80 percent yield, etc.

It should be noted that this advantage cannot be secured without cost by simply shrinking all dimensions and tolerances. To do so opens the door to numerous other problems, such as sensitivity to photographic-mask misalignment. In all of the quantitative functional-density examples presented, equivalent layout-rule dimensions and tolerances were observed.

Finally, in Fig. 15 we note that the simple-process factor also leads to economy through higher fabrication yield; fewer process steps means fewer chances for error. It is the yield improvement stemming from this factor and from the functional-density factor that is the most important consequence of the various MOS features that we have discussed in detail.

Conclusions

For the application of integrated circuits where high speed/power performance is essential, as in the central portion of a large-scale data-processing system, the choice of bipolar integrated circuits is indicated. Bipolar circuits hold a one-to-two-decade median performance advantage over MOS circuits. There are numerous other examples, however, where such performance is not essential, and where indeed it would contribute nothing to overall system performance. Among these are small calculating machines, peripheral equipment in large machines, systems for sending data over telephone wires, systems for generating visible displays, and others. In such areas, MOS integrated circuits will be increasingly applied, their potential economy will be increasingly realized, and new areas of application will inevitably be opened. The bases of the economy cited here are structural compactness and structural and fabricational simplicity; these factors favor economy through their beneficial effect on yield. The unusual advantages of MOS shift registers, both in simplicity and in comparatively good performance, will insure an increasing tendency to design systems around these circuits.

Dynamic logic employs unique properties of the MOSFET and purchases functional-density and performance advantages by discarding dc operation. One can expect rapid acceptance of dynamic logic, and one can also expect further design innovations that will make dynamic logic even more attractive. Automatic custom design of fixed-interconnect-pattern, single-level-metal integrated circuits will proceed faster in MOS technology than in bipolar technology. The first reason is that MOS circuits are easier to describe analytically; they contain but one kind of element and its properties are well predicted by fairly simple equations. The second reason is that MOS circuits permit the designer more interconnection flexibility because crossovers of diffused conductors by metal conductors can be used extensively.

The author is indebted to R. L. Petritz and R. H. Crawford for very helpful comments on transconductance comparisons; to J. D. Merryman for bipolar shift-register data; to J. W. Adamic, Jr., and F. J. Strieter for comments on processing; to M. L. Shopbell and S. Naik for assistance in preparing comparative designs and data; and to INEA, the 1966 International Symposium on Microelectronics, for permission to reprint much of the material contained herein.

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MHD power generators in central stations

The greatest potential for magnetohydrodynamic power generators appears to be for "topping" conventional steam power plants, thereby yielding improved thermal efficiencies

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The broad area of MHD power generation is surveyed in this article, with emphasis on its application to central stations. Following a brief discussion of the MHD principle, three types of combined power plants are described: the coal-burning MHD–steam power plant, the noble-gas MHD generator with a nuclear heat source, and the liquid-metal MHD generator. Design problems and operating characteristics are presented, together with possible advantages and problem areas.

In principle, an MHD generator is not very different from a conventional rotating generator. In a conventional generator, a solid conductor (usually copper) is caused to move through a magnetic field to generate electricity. The making of electricity, therefore, requires three ingredients: conductor, motion, and magnetic field. In an MHD generator, a gaseous conductor (let us ignore liquid metal for the moment) is moved through a magnetic field to generate electricity. The magnetic field is the same in both cases.

The mechanics of motion of solids is a well-established science. The mechanics of motion of gases is somewhat more complicated, especially when magnetic and electrodynamic effects have to be included. Nevertheless, fluid dynamics and magnetohydrodynamics have been sufficiently developed to enable us to predict gaseous motion under a combined electromagnetic field with acceptable accuracy. The most basic difference between a conventional generator and an MHD generator is in the nature of the conductor. A metallic conductor contains 10^{22} or 10^{23} free electrons per cm^3. A typical working gas in an MHD generator contains only 10^{12} or 10^{13} free electrons per cm^3. The electron mobility is higher in a gas than in a solid, but not enough to compensate for the much lower electron density. Consequently, the electrical conductivity of a gaseous medium is much poorer, and the so-called "Hall effect" is much more pronounced. Since this difference is fundamental to an understanding of the MHD principle, let us examine it a little further.

FIGURE 1. Motion of a single electron in (A) an electric field, (B) a magnetic field, and (C) combined electric and magnetic fields.

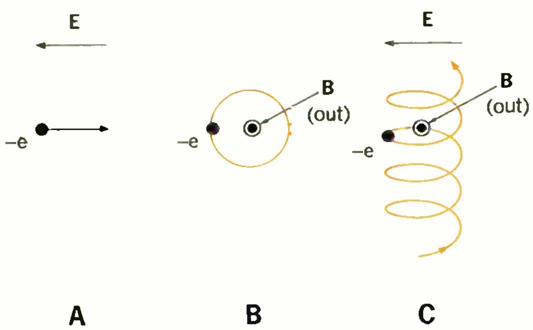


FIGURE 2. Electron motion with collisions.

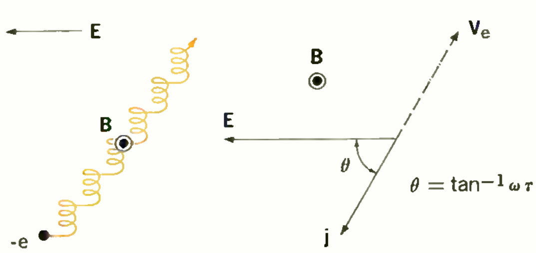
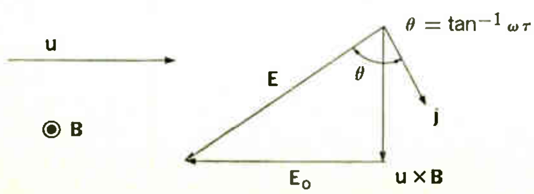


FIGURE 3. Electron drift in a moving gas stream.



Principles of MHD power generation

Figure 1 depicts the well-known motions of a single electron in an electric field, in a magnetic field, and in combined fields. The last motion, called electron drift, is familiar to physicists and electrical engineers.

If an electron is surrounded by other particles, collisions take place; and its drift motion is interrupted by motions to the right due to the electric field **E** (Fig. 2). The mean velocity of many electrons is represented by the vector $\mathbf{V}_e$. The current density vector **j**, which is by definition opposite to $\mathbf{V}_e$, makes an angle θ with the electric field vector **E**. (In a solid conductor **j** and **E** are for all practical purposes always parallel to each other.) The angle θ, called the Hall angle, is evidently determined by the ratio of cyclotron frequency to collision frequency of the electrons. In fact, $\theta = \tan^{-1} \omega\tau$, where ω is the cyclotron frequency and τ is the mean free time of the electrons.

Figure 3 shows the situation for which electron drift takes place in a moving gas stream. The gas velocity **u** and magnetic induction **B** give rise to an induced electric field $\mathbf{u} \times \mathbf{B}$. $\mathbf{E}_0$ is the electric field relative to a laboratory observer and **E** is the field relative to the moving gas. **E** and **j** are separated by the Hall angle θ. Since current-collecting electrodes are necessarily fixed to the laboratory frame, only the scalar product of j and E_0 results in useful power. The Hall angle, however, can vary anywhere from 0 to 90 degrees. To assure good performance at all possible Hall angles, three generator configurations (shown schematically in Fig. 4) have been proposed.[1]

In the segmented-electrode configuration, electrode segments are separated by insulator segments; therefore, no current can flow in the direction of gas flow. The electric field vector has a component along the channel (Hall voltage) as well as a component across the channel (load voltage). In the continuous-electrode configuration the electric field is across the channel only, although the current has components along the channel as well as across it. To minimize losses it is evident that the Hall angle should be small in this configuration. In the Hall generator the electrode segments wrap all the way around the channel; hence there can be no potential difference across the channel. The electric field is parallel to the channel axis, whereas the current has components both parallel to and across the channel. This configuration favors large Hall angle and $E \gg uB$. The field-vector diagrams for the three generator configurations are shown in Fig. 5. Flow velocity is from left to right and magnetic induction is in a direction outward from the plane of the paper. The performance of these generators, which can be deduced directly from the vector diagrams, is shown in Fig. 6, in which a nondimensionalized generator power is plotted against its efficiency η. To combine high power density with good efficiency, a generator should operate in the upper-right-hand portion of its performance curve. In this respect it is seen that continuous-electrode generators favor small Hall angle (low $\omega\tau$); Hall generators favor large Hall angle; and segmented-electrode generators are good for any Hall angle. The only drawback of the last-named configuration is its complexity, as the external load must be divided into many separate circuits (Fig. 4).

To compensate for the generally poor gaseous conductivity, there is great incentive to increase magnetic flux density. Great strides have been made in superconducting magnet technology. Flux densities of about 10 Wb/m^2 have been realized in small volumes, and even higher densities may be possible in the future. Figure 7 shows the effect of flux density on power output of a Hall generator.[2] Power increases to a maximum at $B \approx 100$ Wb/m^2, where Hall effect on the ions begins to be important. Power

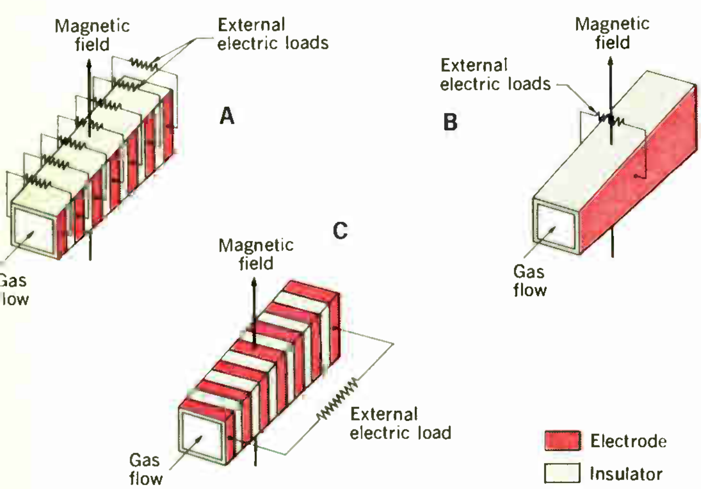


FIGURE 4. Schematic representations of three MHD generator configurations. A—Segmented electrodes. B—Continuous electrode. C—Hall generator.

FIGURE 5. Field-vector diagrams for (A) segmented-electrode, (B) continuous-electrode, and (C) Hall generator.

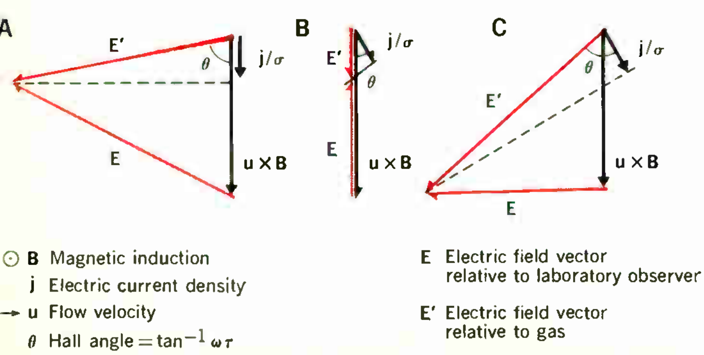
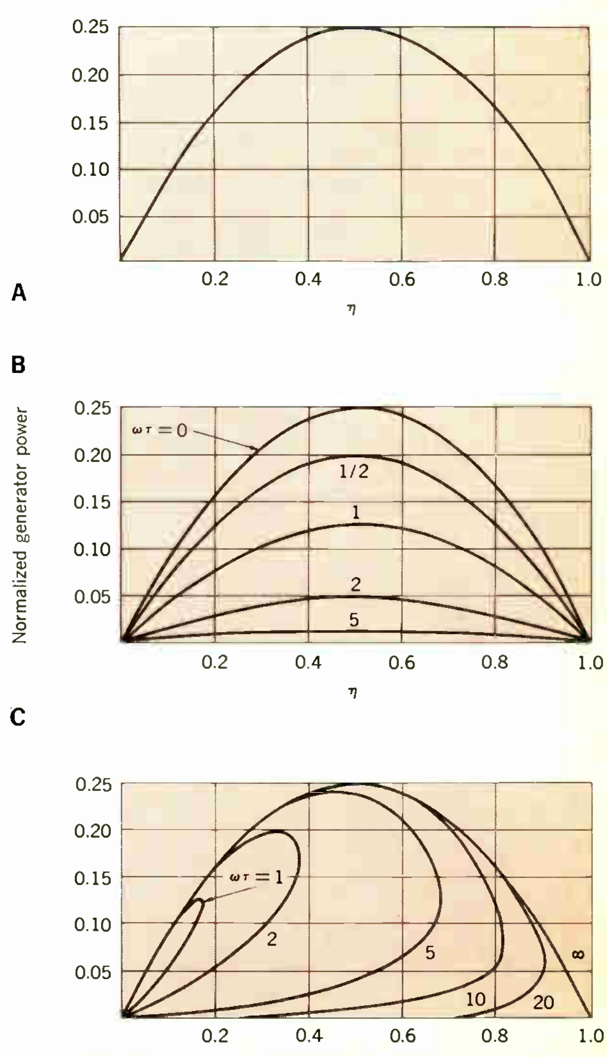


FIGURE 6. Relationships between power and efficiency for (A) segmented-electrode generator, (B) continuous-electrode generator, and (C) Hall generator.



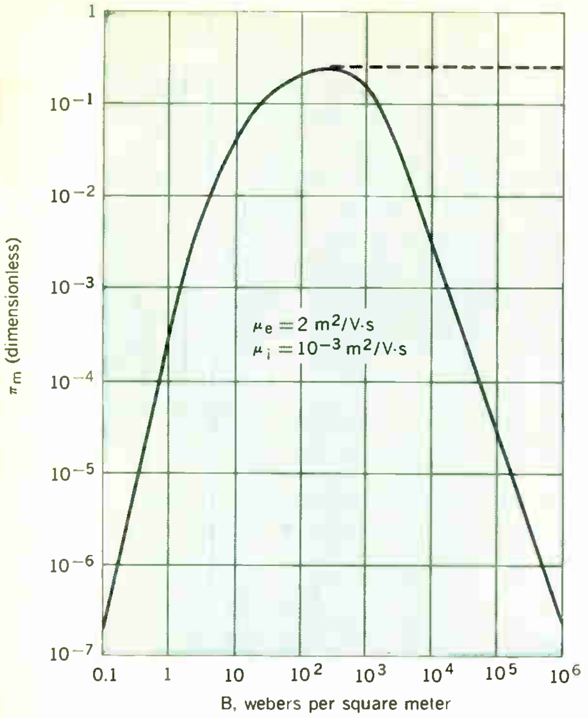
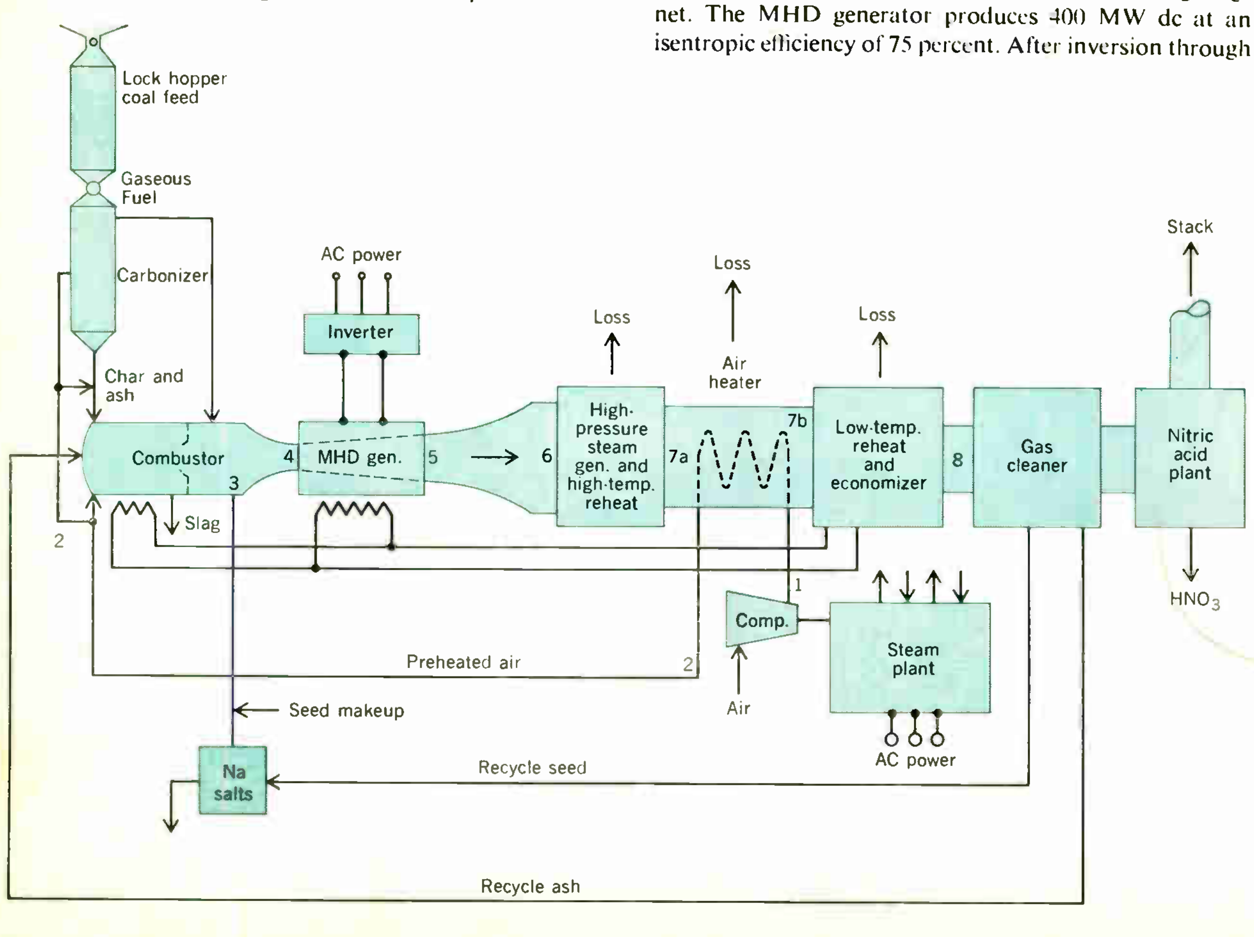


FIGURE 7. Maximum power density from a Hall generator as a function of magnetic flux density. Dashed curve represents Harris–Cobine theory,[1] which neglects Hall effect on ions. (μ_e = electron mobility, μ_i = ion mobility.)

FIGURE 8. Schematic diagram of MHD–steam plant.



drops to zero as B approaches infinity, when all electrons and ions spin in infinitesimal circles and therefore no current flows. The dashed curve represents a calculation in which the Hall effect on the ions is neglected. Although this is a good approximation at low flux densities, it causes serious errors as B exceeds 100 Wb/m².

Coal-burning MHD–steam power plant

It has been proposed to use an MHD generator to "top" a conventional steam power plant. Such a combination would give a higher thermal efficiency than either plant operating singly. This appears to be a natural union for two reasons: (1) the trend toward higher steam temperatures has slowed to such an extent in recent years that binary-fluid topping cycles are looked upon with increasing interest, and (2) MHD generators are inherently suited to high-temperature operation because of their lack of highly stressed structural parts and, more important, because plasma conductivity increases exponentially with temperature. Combined MHD–steam cycles are being investigated at several laboratories in the United States and in a number of other countries as well. One such proposed cycle is shown schematically in Fig. 8.

The combined plant of Fig. 8 is rated at 800 MW, divided about equally between MHD and turbogenerator. Carbonized coal and preheated air are fed into a two-stage cyclone combustor in which slag is removed from the first stage and a cesium seed is added in the second stage. At the combustor outlet the gas reaches a temperature of 2645°K at a pressure of 4.5 atmospheres. The plasma enters the MHD generator at a velocity of 750 m/s with a conductivity of better than 4 mho/m. Plasma velocity decreases along the generator duct while magnetic induction is kept constant at 6 Wb/m² with a superconducting magnet. The MHD generator produces 400 MW dc at an isentropic efficiency of 75 percent. After inversion through

II. Calculated results for a gas-cooled-reactor MHD steam plant

Reactor power rating	1014 MW (t)
MHD generator output	324.57 MW
2% electron guns + ½% cryogenic system	8.12
Balance	316.45
3% dc/ac conversion loss	9.49
Net MHD power	306.96
Steam turbine output	410.58 MW
Helium compressor requirement	203.06
Balance	207.52
2% alternator loss	4.15
Net T-G power	203.37
Net MHD power	306.96
Sum	510.33
2% auxiliary requirements	10.21
Net plant output	500.12 MW
60% MHD, 40% turbogenerator	
Net plant thermal efficiency	49.32%
Net plant heat rate	7300 kJ/kWh

MHD–steam plant does involve some interesting technical problems; for instance, one of the systems-engineering problems is the choice of a proper working fluid and its pressure level.[3] Another is the application of nonthermal ionization to the MHD fluid (a noble gas).[4] I will describe briefly some of the general characteristics of such a combined plant, if for nothing more than its academic interest.

Figure 10 shows schematically the basic components necessary to make up a 500-MW power plant, of which 60 percent of the output is from an MHD generator and 40 percent from a turbogenerator. The reactor delivers 680 000 kg of helium gas per hour at 1400°C and 25 psi (17.2 N·cm^{-2}) absolute. The selected pressure is a compromise between reactor requirements and MHD generator requirements. For the MHD generator, low pressure is preferable because it increases the electron mobility and, therefore, the electrical conductivity of the working gas. Because of heat-transfer and size considerations, high pressure is more desirable for the reactor. Since a temperature of 1400°C is not high enough to ionize helium, some method of nonthermal ionization, such as electron-beam injection, is necessary. Electron impact is known to be effective in causing ionization. The question is whether the rate of ion formation is high enough to overcome recombination. A previous study[4] indicates that this method is at least theoretically feasible, and the power requirement of the electron guns is rather modest. A superconducting magnet is assumed. The dc output of the MDM generator is inverted into ac. Helium gas, which leaves the MHD generator at 1035°C, goes to a steam generator and superheater that make sufficient steam to run a 565°C, 3500-psi (2400 N·cm^{-2}) turbine, which in turn drives a 203-MW alternator and a helium compressor.

Table II shows the calculated MHD output, turbogenerator output, and auxiliary power requirements for operating electron guns and the cryogenic system and compensating for inverter losses, etc. The overall plant efficiency of 49.3 percent corresponds to a heat rate of 6920 Btu (7300 kJ) per kilowatthour. The proposed power plant is admittedly somewhat futuristic, but its efficiency is much better than that of currently operating nuclear power plants.

In an experimental 1.9- by 1.9-cm MHD generator operating on helium gas, a plasma generator produces hot helium to which atomized metallic cesium is added to promote ionization. This generator has been operated successfully at Westinghouse.

Another application of MHD is power generation in outer space. The only way to reject heat there is by radiation, and therefore high-temperature operation is favored. Westinghouse recently completed a three-year experimental program for the United States Air Force. A closed-loop MHD research unit was built and tested. The loop consists of an MHD generator, an MHD motor, and two electric heaters to complete the circuit. Electric power is supplied to the motor to pump the He-Cs plasma around the circuit, and output power is produced in the generator section. In contemplated space applications a gas-cooled reactor would replace the left-side heater and a radiative heat sink would replace the right-side heater. Other details of this unit have been published elsewhere.[5,6]

Liquid-metal MHD generator

In gaseous MHD generators, most of the difficulties encountered by experimenters have their origin in the fact that gaseous conductivity is very poor. Ionization can be promoted by raising the gas temperature, but this practice leads to all sorts of difficult materials problems. Seeding can be very effective in enhancing ionization, but the best seeding materials (Cs, Rb, K) are also extremely corrosive. Nonthermal ionization is theoretically interesting and experimentally intriguing. Although several schemes have been proposed and tried, a really successful method has yet to be demonstrated. This state of affairs has led some investigators to seek an alternative in using liquid metal as the MHD working fluid. The electrical conductivity of a liquid metal is perhaps a million times better than that of a typical MHD gas. In principle, therefore, a liquid-metal MHD generator can be made very compact; it can operate at low temperature under a weak magnetic field and yet be very efficient and very powerful. However, an isolated MHD generator has little utility. To be useful it must be incorporated into a heat-engine cycle. It is a well-known thermodynamic fact that a liquid without changing phase makes a very poor Rankine cycle. Even if a liquid generator is used as a topping unit only, a change of phase is still necessary because some of the liquid enthalpy must be first converted into kinetic energy, which can then be converted magnetohydrodynamically into electricity. The conversion from enthalpy to kinetic energy is most effectively done by discharging the liquid through a two-phase nozzle. The necessity of first creating and then separating a two-phase fluid is the problem one has to face when a liquid-metal generator is used in a power plant cycle. Several schemes[7-11] for dealing with this problem have been proposed, but so far a satisfactory solution has not been demonstrated.

The Elliott cycle,[7,8] shown schematically in Fig. 11, is a two-fluid cycle in which lithium circulates in the liquid loop and potassium circulates in the vapor loop. Both potassium and lithium enter the mixer in liquid form, but the former vaporizes upon contact with the latter. The mixture flows through a nozzle to gain kinetic energy, and then separates into vapor and liquid in the separator. The vapor, having performed its function, goes to a condenser,

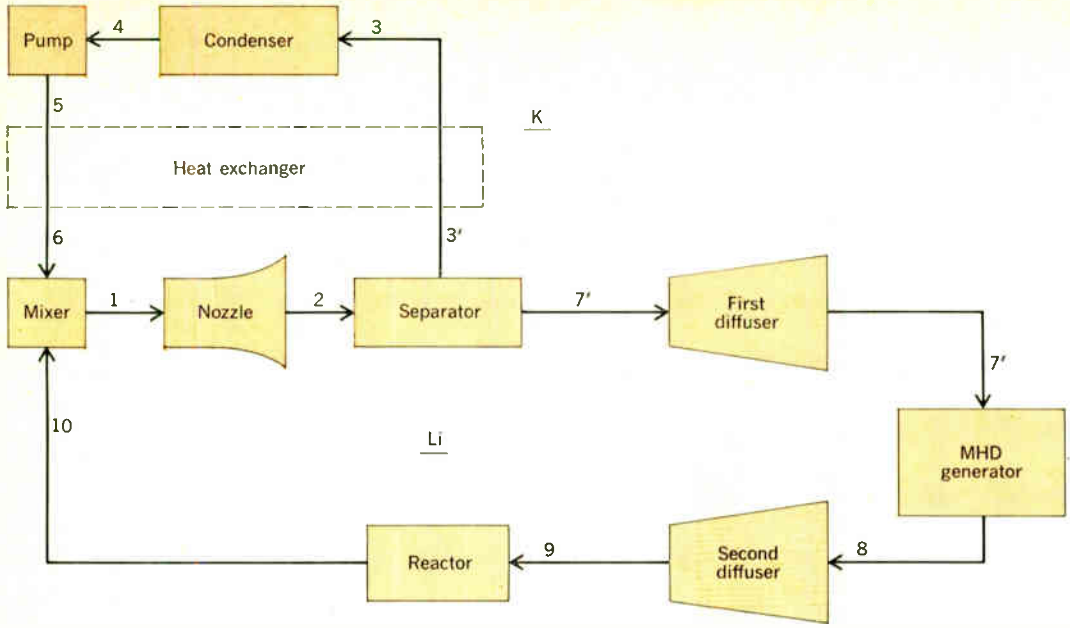


FIGURE 11. Schematic diagram of Elliott cycle.

then a pump, and then returns to the mixer again. The liquid, after passing through a diffuser, goes to an MHD generator to produce electric power. The separator is the crucial component of this cycle. Its losses are high, and it does not do a very good job of separation. The Jackson–Brown cycle[9] and the Petrick–Lee cycle[10,11] differ from the Elliott cycle in some important details, but they all suffer from the lack of a good separator; they would suffer just as badly if an unseparated two-phase mixture were allowed to go through the MHD generator. The seriousness of the latter will be appreciated when one realizes that a one-percent quality creates approximately a 70-percent void fraction, and a ten-percent quality creates a 96-percent void fraction.

In practice, the liquid going through the MHD generator cannot be made entirely vapor-free. Therefore, the question of electrical conductivity of a two-phase fluid becomes important. This question has been studied at the Argonne National Laboratory[10,11] and elsewhere. A void fraction of 60 percent decreases the conductivity by a factor of ten. It is suspected that the situation would be worse in a hot, operating generator. Vapor bubbles would form and collapse; they would not be uniformly dispersed; and they would tend to collect around corners and electrodes.

An experimental NaK loop[10,11] operating at room temperature has produced electric power. A photomultiplier tube is used to measure void fraction.

Concluding remarks

From the foregoing description it is reasonable to conclude that, relatively speaking, the coal burning MHD-steam power plant is closest to technical reality. However, if a central station of this type is ever built, it probably will not be earlier than the last decade or two of this century.[12] The noble-gas generator and the liquid-metal generator with a nuclear heat source are still further away. It is dangerous to make predictions, for unforeseen factors can always come along to upset the basic premises. Nevertheless, in the civilian economy, an MHD power cycle, or for that matter any other novel power cycle, will be successful only if it can compete economically with proved methods of power generation.

Revised text of paper 31PP66-453, presented at the IEEE Summer Power Meeting, New Orleans, La., July 10–15, 1966.

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Applied lasers

Although lasers are basically in the research stage, certain specific types have recently evolved as useful electronic components for communication, ranging, and detection applications

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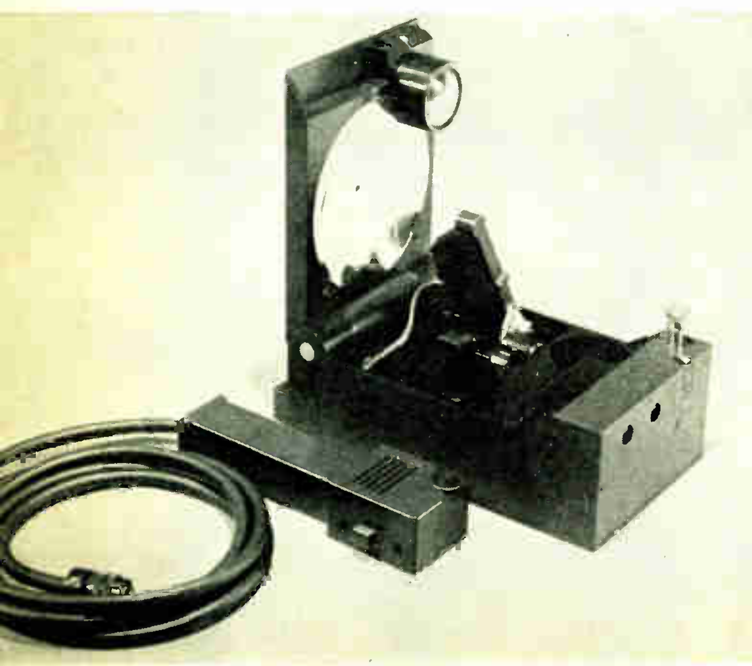
The laser has been found useful for short-distance communication or for communication across the macrodimensions of space. Two short-distance voice-communication systems are described—one requiring careful boresight alignment and the other involving a megaphone-like broad-beam laser that needs little alignment. A laser range-measuring system has been developed that can make distance checks for aircraft refueling or for measuring the altitude of spacecraft landing on the moon. The principles of ranging can also be applied to selective viewing, maintaining a separation of vehicles moving along a set path, or selectively counting certain-sized objects. The laser also can be used in a simple intrusion alarm since its narrow beam can be reflected over a very long distance with little spreading.

FIGURE 1. Experimental model of laser communication system using two GaAs injection lasers. It operates in a pulsed mode, at 8000 pulses per second, and has a bandwidth of 3 kHz and a range exceeding 5 km. Detector is a silicon photodiode.



In today's society, the central theme is communication —by code, by word, by printed page, by picture. It is not surprising, therefore, that efforts to apply the laser to communication came immediately upon its invention. In a sense, the application preceded the invention, inasmuch as the need for greater bandwidths was prominent in the motivation of laser research.

If we classify our communication requirements on the basis of range, we find that lasers can be helpful at the range extremities—that is, for distances less than about 15 km and for those greater than 80 million km. The short-range requirement is admirably met by a pulsed-injection-laser system.[1] An injection-laser diode operable at room temperature with modest current (first reported by Nelson *et al.*[2]) has been particularly useful. It requires only 10 amperes to lase; it is not an eye hazard (the pulse energy can be less than 0.2 μJ); it has a resistance of only 0.3 ohm and hence can be operated serially; it is physically small (0.075 by 0.075 by 0.18 mm); and radiates just outside the visible spectrum (9020 Å).

The transmitter in Fig. 1 employs two such lasers and appears to fill the need for a small, lightweight, private voice-communication link. Because it employs pulsed frequency modulation, the system is insensitive to fluctuations in transmission characteristics of the atmosphere. The low energy requirements permit operation of the system from small batteries for up to 2½ hours. Because the transmitter beam width is small (8 mrad), the system must be aligned by means of telescopes, which are boresighted with the laser. Narrow beam width is simultaneously a burden and an asset. It complicates the alignment of the transmitter and receiver; but it does provide low power drain and great privacy. Operation at 9020 Å enhances this privacy by virtue of its invisibility. Furthermore, the responsivity of silicon photodiodes at this wavelength is orders of magnitude higher than that of photomultipliers. Hannan and Bordogna[3] have shown that in an amplifier-noise-limited system, this higher responsivity of the photodiode results in a significantly better signal-to-noise ratio than could be achieved with a photomultiplier in the infrared region. Restated, at 9020 Å, for a given signal-to-noise requirement, the photodiode system demands less transmitter power than a multiplier phototube system when amplifier-noise-limited.

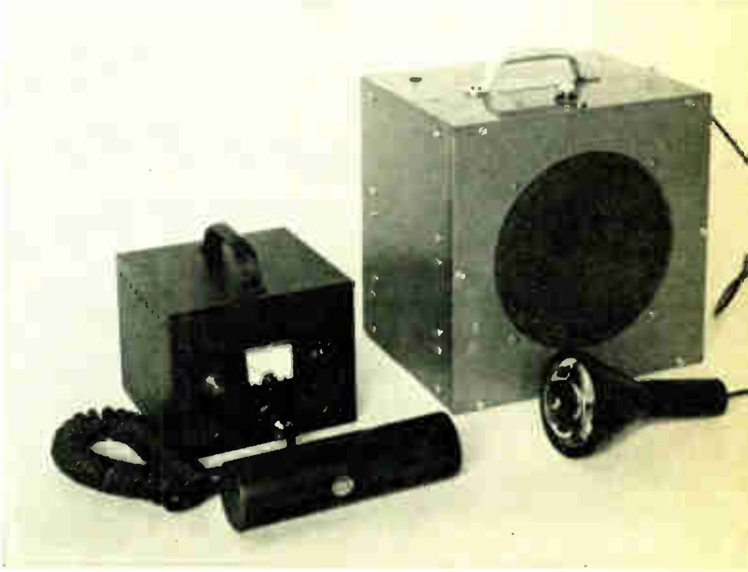
A whole series of practical advantages accrues from the use of a photodiode: it is no longer necessary to have a high-voltage supply; it is no longer necessary to include a narrow-band optical filter; and it is no longer necessary to restrict operation to after sunset. In addition, the detector itself is small and rugged.

In contrast to this narrow-angle system, a wide-angle communication link that employs the same components has also been developed (Fig. 2). This link utilizes a kind of laser megaphone. Through the use of four laser diodes without lenses, a 15-degree beam is formed. Such a wide beam width virtually eliminates any problems associated with alignment. Although the range is greatly reduced (100 meters), this kind of system could be very useful during refueling operations in aircraft or in docking operations in space. Both of these injection-laser systems operate at a pulse rate of 8 kHz,* with a duty cycle of 0.1 percent and a modulation bandwidth of 3 kHz. Each of these links is built around the following general scheme. The transmitter microphone output is amplified and used to vary the repetition rate of the pulses from the laser; thus the system is pulse frequency modulated. In the receiver, a photodiode output is amplified, limited, and demodulated. After additional amplification, the audio signal is brought out through earphones or a speaker.

* The repetition rate of 8 kHz was achieved with experimentally selected units.

Figure 3 shows still another member of this class of laser voice transmitter. This particular unit was part of the Gemini 7 mission, and it is perhaps the only laser system that has had to pass space qualification tests. Four laser diodes were employed in it, each with its own lens. Actually, in this transmitter the laser and lens formed a subassembly. Since the time the first unit was built, a laser lens subassembly that can be replaced as easily and as quickly as a flashlight bulb has evolved. The far-field patterns of the GT-7 transmitter were oriented to illuminate a square, approximately 0.8 km on a side, from an altitude of 240 km. The peak output power of this 2.35-kg unit was 25 watts. This range of hundreds of kilometers is certainly not within the extremes iden-

FIGURE 2. Voice link employing four lasers. Natural divergences of the diodes have been combined to produce a transmitter with a 15-degree beam without the use of lenses. In combination with the wide-angle receiver, it has a range of 100 meters. In this system a light on top of the receiver indicates alignment, and no telescopes are necessary.



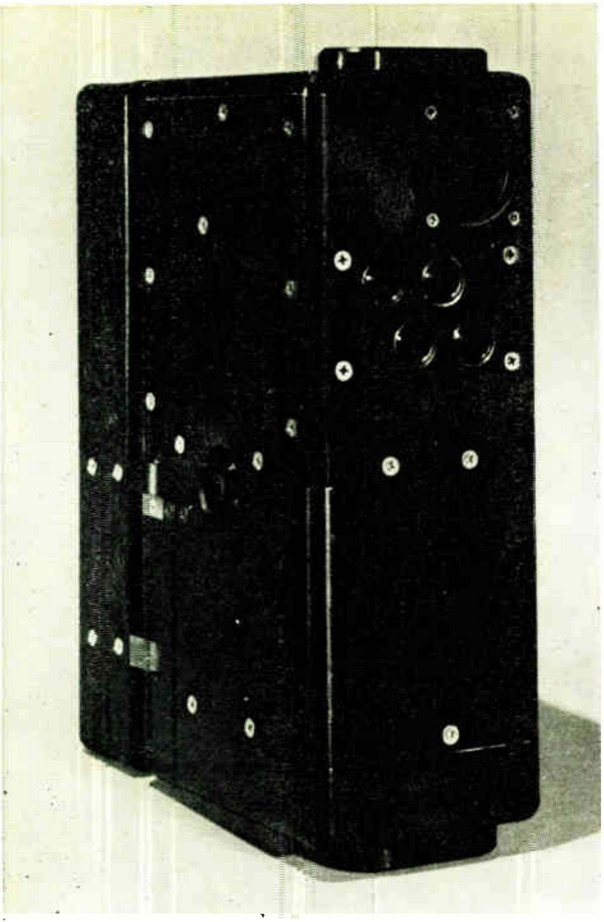
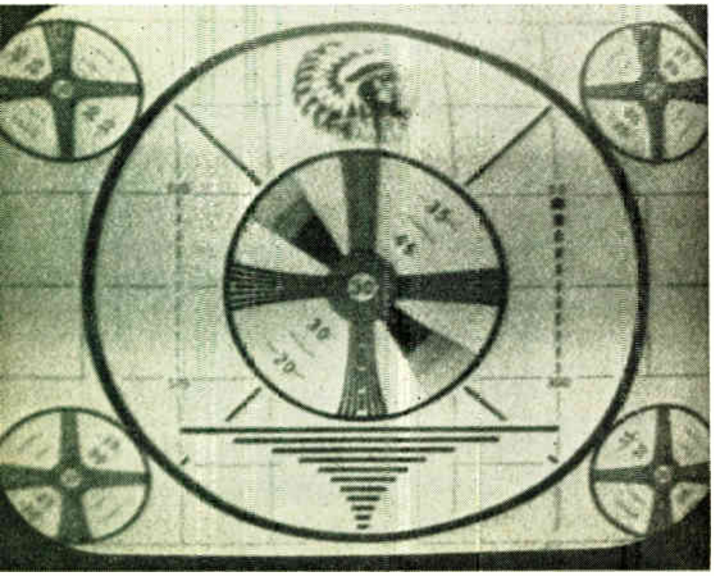


FIGURE 3. Transmitter developed to be flown on the Gemini 7 mission. It employed four injection-laser diodes in series, with a total peak power of 25 watts. Dimensions were approximately 7.5 × 13 × 20 cm. Pulse duration was 70 ns, with two repetition rates available: 8000 and 100 pulses per second. Operating time was 40 minutes for voice, 150 minutes for 100-Hz tone.

FIGURE 4. Television test pattern achieved by the use of a GaAs crystal in an electrooptical modulator. With an applied voltage of 600 volts peak to peak, the depth of modulation was 40 percent. Signal distortion, caused by piezoelectric resonances common to electrooptic materials, was avoided by use of FM subcarrier modulation.



tified earlier. The objective, however, was not to provide an operational communication system for the spacecraft. A microwave link, which is far more suitable for this application, accomplished that function. The goal of the laser experiment was to gain experience and information for more ambitious deep-space links.

A program in which sunlight was used to pump a crystal laser was being carried out simultaneously.[4,5] The requirement was to build a laboratory model, sun-pump it, modulate it at television rates, and make a technical assessment of an optimum system for transmitting television information in real time over a range of 80 million km. In the laboratory system built, an equatorial mount with a clock drive permitted extended operation (up to ½ hour in gusty wind). A mirror focused over 200 watts onto the laser, well above the 25-watt threshold for YAG. Output power was 100 mW on a continuous basis. The material on which most of the studies were performed was yttrium aluminum garnet, doped with trivalent neodymium and chromium ions.[6] Figure 4 is a photograph of a television test pattern transmitted across the laboratory by such a sun-pumped laser. Although it is true that all of the components necessary for deep-space laser television links are not yet available, there appears to be no fundamental obstacle to obtaining them. The potential advantages that such links offer in size and weight seem to justify the effort required.

Laser ranges

If communication has been the dominant application for lasers, ranging is certainly a close competitor. As in the case of communication, ranging applications may be conveniently classified on the basis of distance. In general, earthbound laser-ranging systems are limited by local atmospheric conditions. A typical value of range routinely measured is 20 km or less. Ruby crystal and, more recently, neodymium-doped yttrium aluminum garnet have been used as active elements at 6943 and 10 600 Å, respectively. Optically excited materials such as these are operated in the *Q*-switched mode in order to generate narrow, high-power pulses. Typically, these pulses are 30 ns long. In the *Q*-switched mode of operation, the resonant cavity condition does not exist during the entire pumping period; that is, the *Q* is temporarily spoiled by a mechanism called a *Q* spoiler. This process reduces the stimulated-emission losses during the pumping and increases the extent of the population inversion. At the appropriate moment, a resonant condition is restored and intense laser action occurs. The *Q* spoiling may be accomplished by the use of rotating prisms, saturable absorbers, or Kerr cells.

In addition to generating an intense pulse, these techniques limit the output power to a single, precisely timed pulse. This limiting is of paramount importance since the time required for the pulse to travel to the target and return is the primary measurement. In most packaged systems, the measurement is carried out by a crystal clock, a binary-coded decimal counter, and a readout. In addition to the laser crystal, *Q* spoiler, optics, counter, and timing circuits, the ranger must include a detector. This function is best accomplished by a photomultiplier tube, the gain of which can be continuously varied to a level at which false signals caused by background light are minimized. It is perhaps worth observing that, for ranging, the photomultiplier tube experiences no serious competition from photodiodes.[7]

Figure 5 shows a ruby range finder[8] built to military specifications by RCA. It weighs less than 11.5 kg, provides six measurements per minute, and has a resolution of 5 meters. It can be operated from a battery or an external power supply to measure ranges from 200 to 19 000 meters. It is suitable for mounting on a tripod, an airplane, a tank, or a truck. In terms of military field readiness, laser range finders are probably the most advanced of all electronic laser equipment.

A second regime in which the laser can perform a valuable ranging service is for distances up to 100 meters or so. For example, the maintaining of distance during an airborne refueling operation is vital. Similarly, altitude information accurate to centimeters during the final 100 meters of a lunar landing will be a necessity. A less spectacular, but still important, application is that of maintaining the separation of objects moving at varying speeds along a common line—specifically, cars on highways, trains on tracks, and cars on cables.

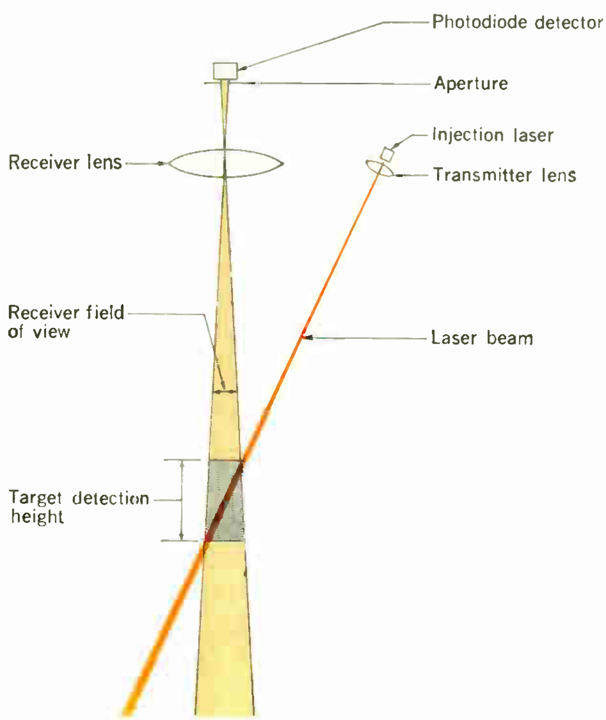
Ranging equipment that uses injection-laser diodes can fulfill all of these needs. The first of two alternative modes follows a traditional radar approach. The diode is pulsed and a time-of-flight measurement is made. A laboratory model based on this principle was built to gain experimental experience with a variety of targets as a function of distance. It transmitted a 10-watt, 3-mrad beam at 70 pulses per second. Using a 4-inch (10-cm) parabolic collector to focus the return on a photodiode,* we measured ranges out to about 100 meters. When a retrodirective reflector was used as a target, the range increased to 2.4 km. Indeed, the combination of a retroreflector serving as a cooperative target with an injection-laser source dramatically extends the range of all of the applications cited earlier.

The second mode of injection-laser ranging depends on a triangulation principle, as illustrated in Fig. 6. The concept is disarmingly simple. The detector can see only illuminated objects that fall within an angle fixed by the ratio of its diameter to the focal length of the receiver lens. The only illuminated objects are those within the beam angle of the laser. Thus, a return signal occurs only if an object is present at the intersection of the two fields of view. Range can then be determined by varying the angle between the two fields of view and calibrating range vs. angle. If the separation between receiver and transmitter is large, and the fields of view are narrow, the ambiguity in the result can be kept small. For example, a 30-cm separation in combination with beam angles of 1 and 1.7 mrad leads to a range uncertainty of 5 cm out of 3 meters. This laser triangulation scheme can be useful in other applications. The angle between transmitter and receiver can be given a predetermined value so that only objects at a particular distance produce a signal. The result is a range-specific counting signal. From an overhead position, it could be used, for example, to count automobiles (but not buses) just on the basis of the heights of their roofs. The transmitter and receiver shown in Fig. 7 have been tested in this way (although they were built for a different application), with gratifying results.

* Although a photomultiplier would have given greater range, the low-voltage operation of the photodiode was too attractive to resist in these experiments.

FIGURE 5. Example of a laser range finder, representing one of the most advanced of all laser devices. Range is determined by a time-of-flight measurement of a pulse and its reflection. The data are displayed in digital form.

FIGURE 6. In most pulsed range-measuring equipment, the resolution obtainable depends on ability to measure time accurately. To measure within one foot (0.3 meter) requires that time be measured to within 2 ns. An alternative approach is shown here. Only a target that occupies the intersection of the transmitter and receiver beam widths can produce a return signal. Accordingly, for a given separation, range can be determined by calibrating the angle between the two fields of view.



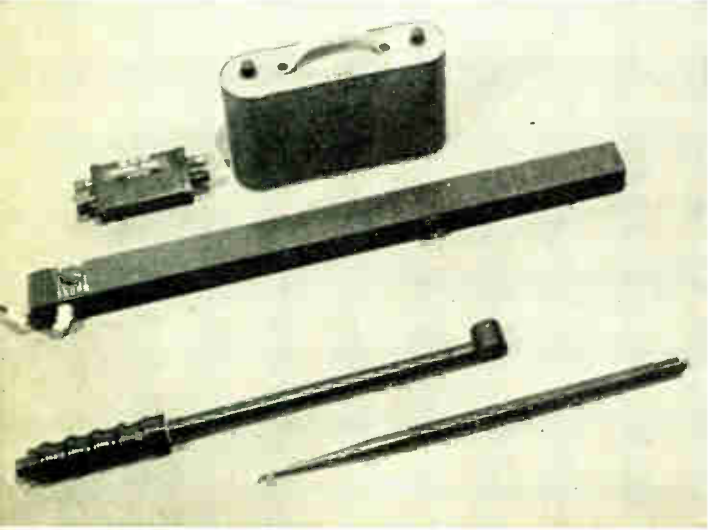
Laser intrusion alarms

The original use for which the equipment in Fig. 7 was built is a traditional optical application, the intrusion alarm. The laser, however, adds a number of important new aspects and simplifies some others. The use of injection lasers leads to low energy consumption, which facilitates extended periods of battery operation. The optical system can be both simple and small because the source is so directional. The transmitter optics consist of a 16-mm microscope objective lens. Because the laser already operates in a pulsed mode, it is easy to code the signal to immunize the system against "spoofing." If a retrodirective reflector is used, the transmitter and receiver can be positioned together in a favorable location relative to theft or environment. The great directionality of the beam permits the path to become long before the linear beam width gets unmanageable. It is thus possible to employ a number of successive reflectors, of modest size, to protect a tortuous path, or a whole doorway, or even a volume of space against unnoticed intrusion.

The system shown in Fig. 7 is an elementary type. The transmitter employs a single laser diode whose peak power output is 8 watts at a rate of 200 pulses per second. The transmitter measures about 5 by 5 by 2.5 cm, including all the drive circuits and the optics to produce a 3- by 0.3-mrad beam. The receiver consists of a silicon photodiode, a low-noise preamplifier, and an alarm relay. The beam width of the receiver is 1 degree. The range over which this system can operate is 100 meters. More complex systems, which use several laser diodes for greater range and which include sophisticated alarms, periodic self-checking, and microwave telemetry, have also been built (see Fig. 8). It seems safe to predict that injection-laser intrusion alarms, as well as related automatic devices and systems, will become a major application area.

FIGURE 7. Laser intrusion alarm employing an 8-watt diode. A 300-volt battery produces a 200-pulse-per-second 70-ns output. With only modest effort the transmitted pulses can be coded to render the system "spoof-proof." When used with appropriately positioned reflectors, the transmitter and receiver can be placed side by side in a region safe from the local environment.

FIGURE 8. Advanced injection-laser intrusion alarm system.



Things to come

The list of applications of lasers to engineering problems need not stop here, however. The applications cited merely represent those approaching the design stage. Still to be fully exploited are the laser tracker, a system that will continuously follow a cooperative target, providing range and angle information; a laser film recorder, for optically recording information with up to gigacycle bandwidths; a laser aid to the blind, which provides the user with a contour map of the region around him; laser computer elements,[9] which carry out all of the logic in an optical mode; and holographic computer memories, which provide storage capacity of billions of bits in a convenient volume of space with short access time and low cost.

All of these applications seem realizable, but their early status dictates that their discussion be deferred to a future review. It seems reasonable to conclude, however, that their identification, in combination with the examples discussed, establishes the correctness of the initial observation: that lasers have become an engineering component, and the extent of their use now rests with the engineer.

The author ackowledges the efforts of his many creative and diligent associates within the Radio Corporation of America.

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Speech—man's natural communication

A ranging discussion on the origin and evolution of speech and language, the relation of culture and language, man's physiological mechanism for speech, linguistics, and speech-oriented technology may not be every engineer's cup of tea, although perhaps it ought to be. Here it is, from some of the masters of these arts

Most of the universe runs along perfectly well without the need of speech for command and control. Why, then, does man need speech? How did he acquire speech? Can it be optimized? What is the future of this form of communication? These questions were put to a group of men who have done distinguished work in diverse fields relevant to speech. Their provocative discussions, reported here, do not add up to a definitive or overall unified theoretical structure such as scientists love to build; nor could they at this stage. Certainly, for those who look closely at speech and language there is no question that the subject is mysterious and complex. It may be that language is mysterious because it is too close to us, too deeply imbedded in the inherited structure of the human organism for us to "see" it. However it is, there is no doubt that many of the questions and ideas raised here belong in the vortex of concerns of all those who are interested in human communications.—N.L.

Socially, says psycholinguist George A. Miller, speech gives us a means to inform, persuade, amuse, control, and curse our fellowmen, so that we can agree or disagree to work jointly for the common good, so that we can regulate ourselves by a system of laws that can be modified, improved, and so on. So powerful are the consequences of this human linguistic skill that we have been enabled to invent ways to violate the very laws of evolution whereby speech originally emerged. A whole new mechanism of evolution is now operating—a man-made kind of evolution—that is proceeding on a much faster time scale than the old biological evolution.

The engineer is brought into this evolution, first of all through his development of machines such as the telephone and radio that handle the acoustic properties of speech, and more recently through his attempts to develop new machines that must handle the underlying structure of language, such as translating machines, and so forth. Such attempts, such new engineering goals, are radically transforming the content of engineering. Whereas the engineer once could attack inanimate nature with calloused hands and little more than Ohm's law in his theoretical armory, he needs today—and doesn't have—the laws governing life itself, the laws underlying all of man's behavior. Casting about for help, the engineer is now looking toward the humanists, the social scientists, the linguists, the psychologists, but he is discovering that those fields are either not ready to give him what he needs, or that they are being transformed by reaction to his own works, or that they are not sciences as he understands them, or that they are in disarray, or that they speak and write in languages that are not his kind of Greek.

To begin to answer the needs engendered by this situation, session 63 of the 1967 IEEE International Convention brought together seven men who are distinguished in diverse fields relevant to speech. They were to discuss the origin and evolution of speech and language, the relation of culture and language, man's physiological mechanism for speech, linguistics, and speech-oriented technology. Furthermore, these subjects were to be discussed in the language of the communications design engineer. The five panelists were Prof. George A. Miller of Harvard University, Joseph Bram, professor of sociology and anthropology at New York University, Dr. Franklin S. Cooper, head of the Haskins Laboratories, Prof. John Lotz of Columbia University and new director of the Center for Applied Linguistics in Washington, D.C., and Dr. Manfred R. Schroeder, director of the Acoustic and Speech Research Laboratory at Bell Telephone Laboratories. Chairman of the session was Dr. Leo L. Beranek, president of Bolt Beranek and Newman; the moderator was Dr. J. C. R. Licklider of IBM and M.I.T. The man who pulled all the strings to bring these men together, who did all the organizing work, and who posed the questions they were to consider, is himself well known for his pioneering work on speech-handling machines. He is Homer Dudley, inventor of the vocoder. He asked the intriguing question of why, since most of the universe runs along perfectly without any need of speech for *command and control*, man does require speech. He furthermore made the request, which any expert might properly consider outrageous, namely, to predict what might be expected in speech and language and communications up to a million years ahead. The panelists took it bravely, countering with projections of experiments on animals to give them speech faculties, with great physiological changes in man's own speech and language equipment, with capacities for man to talk and listen simultaneously, with a great reduction in the number of languages, and with problems and strategies. Through it all ran the somewhat unconscious assumption that man in the future would want to communicate more and more rather than less, an assumption that was finally hauled to the surface by Dr. Licklider who posed the possibility that men might communicate more with machines in the future, to learn and to work creatively, and that men might talk less together, and then mainly for "reinforcement." In all, as might be expected, the discussion ranged widely, although somewhat formally, and only time was lacking. What follows is an abbreviated account of what these men had to say. The intention of the session was not to make the listeners run home and build "one of whatever it is," but to give them some new possibilities and new ideas to mull over in the year ahead.

George Miller on the origins of speech

In his discussion of the biological origins of human speech, Professor Miller considered it in the context of other systems of communication and control.

Information theory has taught us, he said, that the indispensable feature of communication is correlation; in the simplest cases, the input to and the output from a communication channel must be correlated if communication is to occur. And where correlation exists, there is also a possibility for control. In the broadest interpretation, therefore, wherever we see correlation we see possibilities for communication and control. But we see correlations everywhere in nature; it is the task of science to discover correlations and explain them.

Speech is also characterized by correlation—correlation between what the speaker sends and what the listener receives. What is it that sets speech apart from all other correlations? Consider the stages of its evolution. In regard to the inanimate world, we discuss correlations in terms of *cause and effect;* from the electron orbiting the nucleus to the planets orbiting the sun, we see natural laws operating to establish causal correlations and to control the relations among components of a total physical system. In discussing animals, however, we generally say that much of their behavior is the product of *instinct*. Most communicative behavior among animals is purely instinctive and, although somewhat more flexible, shares much of the quality of cause and effect. But evolution did not stop there. Higher animals can learn from their experience, and so some of their communicative behavior is attributable to *habit*. Habit is more flexible and adaptable than instinct, but still relatively predictable. At the level of man, however, a very flexible and productive kind of habit becomes possible, and so we discuss his communicative behavior in terms of *rules*. Rules are important because they have a generative potential; rules can work together in consistent but flexible (i.e., contingent) systems. Human language is the best example of such a system of rules.

In human speech we see all four of these mechanisms of communication and control at work: cause, instinct, habit, and rule. We analyze purely causal relations when we study the acoustic properties of speech and relate those properties to the physical parameters of the speech organs and resonators that produced them. We study instinctive relations when we consider the relation of speech movements to the other biological functions—eating, breathing—that the speech machinery must also carry out. We study habit when we catalogue all the various sounds and words that the speaker of a language must learn to use. And we study rules when we try to characterize the way those sounds are combined and related in the generation of meaningful utterances. Thus we find traces of every evolutionary stage in the communicative behavior of intelligent human beings.

Biological systems that could reproduce themselves were a major evolutionary advance over inanimate systems of pure cause and effect; intelligent systems that could learn from experience were another advance over

The future of engineering

Just as an engineer in the past has put the knowledge of physics and chemistry to work in the service of mankind, so in the future, he is going to exploit our growing knowledge of biology and, perhaps on a longer time scale, our growing knowledge of psychology and sociology when those sciences have been placed on a firmer foundation. I recognize that such innovations will revolutionize engineering as we know it today. In the future, I expect it will be increasingly difficult to distinguish engineers from doctors, and perhaps the distinction will be abandoned and replaced by some more useful distinction. Indeed, a million years from now, our whole scheme of distinguishing among the sciences will probably be regarded, if it's remembered at all, in about the same way we recall the ancient distinction between fire, air, earth, and water.

Prof. George A. Miller
Harvard University

Two varieties of speech?

The day may come when we will recognize the existence of two varieties of speech. The danger at the present time is that there is no clear dividing line between them. For instance, in the sessions of the United Nations, you don't really know where integrity ends and humor begins. Salvation lies not in repudiating irresponsible speech, *which all of us enjoy*, but in making it clear that there are two varieties, one marked by clarity and integrity, and the other satisfying our irrational or emotional needs, etc. I do believe that man will come to a clear recognition of these two levels and cultivate both.

Prof. Joseph Bram
New York University

systems of pure inheritance; and human systems that could follow elaborate rules were still another advance over creatures of pure habit. Let us concentrate on this last innovation, since it is the one that sets man apart from the other animals.

Almost every important difference of behavior between man and the other primates is directly attributable to the system of shared rules we call human speech. Primates communicate. They have elaborate signaling systems. They give warnings of predators. They discipline their young. However, the major social function of their vocal communication seems to be restricted to distance regulation. Before a primate would be able to use his signals in the contemplative way necessary for abstract language to evolve, he would have to relax the highly ritualized use of them to maintain dominance relations within the troop. By comparison, man's unique brain enables him to learn an elaborate system of linguistic rules both for communication with others and for control of his own mental processes.

The *psychological* significance of speech is that a whole new level of intelligence becomes possible. For example, the self concept becomes possible; language enables a child to regard himself as an object, similar to other objects, and that object is his self, his ego, his identity. These selves have names, they have at least the illusion of volitional control, and they claim rights for themselves—all of which is represented in only the most rudimentary way among primates. The conscience emerges when a child can internalize the speech of his parents and use it to control himself as they used it to control him. And information need not be rote memorized; instead, we can learn rules from which the encoded facts can be generated as needed.

Human language is the product of millions of years of evolution from the inanimate world of cause and effect to the human world of rules and intelligence. Recently we have tried to scramble this order of evolution by giving inanimate machines the job of dealing with language directly, and out of this have come the telephone, the radio, the phonograph, the tape recorder, and the whole spectrum of modern communication industries. But these machines deal only with the causal, acoustic aspects of speech, not with its underlying structure.

There has been, however, a kind of evolution of the machine itself. With the emergence of modern computers, we have inanimate machines available that can deal with systems of rules. It was probably inevitable that we would try to scramble the natural evolutionary order by asking computers to process language as people do, that is, to make abstracts, to translate, to answer questions, to teach, to take dictation, etc. This attempt to jump directly from the inanimate to the human level has not been wholly successful.

The basic trouble is that we do not know how to write our linguistic rules in a way that isolates them from all the other knowledge that a person has and uses when he communicates—knowledge that is lacking in the current machines. There is much we know by virtue of being human beings and much more that we have learned; a computer cannot jump over all this and go directly from the inanimate realm to the realm of human language. A computer exposed to language is not innately ready to recognize its significant aspects or to learn its rules by participation as would a human child.

Of course, it is a basic axiom that anything we can describe in the form of an algorithm can be executed by a machine. The difficulty is that we do not yet know enough about human language to write the necessary algorithms for it. Hence, engineers who hope to use their wonderful machines to understand speech are handicapped because behavioral scientists do not understand man well enough to describe him in terms of algorithms. Efforts to reach such a level of understanding will certainly continue, but I think we are today much more realistic about the magnitude of the task than we were in the first blush of our cybernetic enthusiasm. Needless to say, if such efforts are successful, they will constitute one of the greatest possible triumphs of our new, man-made kind of evolution over the old, biological evolution that preceded it.

Real language machines

Natural languages are very complex, comprising not only the signal component, but a semantic component as well; and in the semantic component, the straight communicative reference is only one function. Therefore, full languages cannot be precise; that would kill them. If a word, for instance, has a precise meaning, it cannot be extended easily for a new situation. The implication of this idea for engineers is that they should be well aware of the particular components of language and full-scale communication they are mapping with their gadgets. Most of the current machines are, from the linguistic point of view, very simple external-formal analytical and transmission machines. A real language machine must also be able to handle meaning. Engineers of language machines more sophisticated than present computers should plan a strategy for conquering more and more of the complexities of language functions, or restrict themselves deliberately to cognitive representation.

Prof. John Lotz
Columbia University

Joseph Bram on language and culture

The approach to language taken by Professor Bram was somewhat like that of Professor Lotz in that both are less "familiar" to the engineer and display less immediate relevance to the engineer's usual preoccupations. Yet, in the end, these approaches are no less engaging than the comparatively purer (scientifically speaking) approaches of Miller, Cooper, and Schroeder. This is especially true if one allows oneself to become immersed in their ideas and observations, just as one might easily immerse oneself again and again in the image with which Professor Bram began his remarks.

Fish, he said, could not be counted on to discover water. They live in this natural environment and take it for granted. To some extent the statement would apply to human beings as well—with regard to what we call culture.

Most human beings are born into a particular society, go through all the phases of man's life from childhood to adulthood and old age, and leave the world having felt that they had led a *natural* way of life. But, with more knowledge, we have become aware of the fact that a distinction should be made between what we call "culture" and what we call "a culture," and that it is the accident of birth, in China, Madagascar, Sweden, wherever, that determines the contents of the cultural framework in terms of which we act out our individual existence.

During the period of growth and maturation, the child learns the material techniques, the social rules, and the symbolic forms of his particular culture, such as the arts, music, dance, magic rituals, etiquette; and most of this learning takes place through the medium of speech.

This is by no means true of the so-called civilized nations alone. Numerous, very primitive societies still found in the world may be primitive technologically and politically, but their languages are as rich, structurally (that is, grammatically) and semantically, as any one of our advanced languages. As a matter of fact, quite frequently they are much more complex and more difficult to learn than the languages of the European world; for instance, it takes a minimum of 10 to 15 years to learn Navajo.

Now, this reliance of the transmitted, accumulated cultural heritage on language has given language or speech very peculiar qualities, or characteristics of which we aren't always aware. For example, even the most intelligent animals—anthropoid apes, dolphins, etc.—live in the *here* and *now*, in the here spatially and in the now temporally.

By contrast, a human being can attend to the past or the future through the manipulation of symbolic structures. Through a stream of verbal symbols, as in novels, histories, etc., a man can quite convince himself that he is living in those other times and other places, he can be affected, and even moved very deeply, by imaginary past or future events. Another powerful aspect of our linguistic faculties is that they allow us to speculate and to make plans.

By virtue of language, then, man becomes a somewhat uprooted, detached, and fantastic individual. We can roam all over the dimensions of the spatial and the temporal, and the intellectual and speculative, worlds. As Professor Miller points out in different words, the psychological significance of this linguistic faculty is that a whole new level of intelligence becomes possible.

This obviously is fraught with important implications, and danger as well. We have large, human societies that upset the existing social and economic order in the name of a utopia that has been verbally presented to them as possible, achievable, and desirable. We have human groups, nations, castes, classes, political parties, and movements opposing one another in the name of verbal formulations of a very questionable validity or reality. In fact, even in our daily affairs, we don't always know the meaning of the terms we use.

In other words, language often gives the illusion of reality or stability. The Danish linguist, Otto Jespersen, once said that language serves three functions. One is to communicate ideas, one is to conceal ideas, and the third is to conceal the absence of ideas!

In view of the fact that language permits and invites statements, understatements, overstatements, misstatements, outright lies, fantasy, etc., we live in danger of being influenced, both creatively and destructively, by symbol or language manipulators who are guided by various motives. We are not really immunized against this all-pervasive characteristic or property of our linguistic world. We worry about air and water pollution, contagious diseases, etc., but we are not training ourselves or others to respond rationally to signals and symbols that are reaching us from the moment we open our eyes to the moment we retire. Thus language, which is the mainstay, the basis, of culture and of all the different cultures, is at the same time, paradoxically enough, an ever-present danger and temptation.

From culture to science

What Professor Bram gives us, of course, is a picture of how *everybody* is shaped by his particular culture. But the scientist is not everybody. He attempts to liberate himself from his particular cultural blind spots through some very special methods. Nonetheless, he must ask himself, in the case of language and culture, whether or not his particular methods, so overwhelmingly successful in the inanimate realm, will obtain. Can we, through special symbols and

People and machines

I am concerned that the assumption is made that people are going to continue to talk mainly with people. Whereas, it seems to me, we will have in due course a dynamic, organized body of knowledge not in anyone's brain, but in some vast machine or chemical thing and, for scientific and technical and intellectual purposes, we'll want to talk mainly with it. Talking among people might be mainly for positive reinforcement of one another, although I suspect that even that could be handled better through some organized reinforcement arrangement.

Dr. J. C. R. Licklider
M.I.T.

One thousand years

Evolution is not necessarily going to proceed along the lines that it has proceeded. We have various techniques now for nudging it along a bit. In a thousand years, we may be using a basic language that is more directly meaningful, man to man, because machines will have had a chance to inject standard meanings for the words that each of us uses. In short, things are not going to be the same after we have each been plugged into the Universal Semantic Intracerebral Neologizer (USIN).

Dr. Franklin S. Cooper
Haskins Laboratories

special languages, mount a useful attack on our given, living language that is as integral to us as is water to the fish? As Professor Miller puts it, in his now-classic *Language and Communication*, "Is a science of communication possible?" Can we, he asks, advance our knowledge of the use of symbols by the use of symbols? "Such a bootstrap undertaking requires a new attitude toward language. To the student who begins the study of verbal behavior for the first time language is a personal, almost magical thing bound up inextricably with his private thoughts and feelings and ideas. Before he can begin a scientific study of speech and communication, he must learn to take a detached, *formal* attitude toward it. In the formal attitude the personal, meaningful aspects of verbal behavior are often ignored, and the symbols are seen as simple patterns of muscular twitches, or agitations of the air molecules, or patterns of squiggles on the page. The scientific study of language begins with this formal impersonal attitude toward these twitches, agitations, and squiggles." It is an important first step.

Franklin S. Cooper on man's mechanisms for speech

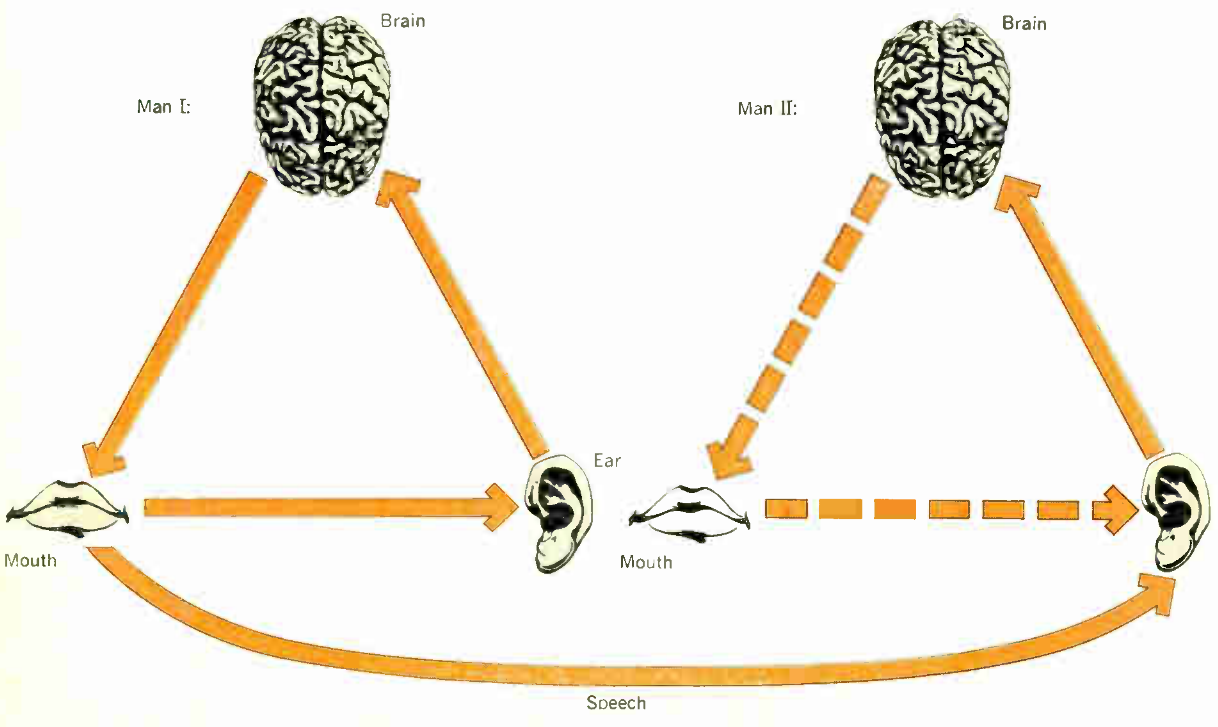
Having roamed, metaphorically speaking, out to the cultural limits of the world of speech and language, one must now adjust one's conceptual system, in a fashion that exemplifies exactly Professor Bram's point about how one projects a reality into symbolic formations. To "tune in" on Dr. Cooper, we must leave aside the cultural waters in which this fantastic human fish swims, and consider the other universe, that inside the fish himself, the source of these peculiarly powerful "agitations." It is a strange and even preposterous system, as Dr. Cooper suggests. If one reads Dr. Cooper's ideas very carefully, they come through with great force.

We should really ask the question, he begins, of whether or not a man possesses a mechanism specifically made for speech, as distinct from mechanisms that have been borrowed from other functions such as breathing, eating, sensing, air conditioning, cleansing, safety management, etc. But Dr. Cooper defers the answer to his own question, and starts with familiar things.

We usually think of speech, he says, as simply the airborne acoustic signal that passes from speaker to listener; hence, the mechanisms are the mouth, larynx, and lungs of the speaker and the ear of the listener. The brain, too, must be credited with a role in speech reception, and likewise in its production. The first point that should be stressed is that the brain's role is an essential one, as indicated in Fig. 1. Indeed, both the speaker and listener employ tightly locked loops of brain, mouth, ear, brain, and nerves when they communicate by voice. A consideration of this total system will help us understand how and why the speech signal out in the air can have such special properties and can pose such challenges, both to the engineer who tries to process it and to the speech scientist who tries to understand it.

The main point to be made about speech concerns its special nature as an acoustic signal, and the very important advantages for us that flow from these special properties. Professors Miller and Bram point out that speech differs from animal cries—or even human cries—in fundamental ways; thus, it has an hierarchical structure that is several layers deep and organized according to rules. Also, at the comparatively low level of individual words, which one might be tempted to compare with animal cries, there is an enormous inventory that can be still further enlarged by putting the unit sounds, or phonemes, into new combinations allowed by the language. And even at this low level of unit sounds and their combinations, speech has many special properties that set it off from

FIGURE 1. In asking how speech can be so efficient, Dr. Cooper stresses that the entire loop systems shown here must be taken into consideration.



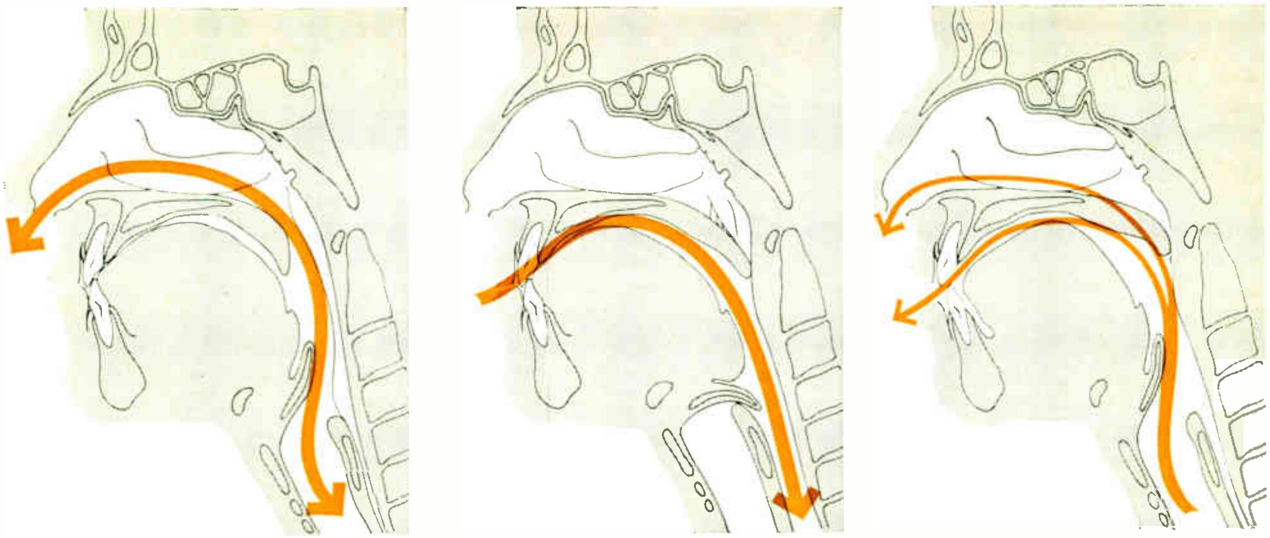


FIGURE 2. The high-speed performance of the speech mechanism must be accounted for, to some degree, by the multiple functions that its component parts must be able to perform.

FIGURE 3. The transmission of Teletype characters in a parallel rather than a serial fashion enables a higher character transmission rate. Such a system displays some features roughly analogous to the parallel processing of speech.

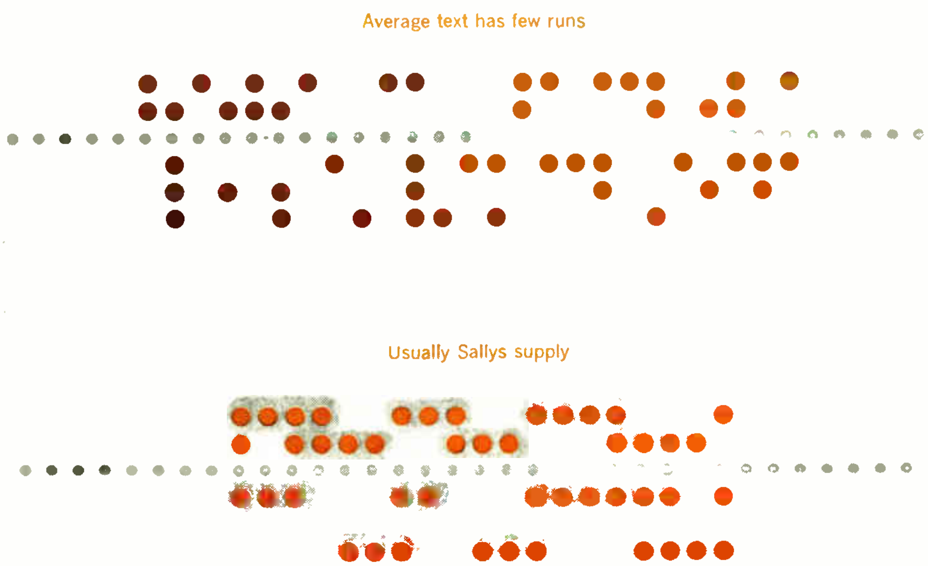
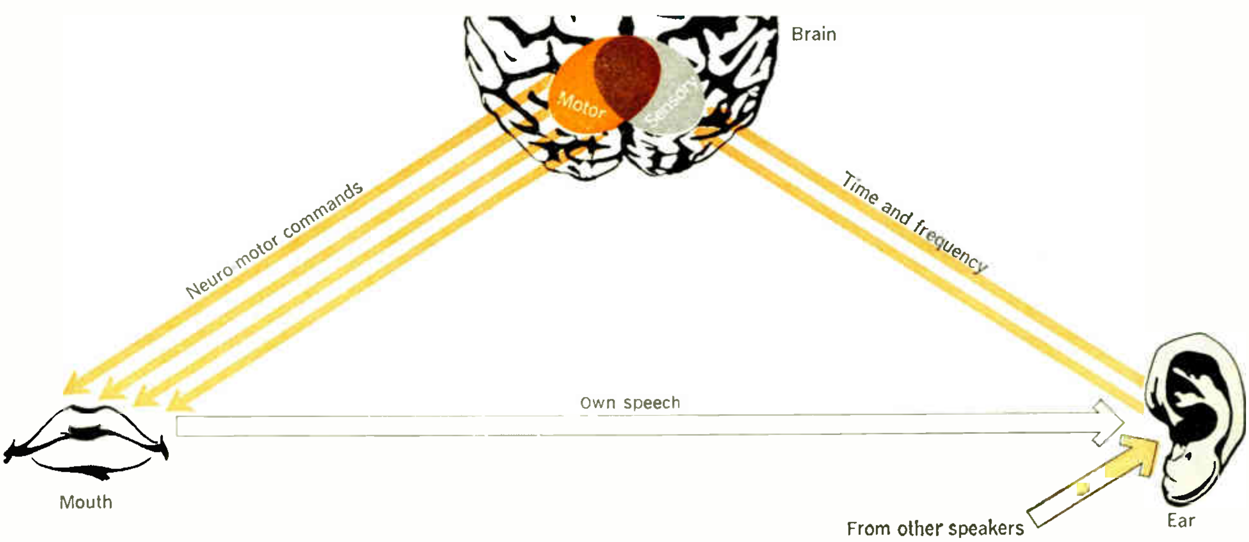


FIGURE 4. In the human, the "decoding" of speech signals may well involve some form of neural reference to the motor system that is used in encoding similar signals when one speaks.



other acoustic signals. However, let us concentrate on just one of these properties, namely, the efficiency of speech as a signaling system, if we take rate of production or reception as our criterion.

Consider reception: We understand speech at rates of several hundred words per minute. This means that the unit sounds of speech—the phonemes—are coming at us at rates of 10 to 20 or more per second. This rate is far faster than we can deal with any other set of discrete acoustic signals put end to end; for example, it is generally faster than an expert telegrapher can read International Morse, and, in fact, approaches the rate at which a sequence of clicks merges into a steady buzz.

Or consider production: A speaking rate of 10 to 15 phonemes per second would hardly be possible if each phoneme required a complete, unitary gesture, as is the case in typing, where each character has its own key stroke. Even with all ten fingers and years of practice, the expert typist will fall behind the leisurely speaker.

This is not meant to prove that the human being cannot talk or listen as fast as, in fact, he does, but that he doesn't achieve these rates by the brute force method of making or hearing an invariant unit of sound for each of the successive linguistic units of his message. What he does do is to generate an acoustic code in which the linguistic units—specifically, the phonemes—are represented by merged and overlapping parts of the acoustic signal. In short, the message has been restructured in the process of being spoken so that it has become an acoustic *code*, not just an audible cipher.

It is easy to see how this makes life difficult for the engineer who is trying to build a speech recognizer, but how can it account for the remarkable rates at which speech signals are produced and received by humans? Perhaps speech is so fast, and so thoroughly restructured, because it drives a stolen vehicle, or at least a borrowed one. Figure 2 shows three diagrams of what is often called the vocal tract.

It is quite obvious that the anatomy used for speech serves other primary functions in man, as it does in animals. By and large, it serves these functions well, though certain aspects of the overall design would not please a master plumber. The pathways for food and air must cross each other in the back of the mouth. Thus, eating and breathing can be managed only because the system is equipped with a number of valves that would not otherwise be needed, and with extra neural controls and interlocks to regulate the cross traffic. It is a preposterous system—and yet it may well be that most of man's potential for speech resides in this seemingly clumsy design, with its many component parts. If each valve and actuator can operate independently, and if each change in the overall configuration changes the output to a new phoneme, then the phoneme rate can indeed be much higher than the rate at which any single articulator must move.

This is a familiar trick to engineers: If you must get high-speed performance from low-speed mechanisms, then you use several of those mechanisms in parallel. Figure 3 shows an example. When the transmission is serial by bit, as in Teletype, then the rate at which the characters are transmitted will be much lower than the bit rate. It is possible, of course, to increase the character rate, making it equal to the bit rate, by using five lines in parallel, one for each row. Finally, the character rate can be made substantially *higher* than the bit rate (on each separate line) by imposing longitudinal constraints on the alternation of ones and zeros. The bottom row of Fig. 3 is an example of this. It shows also that, even when one plays fast and loose with the punctuation, there are serious limitations on the message unless additional transmission lines are available.

This analogy to speech has obvious limitations; nevertheless, it is suggestive to replace the letters by phonemes and the rows (or channels) by distinctive features of the speech signal—features that correspond more or less directly to the independent valves and actuators of the anatomy. Then one may see how the phoneme rate can be so high in speech production.

But the rate is high for speech reception also. Does this imply a decoding process that abstracts features corresponding to the units of articulation? Perhaps the auditory signals go to neural networks that have a functional overlap with those parts of the central nervous system that control speech production, as suggested in Fig. 4. If such overlapping exists, then the incoming auditory signal may be referred to parts of the motor system that could have produced the same sound, and so back upstream to the neural circuitry that is concerned with linguistic entities. Some such mechanism would provide a neat solution to the problem of decoding the speech signal; moreover, its operation would be consistent with a substantial body of experimental data that points to very close links between speech perception and speech production.

Perhaps the central nervous system is where we should look for special speech mechanisms. The experimental search is not an easy one, for obvious reasons; moreover, even after the neural area and mechanism are pinpointed, there is likely to remain a question about how much of the neural machinery is inherited from man's evolutionary past, and how much has to be rebuilt in each generation on the basis of a cultural inheritance that goes back in an unbroken line to that ancient but magnificent "invention," human speech.

John Lotz on linguistics

Having regarded speech's "stolen vehicle," and how it presumably operates—that is, its constructive coding and decoding capabilities—a natural question is to ask what man has done with such equipment. What about the actual languages he has produced? Many perplexing questions about languages have troubled linguists for centuries, for the very multiplicity and changeability of languages can be blinding. Where does one begin? Professor Lotz began by seizing on two questions posed by Homer Dudley; one is a very deep and old question, but the other has a modern twist.

The first question is: Why is it that we have so many languages (we list some 3000 to 4000) whereas man's biological constitution is a single one? The second question is: What is the optimal language; would it be possible to improve languages, to *engineer* them?

Both are very basic, intriguing questions. It is clear that the first question needs some elucidation because what we mean by the "difference" or "identity" of two different systems is not so easy to answer. It is clear that men have different blood types so that, in the biological realm, you can speak about differences. But it is also clear that language does not belong entirely to the biological and not even entirely to the sociological realm. That is, language is unique and not identical with the gross cultural features or the biological traits of mankind.

How to get there

There are several significant prerequisites upon which speech-oriented technological progress during the next few decades will depend.

First is a deeper understanding of how man produces speech and how he perceives it. Future technology will depend critically on the understanding of these basic human capabilities and their limitations.

An important factor in this quest for new knowledge is an even wider spread and more diversified use of computers than we have today, in particular, for on-line computation in basic research.

Finally, many applications will depend on further sophistication in the art of microelectronics. Many of the functions of future information-processing systems will be so complex that only fully integrated, microelectronic circuits will be able to perform their prescribed functions within acceptable limits of space, time, cost, and reliability.

Dr. Manfred R. Schroeder
Bell Telephone Laboratories

Honesty and ambiguity

It has been said that, as opposed to ordinary speech, there seems to be in engineering and science an honest, unambiguous form of speech. I am not quite confident that there is, and I wonder if it is possible for us to evolve a language that would permit us to delineate clearly integrity from deception. Perhaps the biggest job today is to speed up the evolution of understanding, in findings ways of sorting out the honest statements from the deceptive.

Dr. Leo Beranek
Bolt Beranek & Newman

Linguists distinguish about 3000 or 4000 languages today. This rather vague number springs from the fact that we don't define exactly where one language ends and another begins. In Scandinavia, for example, Swedish, Norwegian, and Danish are close linguistically, although they represent political entities. On the other hand, Lappish, spoken in northern Scandinavia, certainly comprises five distinct varieties, so that communication among them is impossible; yet we speak of a single Lappish language. Thus, it is more realistic to talk about 5000 to 6000 varieties of language, if by "languages" we mean groups that cannot intercommunicate. Of these languages, 130 or 140 are spoken by groups comprising more than a million speakers and a number of them are very large, over a hundred million. Those are Chinese, English, Spanish, Russian, German, Hindu, Urdu, and Japanese. All the others comprise smaller groups.

There probably were more languages about 150 years ago; many of them died out owing to colonialism, extinction of groups of people, assimilation. It is probable that at the beginning of evolution there was only one or possibly a few varieties of language, which drifted apart, reaching an optimum of 6000 or 7000 languages about the beginning of the 19th century, and from then on diminishing quite rapidly in number. It seems certain that a hundred years hence we will have far fewer languages than now, well below a thousand, and they will probably decrease even further. Thus, we have an increasing curve of the number of languages and then a decreasing one.

The Bible has an explanation for this modification of language and actually associates it with an engineering enterprise, with construction engineers to be sure, not with electrical engineers. But it's quite clear that our real Babel was the result of a slower process; the proliferation of languages came about through some kind of a drift.

Through language, man associates in his brain, or psyche, anything that is accessible for formation with very-low-level-energy nervous signals. These symbolic events man can produce at will in his own body, which is part of the reference itself; it's a kind of system where an enormous, complex system is projected on a very small symbolic stream.

Man has at his disposal for communication a number of fully developed media—speech, script, and even gesture languages. And not just concomitant gestures, but fully developed languages such as the sign language of the Plains Indians. They can talk, preach, confess love, and so forth, in sign language; it has no limitation whatsoever. Nevertheless, it is quite clear that speech has a unique and special position as the general and universal means of communication. It has many advantages over the other communication media. Speech requires no tool external to the human body, as does script. Being independent of light, it can be used day and night. It fills the entire space around the speaker and does not require that the speaker and listener be in line of sight, as do gestures. It can also be varied greatly, from whispers to long-distance shouts, and it requires a very small amount of energy. Also, since speech involves the mouth and ear, it leaves the body free for other kinds of activities.

Throughout the diversity, however, there is a uniformity among languages. Although, on the one hand, language seems to be drifting apart from its social and cultural connections (since there is no stability in man's preoccupations with work, culture, etc., and since even the verbal expressions pertaining to these preoccupations are ephemeral), and even though we have, therefore, evolved so many languages, there is a perceptible unity. Think of it this way: Suppose all mankind could be resurrected. Then, everybody could talk to all the preceding generations, through intermediaries where necessary, about topics that belong to all mankind (e.g., about eating, sleeping, etc.). It would be possible to communicate all the way back to Adam and Eve. In this way, one sees that there is only one general *filum* of language. Thus, although there is variation in the development of many languages, in reality there is a kind of tie that gives an evolutionary unity to this whole development.

However, languages constitute a very complex phenomenon; it is an illusion to believe that "simple" sciences such as physics, or logic, could really solve the problems of linguistics, as many people believe.

The second question is somewhat easier to answer. Would it be possible to develop an ideal language and to engineer a language? Since language is associated with a very large part of the psychological makeup of man, the question would imply that we also could determine the ideal makeup of man. Only then would the problem make sense. Otherwise, since language covers all kinds of functions, there is no way of reducing it to a single optimum. Just as there are many functions for language—poetry, lies, communications, discussions—there might be a number of optimal languages for various purposes. This is precisely the character of natural language, not to be tied down to the single function that some people associate with it; that is, communication or information about factual things. Natural languages might be the best, just as they are, multipurposed. It is doubtful that there is any way of developing an optimal language or engineering it toward an optimal goal of this kind, because there is no such goal.

It is possible, however, that there could be an exception in the scientific field, in the objective-information field. It seems clear that the enormous amount of production could force scientists to use a more rational, more formalized language; and computers might play a role in this. However, to echo Dr. Miller's thought, languages are much more complex than any of the gadgets or machines we shall be able to build, so it will take a long time before real language machines will be built.

Manfred R. Schroeder on technology

A point made somewhat implicitly by Professor Lotz, concerning the ideal makeup of man, is refracted into a more explicit form by Dr. Manfred R. Schroeder. Technological progress to date, he says, has been largely based on expertise in the physical sciences. Future progress will depend much more on a better understanding of the human: his perceptive capabilities, his behavior, *and* his individual preferences. But in his formal presentation, Schroeder adheres closely to his mandate. He discusses technology.

The technology man has developed for recording and transmitting speech covers an exceedingly wide range of sophistication and complexity. Beginning with the knife and chisel to record messages in wood and stone, we, as a species, have witnessed the successive evolutions engendered by the brush and pen, by movable type and the printing press, through the teletypewriter up to the most modern processes of display and duplication of the written word made possible by the cathode-ray tube, photography, and xerography.

For the spoken word, we can point to an equally dramatic technological development, from the ear trumpet and the megaphone (to increase the range of man's natural voice) to the modern hearing aid, the electronic artificial larynx, public address systems, talking motion pictures, radio, and television.

Two fundamental inventions, Edison's phonograph and Bell's telephone, signal a turning point in this continuing development. The phonograph allowed man for the first time to record sounds and to recreate them at a later time, thereby bridging time. The telephone enabled man to speak over great distances, thereby to bridge space, at speeds limited ultimately only by the velocity of light.

Other important discoveries and innovations that have magnified the impact of these inventions on contemporary society are the use of electromagnetic waves for wireless communication, vacuum tubes, the principle of negative feedback, and the transistor with its myriad uses in radio, high-fidelity and stereophonic equipment, electronic switching, submarine telephone cables, and communication satellites.

The ever-increasing amount of information transmitted electrically and the resulting scarcity of transmission bandwidths led to still another turning point in the art of communication: information theory. Information theory, with its concepts of source entropy, channel capacity, and redundancy, has given us tools for evaluating the efficiency of existing communication systems and has, in some cases, led to new methods of coding and transmitting information-bearing signals such as speech.

Even before the advent of information theory, thoughtful engineers pointed out how inefficient ordinary electrical voice communication is. As early as 1928, Homer Dudley showed that a few hundred hertz of bandwidth should be ample to transmit intelligible speech. Dudley's ideas led to the invention of the vocoder (from *voice coder*), the first of a still-growing family of electronic devices for transmitting and storing speech signals more efficiently. The vocoder is based on the powerful concept of the short-time spectrum, which itself is an elaboration of the well-known Fourier transform.

Figure 5 shows such a short-time spectrum (called visible speech) as it is used in much of today's speech research. The acoustic spectrogram is a visual representation of a spoken message preserving most of what a human listener can perceive and discarding what he cannot. The abscissa is time and the ordinate is frequency. Black markings correspond to the time- and frequency-dependent spectral intensities of the spoken message; in this case the message is "IEEE Convention."

Vocoders transmit the information displayed in Fig. 5, that is, the time-varying intensities of the different frequency components making up the speech signal. Early vocoders spoke with a strong electrical accent, but intensive speech therapy over the last three decades has given the vocoder a quite pleasant human-sounding voice. A few months ago the first vocoder went on the air, or rather under the water; it is being used to double the capacity of a transatlantic telephone cable circuit between New York and Paris.

Short-time spectra, such as that in Fig. 5, produced on a running basis (in "real time" as we would say today), have also proved useful in teaching deaf children to speak.

In addition to bandwidth compression, spectral manipulation of speech signals allow changing the time scale to slow down speech or to speed it up without changing its frequency content. Modern methods of speech processing based on spectral analysis and synthesis have opened up a whole range of useful applications, including such improbable feats as the separation of speech and noise, a process called noise stripping. It has not been shown that intelligibility can be improved, but listening to noise-stripped speech should at least prove less fatiguing in extended listening.

Of even greater practical interest is the reversible *reduction* of intelligibility to ensure voice privacy. Here, many

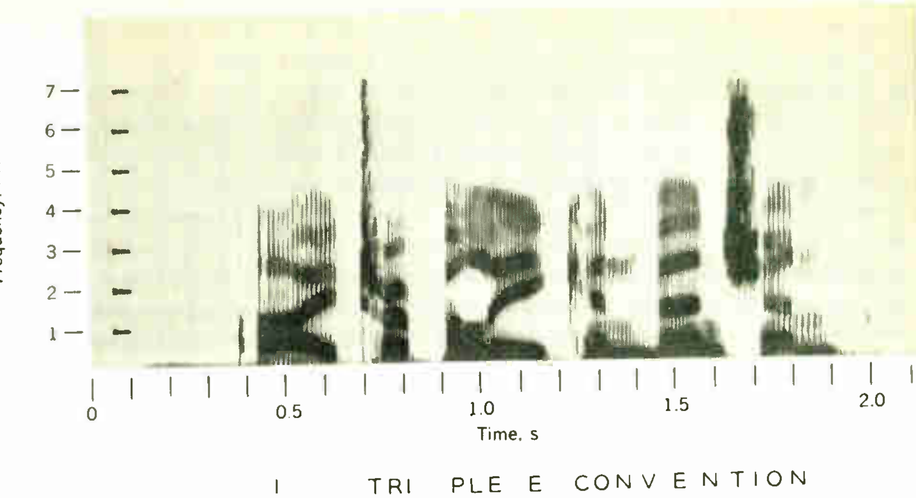


FIGURE 5. Real-time spectrograms, called visible speech, have proved to be valuable in speech research and in speech therapy. This is a spectrogram of the words "IEEE Convention." The darker bands of higher energy concentration are called formants.

methods have been studied, both digital and analog, and it seems certain that voice-privacy systems will play a large part in business as well as government telephone communication.

Another new dimension in voice communication is conference telephony, which permits groups of people to confer with each other from distant locations thereby eliminating the need for time-consuming travel. The advent of conference telephony poses new problems for the communication engineer, one of which is the suppression of room reverberation and background noise, a task so ably performed by our two ears, but difficult to translate into electronic and electroacoustic devices.

These applications are, of course, only samples from a much wider range of useful things that modern technologies allow us to do for communication by speech and the written word. Other areas in which the conjunction of human speech and technology are important to engineers include: automatic word recognition; automatic talker verification; reading and speaking machines; new grammars that make machine comprehension of written text feasible; the correction of aquanauts' speech produced in a helium–oxygen atmosphere; and the use of computers to simulate the human vocal and hearing mechanisms in order to further our understanding of these important links in speech communication.

It is safe to predict that in the next ten years we shall witness a large increase in man–machine interactions by all kinds of means: graphical, symbolic, and, notably, voice. We will have voice-actuated machines, and perhaps even machine-actuated people.

Of things to come

In their formal presentations, each of the panelists at least broached the future, and in research such as is represented here, in language and speech, it is almost unavoidable. The future takes on an added reality because the work is on-going, unfinished, perhaps barely begun.

Furthermore, the predictions of things to come made by men who are immersed in research take on a special relevance because speculations of such men may constitute plans as well. Thus, when Dr. Licklider, the moderator, speculates that people may talk more with machines in the future, and talk with other people mainly for reinforcement (see box, page 78), one must also remember that that is a vision of the future he personally is working very hard to create in hard fact. One might also pause to wonder whether or not Professor Miller is holding prisoner at the Center for Cognitive Studies a primate (i.e., euphemism for poor ape) to whom each day he feeds a potion of RNA on the supposition that one day the ape will exclaim "Eureka!" or "Help, I am being held prisoner!" If there is such an ape, and if he is smart, he will lie low and say nothing; otherwise, he will only exchange his chains for the public school system or its computerized equivalent.

In calling on the panelists to make their predictions, Dr. Licklider congratulated them on having come up with cogent, precise remarks on such a wide variety of topics. Their predictions share the same qualities.

Manfred Schroeder started things off, looking ahead just ten years. What progress will be made in technology? He foresees a particularly fertile field for man/machine conversation in the field of information retrieval. Machines will be able to understand at least a limited number of verbal questions and give answers in a synthetic but, hopefully, human-sounding voice. Machines may even be able to verify the identity of talkers, a capability that will surely revolutionize the banking and credit business. Automatic talker verification will also help to protect the privacy of limited-access information files and safeguard chains of command in the military and government against illegal intrusion.

Man/machine conversation, he believes, will also play a substantial role in education in the form of second- or third-generation teaching machines. In the next few decades we are bound to see all kinds of machinery controlled by voice, from the sorting of mail to the maneuvering of space capsules. Voice dialing of telephones and voice-operated computer programming are also perhaps somewhat more remote possibilities. The advent of speech synthesis by rule in combination with character-reading devices might make possible machines that will read printed text, although some formidable problems remain in translation.

The most significant advances, Schroeder is convinced, will be in the multifaceted interface between man and machines, and particularly those interfaces relying on language, spoken and written, natural and artificial.

During his discussion, Dr. Schroeder played a number of tapes, including a sample of artificial speech from Peter

Denes' computer-controlled synthesizer at Bell Telephone Laboratories, that demonstrated how the incorporation of relatively sophisticated rules for speech synthesis enables the computer to handle humanlike stress in short sentences. But, as Dr. Schroeder pointed out, the speech synthesizer has not yet lost its machine accent, and much research is still needed on how humans actually produce and perceive speech.

One important aspect of this research will focus on finding out how the articulators (the tongue, the lips, and the soft palate) move during connected speech. The classical tool for such studies is an X-ray movie of the human head—a cumbersome and dangerous technique. More recently, it has become possible to deduce articulator positions from spectral analysis of the speech signal itself. One exploitation of this technique is a model of the vocal tract (proposed by Cecil Coker and Osamu Fujimura at Bell Telephone Laboratories) whose five parameters can be derived just from spectral measurement. With this setup it is possible to speak into a microphone and then, through the use of fairly complex analyzing equipment, produce at the output a cartoon version of the vocal tract in a motion picture or perhaps in a moving display on a cathode-ray tube. This technique might be useful to enable deaf people to communicate—a kind of extended lip reading, in which they could see the tongue and other vocal parts usually hidden. This technique, which could supplement visible speech, might, Schroeder concluded, be called visible articulation.

Following Schroeder, Dr. Lotz was asked how he saw the evolution of languages a hundred years from now. In his reply, Dr. Lotz made several points: (1) The number of languages will sharply diminish from the present 3000 to 5000 to well below 1000. (2) A small number of languages, among these English, will expand considerably in international communication and in the sciences. (3) No artificial international language such as Esperanto will be actively in large-scale use. (4) For some purposes, such as science and public and business administration, certain parasitic, computerized languages will be developed and used. (5) These developments will not affect the structure of everyday language, which will remain as idiosyncratic as ever due to the unchanging psychological makeup of man, but variation—dialectical, and so forth—will diminish or disappear. (6) The storage and retrieval of information may be entirely organized by complete information centers replacing libraries, and other new media replacing current publication and communication media to a large extent.

Dr. Cooper was called upon to look ahead 1000 years. What will happen to speech production and perception in the human? He answered by pointing out, first, that the time span is all wrong for normal evolutionary change. If it were ten years, one might say, with assurance, nothing will be changed; if a million years, one could say that there would have been significant drift, probably toward shriveling arms and legs, but a massive jaw and ear, and possibly a larger cranium. However, a thousand years is both too long and too short.

Nonetheless, Dr. Cooper continued in a dialectic vein, perhaps one should not dismiss the possibility of evolutionary change. The enormous time scales usually associated with evolution might be very different if the payoff schedule and the randomness of mutation were changed by man himself. Moreover, communication has, also, catalytic properties that we cannot ignore; the ability to communicate effectively has increasing survival value in an increasingly complex society, and our habit of communicating makes that society more and more complex. In fact, culturally, attitudes may play the decisive part in selecting the gene pools that will survive under increasing pressures from overpopulation. Then, too, population pressure affects some of the rate-setting factors. Probably the mutation rate is affected by ambient radiation that will continue to increase; indeed, a major hazard of our times is too much radiation, too soon.

We should not overlook the possibility of direct chemical intervention, either to manipulate genetic constitution, even by 2967, or to enhance and modify the operation of the central nervous system by subtle steering of the existing genetic constitution. All in all, it may be brash to conclude that no evolutionary change will occur in man's mechanisms for speech, although it's not easy to see just what the changes might be.

Some things not now possible will certainly be standard practice in much less than a thousand years—for example, the replacement of such organs as the larynx or tongue, just as we now provide false teeth. Also, the ways that machines could by then intervene in the human links between ear and mouth and brain may be even more significant than the assistance we get from external machines. Cooper added that he is not thinking so much of general-purpose computers implanted in the skull as of machines that can profoundly modify man's own mechanism for talking and listening. Consider the deaf, for example: We are already on the verge of using machines that extract information from speech and present it in meaningful ways that can help deaf children learn to speak naturally without the machine. Certainly, this is not a thousand years away nor, in all probability, is the more elaborate machine that could teach us to speak another language.

Beyond these, there might even be machines that could somehow store the vivid personal experiences each person associates uniquely with his words, and thus provide a richness of communication that is not now possible, or possible only through extensive dialogue.

Upping the ante to 10 000 years ahead, Dr. Licklider called on Professor Bram.

Professor Bram pointed out that the so-called primitive human groups do not really speak primitive languages, but fully developed, rich, structurally complex languages. However, there is an interesting corollary to this point, namely, that we educated, civilized humans are actually using "primitive" languages most of the time, languages that are not primitive structurally or phonemically, but in their effectiveness and efficiency in grasping reality and in communicating. It's a peculiar lag. We have moved forward with regard to the production and control of energy and have made fantastic scientific progress in various domains but, where language is concerned, we have no right to feel that our speech is in any way superior to that of the naked savage.

However, there is one sector of our society that has a distinction of having developed an honest, direct, and meaningful language—the language of science and the language of engineering—where a statement means just what it means and nothing else and where there is no room for equivocation or ambiguity. Perhaps the future, the distant future, of mankind may see a clear recognition of two types of speech (see box, page 76).

Following Professor Bram, George A. Miller was given the uneasy task of forecasting a million years ahead. Or perhaps the time scale involved is so absurdly large that speculation is liberated. Anyway, Professor Miller plunged in, and produced some intriguing ideas:

People like ourselves will certainly by then be fossils and a new species will have replaced us, being as different from us as we are from the great apes. Now, what would such a species be like? Since the possession of language is the most important feature that sets man off from the other primates, any simple extrapolation from the past, from the apes to us, must emphasize the importance of further improvement in his communicative ability. Physically, the most impressive change from the apes to man is in the size of the brain and, since changes in the brain are obviously going to be related to any evolutionary improvement in communicative ability, we might focus the extrapolation on the changes that have occurred in the brain. If things go on as they have, in the next million years the brain would be about three times its present volume and the proportion of this larger brain devoted to the hand and to speech could be about double the present proportions. Thus, after birth, a child might go on growing and learning much longer than at present.

However, I distrust any such simple, linear extrapolation. The machinery of evolution, itself, has been changing, and today we are on the threshold of being able to understand and control the genetic process, to substitute our own designs. If we really do gain control of human heredity, the prospects are unlimited, or limited only by our descendents' imagination. What might they, through genetic engineering, want to turn themselves into? I think it's safe to predict that, before using genetic engineering on ourselves, we will want to try it on animals first. One project that will almost certainly be undertaken will be the modification of the genetic structure of some of the other primates, let's say, so as to enable them to use speech. Such experiments would help us to understand better the nature of the gap that presently exists between man and all his fellow creatures. If we were successful in such experiments, in breeding animals that could talk, then we might have a basis on which to initiate genetic experiments to improve our human capacity for communication.

If we had such a technological capacity, what could we do with it? Well, I doubt that we'd be able to evolve nerve cells that operate much faster or more reliably than our present ones do, so any improvement would be probably along the lines Dr. Cooper mentioned, of parallel processing, and larger and larger memory stores. If our descendants do decide to give themselves larger brains, they will probably be able to use a much richer variety of symbols than we do at present and, at the very least, their vocabularies will be a lot larger than ours are; probably the complexity of the relation between the domain of sound and the domain of meaning will become even subtler and more complicated. Parallel operation, already an important feature of man's present brain, would presumably be greatly extended in a million years, and with consequences that would be very hard to foresee, but perhaps the simplest one of them that we could foresee would be the capacity to send and receive—that is, to talk and to listen simultaneously—which is a kind of efficiency that we are very poor at with our present nervous system.

There you have it—talking animals, larger memories, and larger vocabulary, and perhaps simultaneous talking and listening.

Some questions

In rounding out a session such as this, in which a medley of ideas, speculations, and questions have been presented, one is tempted to try to impose on it a kind of synthetic unifying statement, but it is better not to; it is better to listen to the medley or to the parts that sound best in one's own ear.

On the other hand, one might pose further questions as Cooper suggests. For example, we might inquire into the many consequences of Licklider's idea that man *will* talk more with machines. Or we might consider further the implications (for the computer art, say) in Cooper's implicit point that the kind of parallel processing that occurs in the acoustic signal may pervade the entire process of spoken communications—that is, simultaneous parallel processing at every level: sound, word, sentence, meaning.

Another alternative, for the attentive reader who is now bristling with questions, is to lead him out through a kind of verbal funnel. At its wide end, one could conjure up Marshall McLuhan, as Schroeder did: If McLuhan is right that "societies have been shaped more by the nature of the media by which men communicate than by the content of the communication" then we shall see a vastly changed human society. At this open end, one could spiral out into a cornucopia of airy ideas and speculations about society, culture, and whatnot. The other way, perhaps more natural to engineers, is to hammer down the funnel, logically and analytically, to a significant point, as Miller did: The fact that man is the only animal that talks, the fact that all human societies have languages, the fact that all human children can acquire language without special training, the fact that the stages of speech development in children are so uniform, the fact that all human languages share certain basic design features—all these facts indicate that human language is deeply based in the inherited structure of the human organism. What this means for communication engineering is that there is still a great gap between the kind of rule processing that human beings do when they talk and the kind of rule processing that computers can do today. Closing that gap poses a challenge to both the engineers and the behavioral scientists who are interested in human communication.

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Smith, F., and Miller, G. A., eds., *The Genesis of Language*, Proc. of Conf. on Language Development in Children. Cambridge, Mass.: The M.I.T. Press, 1966. (See especially "Developmental Psycholinguistics," by David McNeill.)

Solid-state microwave delay lines

Extensive research in the use of solid-state devices for microwave applications has resulted in a new generation of delay-line equipment combining greater accuracy with tremendous reduction in size

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Solid-state delay lines operating at microwave frequencies can provide many advantages over conventional delay techniques. These devices use sound waves or magnetic spin waves to obtain fixed, variable, or dispersive behavior. The size and weight of electromagnetic delay lines, together with inherent high cable loss, are avoided with solid-state units. Pulse compression filters with bandwidths of several hundred MHz have been constructed, and the future promises even greater capabilities.

There is an increasing need in electronic technology for devices that can provide real-time delay of microwave signals. Coaxial cable and waveguide delay lines can be used in some applications, but these must be approximately 300 meters long for a time delay of only 1 μs. Thus, the size and weight of electromagnetic delay lines are prohibitive if a delay of more than a few nanoseconds is required. The cable loss is also quite high, with typical values from about 20 dB/μs in the L band to 100 dB/μs in the X band. The transit time of sound waves ranges from 1 to 5 μs/cm in various materials, so that an acoustic delay line is five orders of magnitude shorter than the equivalent length of cable. Compact ultrasonic delay lines have been available for many years, but were restricted to the frequency range below 100 MHz by limitations in transducer performance and by attenuation of the delay medium. When used for signal delay and processing, the narrow bandwidth of these IF delay lines restricts the system performance. Significant improvements are possible if the signal delay can be performed at a microwave frequency.

Recent improvements in transducer fabrication and in crystal growth techniques have led to the development of microwave delay lines that use the acoustic and magnetic properties of solids.[1] Superior performance in a smaller, more reliable component makes these devices attractive for use in test equipment, Doppler or pulse compression radar, and other microwave systems. The microwave acoustic delay lines provide a fixed delay. In devices that use the magnetic properties of solids the delay time can be varied continuously by changing an applied magnetic field or the frequency.

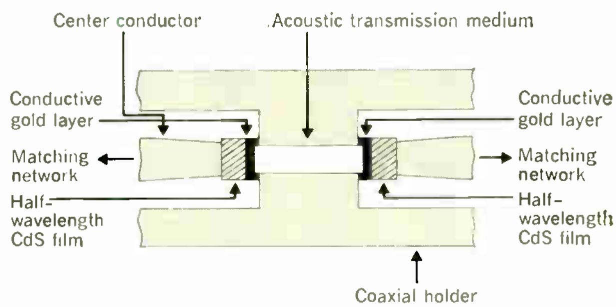


FIGURE 1. Transmission-type acoustic delay line.

Fixed delay lines

Principle of operation. The fixed delay line makes use of the slow propagation velocity of sound waves in solids. The basic structure is shown in Fig. 1. A microwave transmission line is coupled to a transducer (piezoelectric CdS in the case shown), which generates sound waves in response to a microwave signal. The sound waves propagate into the low-loss acoustic transmission medium and the delayed signal is reconverted to electromagnetic energy in a similar structure at the opposite end of the line. A substantial fraction of the acoustic energy is usually reflected at the far end of the delay line, so that a one-port reflection mode of operation may be used instead of the transmission mode. A series of multiple echoes can also be obtained, with spacing equal to the round-trip travel time in the delay line; see Fig. 2. Out to a time delay of 60 μs the echo amplitude is constant because of receiver saturation, after which the intensity decays at about 0.4 dB/μs. Electronic gating

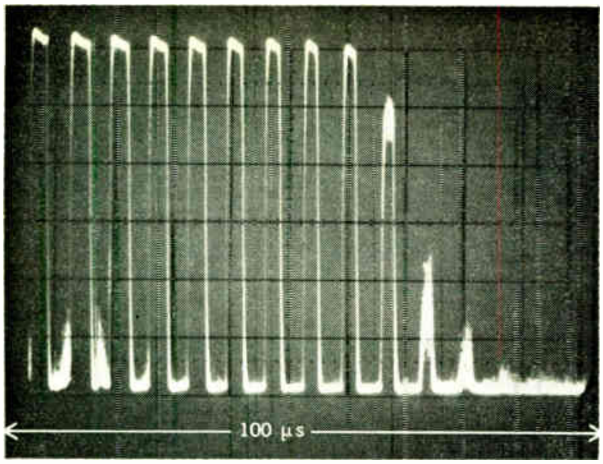


FIGURE 2. Multiple echoes of shear acoustic waves at 1600 MHz in a YAG rod with CdS transducers.

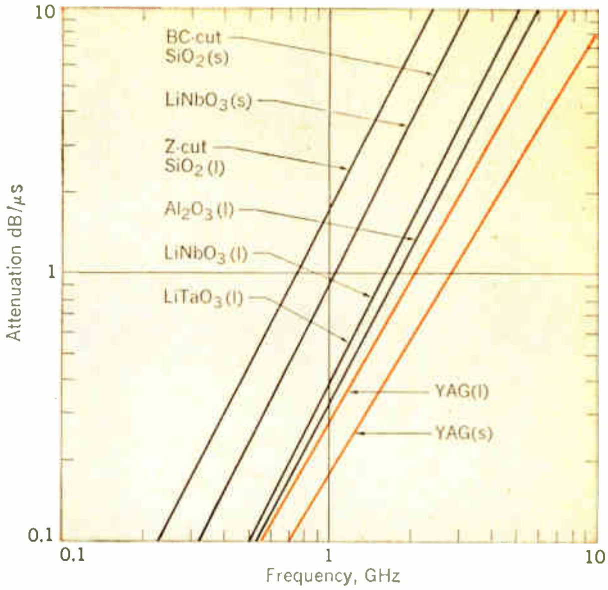
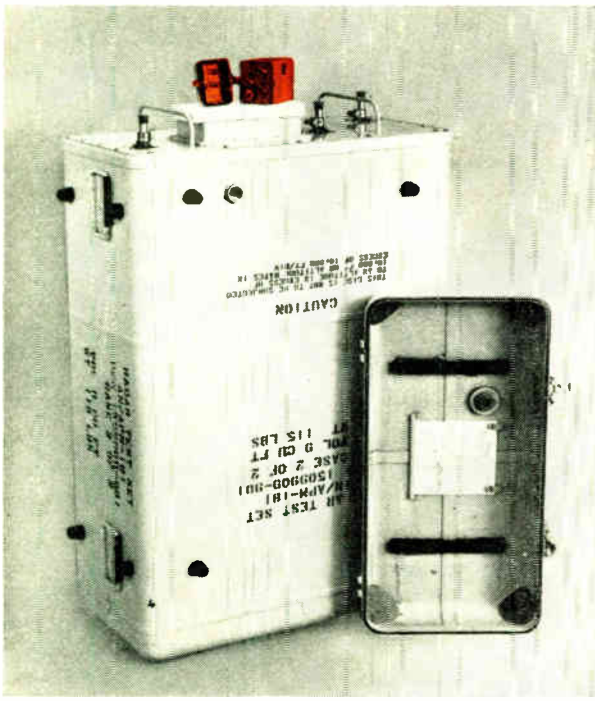


FIGURE 4. Frequency dependence of acoustic attenuation at room temperature in delay-line materials, for shear waves (s) and longitudinal waves (l).

FIGURE 3. Compact acoustic delay line (colored area) rests on top of bulkier conventional unit.



techniques can be used to obtain a single pulse of long delay time.

A microwave acoustic delay line is compared with a cable delay line in Fig. 3; both devices are used for test and calibration of C-band altimeters. The acoustic delay line, besides the obvious advantages in size and weight, provides longer time delay and better electrical performance than the conventional delay line. A detailed comparison will be made later.

Acoustic transmission materials. The earliest experiments in microwave acoustic propagation used quartz rods, but it was soon found that attenuation at room temperature was too high to be practical. The acoustic attenuation of some representative materials[2-10] is shown in Fig. 4.* The most useful crystals for microwave acoustic delay lines are sapphire (Al_2O_3), yttrium aluminum garnet (YAG), and lithium niobate ($LiNbO_3$). In cubic crystals such as YAG the lowest attenuation is obtained for shear waves, whereas in trigonal Al_2O_3 and $LiNbO_3$ the longitudinal waves have the lowest attenuation.

The causes of this attenuation are understood in a general way[11]; and very simple physical models account for the fact that, in insulating crystals, the loss at room temperature increases approximately as the square of the frequency. However, it is not possible at this time to specify in detail the crystal chemistry and structure required to obtain lower intrinsic loss, and the search for improved transmission media must be conducted empirically, with only general guidance from theories that relate the loss to other physical parameters.[12]

It is important that the delay-line material be a high-quality single crystal. Imperfections and strains in the material increase the attenuation substantially above the values shown in Fig. 4. The crystal is usually fabricated in the form of a rod whose length is chosen to provide the required delay. The crystallographic orientation of the rod must be carefully aligned for the desired mode of acoustic propagation, because the shear and longitudinal sound waves are coupled by crystal anisotropy except along specific crystallographic directions. The ends of the rod must be polished parallel and flat to a small fraction of an acoustic wavelength. The acoustic wavelength at microwave frequencies is comparable to the wavelength of light, so the fabrication specifications are similar to those for laser rods.

Transducers. In most delay-line applications, the transducer is the principal source of insertion loss. The conversion loss of several types of transducer is

* See also refs. 1, 12, and 14. Some of the data on YAG, $LiNbO_3$, and $LiTaO_3$ are from unpublished results of G. P. Rodrigue and A. B. Smith.

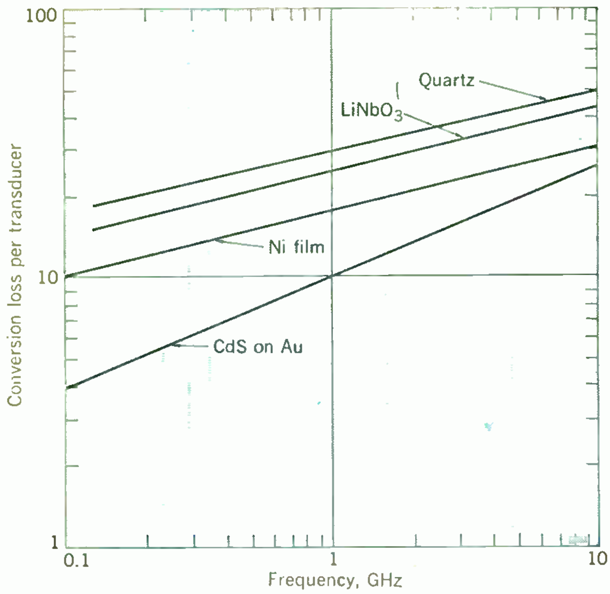


FIGURE 5. Frequency dependence of transducer conversion loss for four methods of exciting acoustic waves.

shown* in Fig. 5. The earliest experiments used the piezoelectric properties of quartz.[13,14] Resonant plates cannot be fabricated at microwave frequencies, so a nonresonant process is used in which acoustic excitation takes place at the end surface of the rod. Lithium niobate, which is also piezoelectric, is commonly excited in a nonresonant mode similar to that used for quartz.[15] In both cases the piezoelectric crystal also serves as the transmission medium.

A significant improvement in the conversion efficiency is obtained by using resonant transducers, which are thin films with thickness equal to a half-wavelength of sound. Ferromagnetic films may be used, such as Ni, where the conversion takes place through magnetostriction.[16] These transducers operate at higher input power than other resonant transducers. The most efficient transducers have employed thin films of CdS with a metallic layer to concentrate the RF field.[17,18] The performance of a longitudinal-mode CdS film transducer

* Sources include refs. 1, 13–19, and unpublished results of G. P. Rodrigue and A. B. Smith.

I. Performance specifications of typical microwave delay lines

Frequency	Bandwidth, MHz	Delay, μs	Insertion Loss, dB
L band*	20	1.52 (min.)	70
		120 (max.)	130
C band	400	2.77	100
X band	750	3.5	112

* Multiple-pass device, with gate selection of desired echo.

over a broad frequency range is shown in Fig. 6. In the preparation of this transducer, the thickness was monitored by observing the interference fringes formed with a laser.[19] The insertion loss is significantly lower when the film thickness is near an odd number of half-wavelengths of sound. The double minima near the λ/2 and 3λ/2 thicknesses are expected from the theory of piezoelectric excitation when the transducer impedance is less than that of the delay medium.[20] For longitudinal waves, Z(CdS) = 21.2 × 10^5 g/cm^2·s and Z(Al_2O_3) = 43.6 × 10^5 g/cm^2·s.

Delay-line performance. A wide variety of delay lines have been constructed on the basis of these principles. Some representative performance characteristics of delay lines that are currently in production are shown in Table I.[21] These devices can be used with input power levels above of 1 kW, with spurious leakage more than 20 dB below the desired signal, and over an ambient temperature range of at least −20°C to +55°C. In order to provide a comparison with conventional delay lines, we consider the altimeter calibrator (shown in colored area in Fig. 3) in more detail.[21] This device contains two delay lines and three circulators to simulate simultaneously round-trip delays equivalent to 270- and 480-meter altitudes. It is designed to airborne military specifications and operates in the C band with 200-MHz bandwidth. The insertion loss is less than 100 dB and the voltage standing-wave ratio is less than 1.5:1. An output for 1200-meter altitude (8-μs delay) can be provided with a 110-dB insertion loss. By comparison, the conventional delay line shown simulates an altitude of less than 60 meters and has an insertion loss of 75 dB.

By relaxing some of the foregoing specifications (such as maximum input power level), substantial improvements can be obtained in bandwidth and insertion loss.

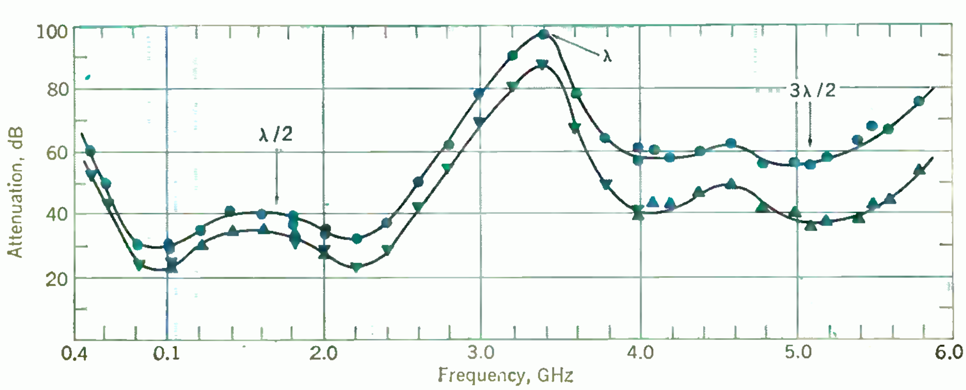


FIGURE 6. Conversion loss vs. frequency for a CdS transducer on sapphire. Circled points indicate insertion loss for delay line, while triangular points are two-way conversion loss of transducer obtained by subtracting acoustic loss in sapphire.

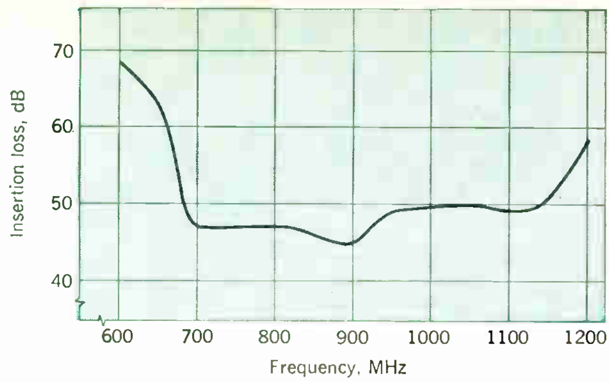


FIGURE 7. Total insertion loss of a 5-μs broadband delay line using CdS transducers on a ruby rod.

FIGURE 8. Structure of a reflection-type YIG delay line.

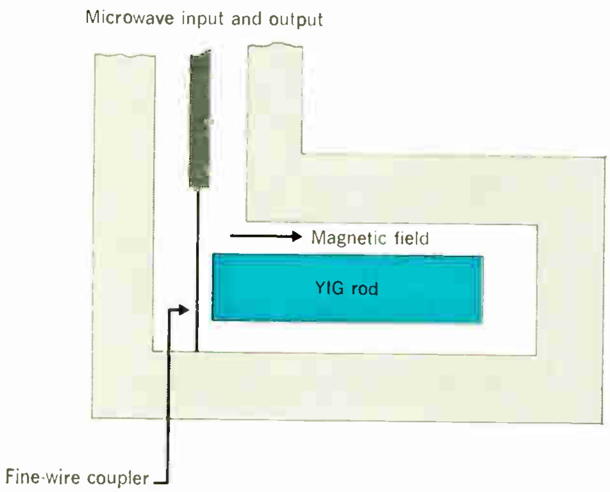
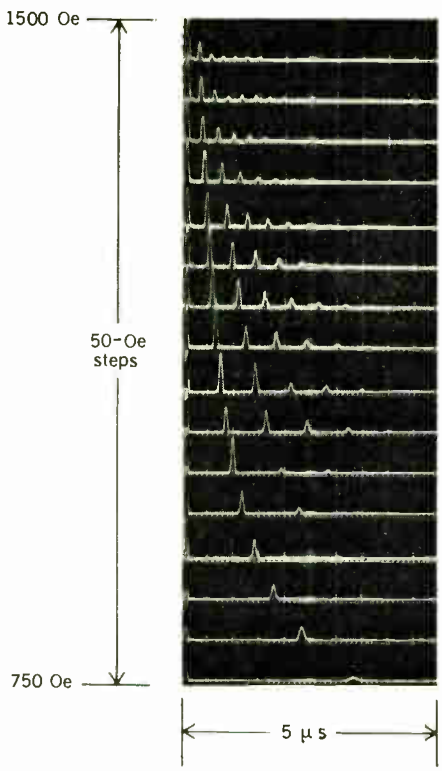


FIGURE 9. Field dependence of magnetoelastic waves in an axially magnetized YIG rod at 1150 MHz.



For example, acoustic delay lines can be constructed in the L band with 50 percent bandwidth and less than 50-dB insertion loss, as shown in Fig. 7. According to the data of Figs. 4 and 5, this performance can be improved further by the development of broadband coupling circuits that provide a better impedance match to the transducer.

Variable delay lines

Principle of operation. In magnetic materials the propagation of microwave energy can occur partly as a magnetic spin wave and partly as an acoustic wave. This is called a magnetoelastic wave. The specific form of the energy depends on the signal frequency and the applied field strength. The energy can be transformed between the magnetic and acoustic form as a function of position within the magnetic sample by shaping the sample so that the internal magnetic field is inhomogeneous. The propagation characteristics of these magnetoelastic waves are well known.[22] Another mode of propagation, termed magnetostatic waves, can also provide variable delay.[23]

Only single crystals of yttrium iron garnet have low enough magnetic loss to be useful. The YIG acts as its own transducer, because the RF magnetic field couples to the magnetization of the crystal.[24] Excitation takes place within the delay line at a specific location z_0, which is determined by the operating frequency and the magnetic field strength. In an axially magnetized rod the excitation point is given by the relation $H_i(z_0) = \omega/\gamma$, where $H_i(z)$ is the internal magnetic field in the YIG, ω is the signal frequency, and γ is the gyromagnetic ratio (2.8 MHz/Oe in YIG). The excitation travels as a spin wave into the region of weaker field. It transforms into acoustic form at the point z_c defined by

$$H_i(z_0) - H_i(z_c) = \frac{D\omega^2}{v_s^2}$$

where D is an exchange constant (5.2×10^{-9} Oe·cm² in YIG) and v_s is the speed of shear waves (3.8×10^5 cm/s in YIG). For propagation along the field, the acoustic waves are circularly polarized, rotating in the same sense as the precession of the magnetization about the magnetic field. The sound waves reflect from the polished end face of the rod, and detection takes place by a process inverse to that of excitation. The time delay depends primarily on the time spent in the spin-wave form, because the speed of the spin wave is much less than the speed of an acoustic wave. At a given frequency, the distance traveled in the spin-wave mode depends on the applied magnetic field strength; thus the delay can be varied electronically.

Construction and typical performance. The single-crystal YIG is usually fabricated in the form of a rod, approximately 3 mm in diameter and 10 mm long, with the end faces polished as in the acoustic delay lines. A typical delay-line structure is shown in Fig. 8. The magnetic field is axial, with a strength ranging from approximately 800 Oe in the L band to 2500 Oe in the C band. An auxiliary coil produces the variable delay. The RF coupling circuit is a fine wire loop at the end of the rod. The field dependence of a delayed magnetoelastic wave echo is shown in Fig. 9. These data show typical performance in the L band at room temperature. The input power was 1 mW, and the receiver gain was the same for each trace in order to show the attenuation of approximately 5 dB/μs at this frequency. The attenuation occurs principally in the spin-wave portion of the delay path and increases approximately proportionally to frequency.[22] In typical devices, the total insertion loss for short time delays ranges from 25 dB in the L band to 85 dB in the X band.

In the usual mode of operation of a YIG rod the variable delay line is a reflection device. Two-port operation, which is desired to suppress leakage of the undelayed pulse, can be achieved by using orthogonal coupling wires for the input and output at one end of the rod. A better method is to operate in a transmission mode by attaching acoustic quarter-wave plates of YAG to the ends of the YIG rod.[25,26] One plate converts the acoustic waves into the sense of circular polarization, which does not interact with the spin waves, so that the reflected energy travels to the far end of the rod. The second plate converts the energy back to the interacting circular polarization, which couples to the spin waves and is detected.

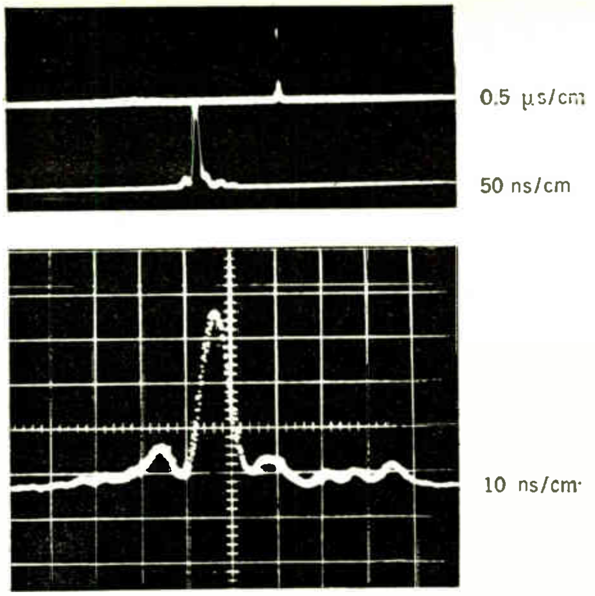


FIGURE 10. Compressed L-band signal with 150-MHz bandwidth using magnetoelastic waves in a reflection-type YIG pulse-compression filter.

Dispersive delay lines

Principle of operation. It is clear from the earlier description of the variable delay line that there is a parallelism between the roles of magnetic field and signal frequency. At a fixed value of applied field the time delay in a YIG rod is a function of frequency. In an axially magnetized rod the delay increases with increasing frequency. The behavior is very similar to the field dependence shown in Fig. 9. The dispersion can be exploited to construct pulse compression filters, which operate at a microwave frequency. These devices show great promise for providing radar performance with unprecedented bandwidth and range resolution. In a pulse compression filter for L-band operation, orthogonal coupling wires are used to reduce direct leakage. This device has operated with a bandwidth of more than 50 MHz and a compression ratio of 50 to 1.

Pulse compression with YIG lines. The delay dispersion in an axially magnetized YIG rod is nonlinear, ranging typically from 500 MHz/μs with a 1-μs delay to 50 MHz/μs with a 5-μs delay. To obtain pulse compression, the FM signal must match the delay dispersion. This matching has been accomplished by suitably shaping the voltage applied to a voltage-tuned oscillator.[27–29] For operation in a reflection mode, orthogonal fine wires are used at the end face of the YIG rod to provide input and output coupling with minimum direct leakage. A compressed pulse obtained at room temperature in the L band with this equipment is shown in Fig. 10; the uncompressed pulse can be observed in the top trace, approximately 2 μs before the compressed pulse. In this case, the compressed pulse is 11 dB below the uncompressed input pulse. The input leakage is 36 dB below the input pulse level and 25 dB below the compressed pulse. Careful adjustments of the wire positions can provide a ratio of compressed pulse to input leakage of 40 dB. The bottom trace in Fig. 10 shows a sampling oscilloscope display of the compressed pulse. As expected from the bandwidth of 150 MHz, the width of the pulse is 7 ns; the spacing of the side-lobe nulls and maxima is also consistent with this bandwidth. Other experiments have demonstrated filter bandwidths in excess of 250 MHz and compression ratios greater than 300 to 1.

It has recently been reported that YIG rods can be operated in the transmission mode, rather than in the usual reflection mode, by optical-contact bonding of quarter-wave plates to both ends of the rod.[25,26] The result of a pulse-compression experiment[30] using this assembly is shown in Fig. 11. The undelayed direct leakage at the output wire was 72 dB below the input pulse, and the insertion loss of the compressed pulse was 28 dB.

The upper limit on the bandwidth is established by the total variation of internal magnetic field in the delay medium. In the long cylindrical YIG rod, for example, magnetized along the rod axis, the field at the center of the rod is $H_0 - 2\pi M$. Thus the maximum variation of the turning point occurs over a range of field of $2\pi M$ or a frequency variation of $2\pi M$. In YIG ($4\pi M = 1750$ Oe at room temperature), this variation corresponds to 2400 MHz. For a cylindrical YIG delay line, the delay time varies by approximately 20 μs over the bandwidth and a time–bandwidth product of nearly 50 000 is physically realizable. The practical limit on pulse width is determined by the amplitude shaping employed to compensate for attenuation. The remaining problems to be solved reside in developing means for controlling the dispersion and matching the delay dispersion to the desired pulse width and bandwidth.

For many systems applications the desired delay characteristic is a linear dispersion, which can be achieved by proper shaping of the internal magnetic field in the delay line. By use of a general formulation for the dependence of time delay on the operating conditions,[31] the internal field variation that gives a linear dispersion can be determined; it turns out to be a relatively simple field distribution.[32] No experiments have been reported on the operation of microwave pulse-compression filters with the field synthesized to produce linear dispersion. The prescribed variation should not be difficult to achieve, however, and these devices offer substantial benefits in system performance.

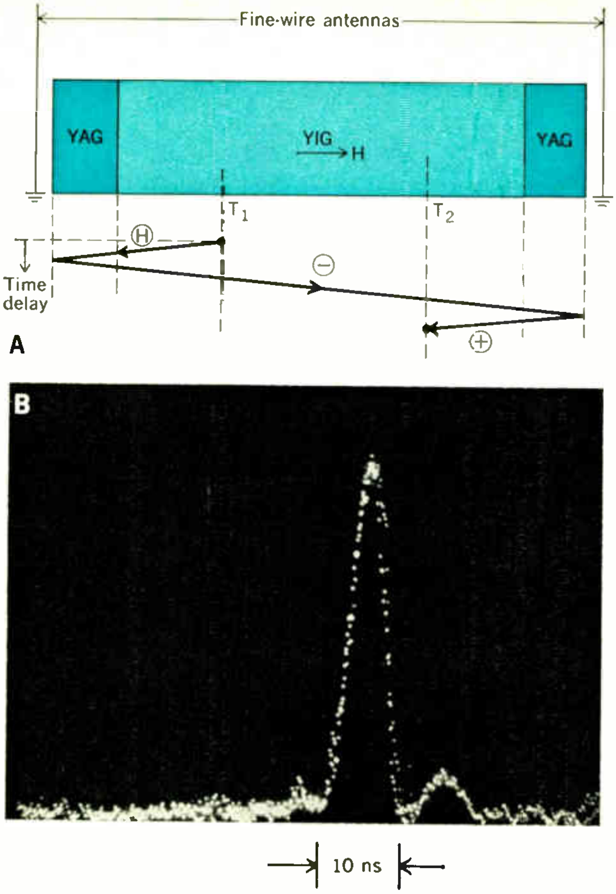


FIGURE 11. (A) YAG–YIG–YAG assembly and schematic representation of magnetoelastic wave propagation. (B) Compressed L-band signal with 150-MHz bandwidth and compression ratio of 150. Insertion loss is 28 dB.

Conclusions

Solid-state delay lines operating at microwave frequencies have many advantages over conventional delay lines. The acoustic lines provide a fixed delay. Improvements in transducer fabrication and in crystal growth techniques have permitted the development of devices that provide superior performance in a smaller, more reliable component. In devices in which the magnetic properties of YIG are utilized, the delay time can be varied continuously by changing the intensity or frequency of the applied magnetic field. Pulse-compression filters have already been constructed with bandwidths of several hundred MHz, and substantially improved performance is expected in the future.

The efforts of G. P. Rodrigue, B. R. Savage, R. W. Kedzie, A. B. Smith, and H. van de Vaart of the Sperry Rand Corporation are appreciated. The research was partially supported by the U.S. Army Electronics Command and by the U.S. Air Force Systems Command.

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IEEE Reports for 1966

W. K. MacAdam *President IEEE*

Introduction

It is my privilege and pleasure to present to the members the Annual Report of IEEE's operations, financial status, and membership statistics for the year 1966. It should serve as a condensed review of our Institute activity and I commend it to the attention of every Institute member. Last year was a year of accomplishment, and much of this progress was made under the wise and imaginative leadership of our Past President, Dr. W. G. Shepherd. Credit must also go to the Institute's other officers and the members of the Board of Directors and to the standing committees and organizational units. Most important, our performance is a reflection of the active participation and interest of our members and their support of our conferences and publications.

The year 1966 was of great significance. It was the year, for example, in which the decision was made to raise the Institute dues. This decision carried with it the obligation on the part of the officers and Board of Directors to make a complete reappraisal of our programs and long-term objectives in order to establish a firm foundation on which to build a balanced budget and a carefully selected program of new and expanded services. To this end we asked for the assistance and advice of all members and organizational units of the Institute. Only in this way could we make sure that our plans would be in line with the expressed needs of the majority of our members.

President Shepherd's article in the June 1966 issue of IEEE SPECTRUM described in great detail the circumstances underlying the Institute's requirement for added income and requested comments and suggestions from all sources. During the summer, reports and recommendations were received from Sections, Groups, and committees of the Institute, and from many hundreds of individual members who responded to President Shepherd's invitation to express their views. A few had frank misgivings as to the wisdom of the dues increase at that time; others recognized the need for the change and recommended preferences and priorities for new or expanded services. All of this discussion was helpful to the Executive Committee and the Board of Directors at their meeting in August to establish a program and budget for 1967. The details of that program were contained in President Shepherd's article in the October 1966 SPECTRUM, entitled "IEEE Launches Program for New and Expanded Services." His report was both comprehensive and illuminating and I urge any member interested in the activities and future of our Institute to study the report carefully. The article speaks for itself and I will not attempt to duplicate its contents in my present statement.

It was heartening to note that 1966 was a year of substantial growth. For the first time, Institute membership exceeded 160 000. Compared with the three previous years, there were more new memberships, more transfers to higher grade, and a substantially higher net membership gain—all in the year in which a dues increase had been announced. The Institute held a total of 97 conferences with attendance in excess of 197 000. Omitting the very large meetings (the International Convention, WESCON, NEREM, SWIEEECO, and NEC), the average attendance was 710 per conference, a creditable performance. In the field of publications, the Institute published more than 30 000 pages in 42 separate journals, ten times as many as were published by our two predecessor societies 21 years ago.

A major contribution to the long-term plans of the Institute was made last year in establishing improved procedures for cost analysis and financial management of our individual publications and services. Allocations were made of the major account classifications (salaries, floor space, general services, computer rental, etc.) to determine complete costs of specific activities. For the convenience of members, this was also estimated on the basis of "cost per member"—a useful procedure that we are planning to continue this year. One of the first applications appeared in President Shepherd's article in the October 1966 issue of SPECTRUM, in which the combined direct and indirect costs of various service categories were tabulated in this manner.

The use of full cost analysis was found to be of great value in analyzing the annual publications and conference expense budgets of individual Groups. It was in this area that, for many Groups, allocated support from Institute-funded Headquarters operations exceeded Group fee and net conference income. Having information available on complete costs made it possible for the Groups and the Technical Activities Board to establish a recommended support program for 1967, based on past performance and future need, and in conformity with the overall Institute plans and budget. This year the procedure will be further strengthened and should be of substantial assistance to the Groups in managing their finances. In addition, plans are under way to furnish Sections more complete information on financial support provided by staff services in addition to the normal Section rebates.

With the continued expansion of the Institute's publication program, two general problem areas have been requiring increased attention. In the first place, the immense quantity of published technical literature is placing an increased strain on the ability of engineers to search out and to read material of direct personal interest. We find ourselves printing and shipping great quantities of paper with the realization that, for the most part, any individual member studies only a small portion of the information received. Second, there has been a real question as to whether even an enlarged Institute budget can successfully cope with the cost of the expanding production of technical literature.

It was for these and similar reasons that the Institute last year allocated substantial funds for 1967 for preliminary planning of a modern, compatible information digesting, indexing, and retrieval system. Under this program it has been possible to add to the Institute staff, as Director of Information Services, effective July 1967, Prof. Howard E. Tompkins, an outstanding expert in the field and previously head of the Electrical Engineering Department at the University of Maryland. Under his guidance we should make substantial progress toward introducing increased selectivity into our operations.

As announced earlier to the membership (IEEE SPECTRUM, June 1965, p. 87), IEEE has before it a major question of the taxability of income derived from its Annual International Convention and Exhibition. The Board of Directors has authorized legal counsel to proceed to obtain a judicial determination of this alleged liability.

On April 14, 1967, the U.S. Internal Revenue Service announced the completion of a major study of the "unrelated business income tax" applicable to tax-exempt organizations and published proposed regulations reflecting the conclusions of the study. Principal areas of attention included the tax status of income derived from certain types of trade shows and from advertising published in exempt organizations' publications.

As we go to press, it is not clear what effect these proposals will have on the taxability of income derived from the Annual International Convention and Exhibition or from IEEE's publication activities, or on IEEE's financial policies and activities. These matters are currently being actively considered by Headquarters and legal counsel. The membership will be informed in the pages of IEEE SPECTRUM of further developments in these areas.

The reports of the Secretary, the Treasurer, and the Auditor, which follow, provide more details on the extent of our operations, our current financial position, and some indications as to current trends. I urge that all members interested in the viability of IEEE and in its future review this material and discuss it with others active in Institute affairs. In this way, the Institute can be made most effective in serving your needs and those of our other members.

Report of the Secretary—1966

Clarence H. Linder

To the Board of Directors
The Institute of Electrical and Electronics Engineers, Inc.

Gentlemen:

The Report of the Secretary for the year 1966 is presented herewith.

Membership has increased about 3.8 percent during the year. There was an increase in the number of Associates from 8 to 9 percent of the total. The number of Students dropped substantially owing to the automatic upgrading of Students to higher grade in the month of graduation. The transfers reported reflect this change. A 10 percent increase in Group members is noted for the second year in succession. Group Affiliate memberships increased from 510 to 719.

Attention is called to the 29 414 editorial pages published by the Institute during 1966, as against 29 187 in 1965.

Attendance at the 1966 International Convention was 63 650, up 9 percent over 1965.

The number of IEEE and jointly sponsored technical meetings went up to a total of 97, compared with 95 the previous year.

These data indicate a general growth trend with increased services to members and continued improvement in the effectiveness of the Headquarters management.

Respectfully submitted,
Clarence H. Linder
Secretary

Membership

Table I gives a three-year comparison of the distribution of the membership by grade and by percentage and Table II gives the geographical distribution of the membership.

Technical activities, Technical Activities Board, Groups, general committees

In 1966, IEEE supported a great variety of technical activities at all levels throughout the IEEE organizational structure. The activities with the greatest impact on the largest number of members are in the areas of publications and conferences. The accompanying tabulations of publication and conference activities, including Chapter meetings, clearly indicate that IEEE is adjusting its programs to meet the requirements of an expanding and growing electrical and electronic technology. Although IEEE is by far the largest of the engineering societies, it seeks to retain the alertness and flexibility so necessary to support our members' changing needs.

I. IEEE membership by grade, by percentage (three-year comparison)

Grade	December 31, 1964 Number	December 31, 1964 % of Total	December 31, 1965 Number	December 31, 1965 % of Total	December 31, 1966 Number	December 31, 1966 % of Total
Honorary (H)	8		6		5	
Fellow (F)	2 595	1	2 681	2	2 759	2
Senior Member (SM)	26 182	17	26 387	17	26 254	16
Member (M)	87 435	57	87 916	57	97 834	61
Associate (A)	13 682	9	12 949	8	14 114	9
Student (S)	24 076	16	24 259	16	19 104	12
Total	153 978	100	154 198	100	160 070	100

Publications. A new publication, the Journal of Solid-State Circuits, was inaugurated on a quarterly basis, with the first two issues appearing in September and December. A Solid-State Circuits Council was formed to serve as banker and publisher of the new Journal, on behalf of the Circuit Theory and Electron Devices Groups, which share financial responsibilities, and the Computer and Microwave Theory and Techniques Groups, with technical inputs; the Magnetics Group asked to join the latter technical participants as the new year approached.

Budgetary limitations applied a brake to the total number of Transactions and Journal pages published by the Groups. Nonetheless, the 1966 total of 16 826 pages represents a modest increase over the 1965 total of 15 127. Because of the IEEE deficit position, many of these 1966 pages were printed by the Groups without direct cash support from IEEE. A by-product of this situation has been a growing awareness throughout the Group system of the need for more refined and selective review and acceptance procedures.

A number of Groups have placed greater reliance on newsletters to disseminate information not of archival status. The rejuvenated *Computer News* was so warmly received that it had to be placed on a subscription basis to accommodate libraries and other nonmember requests.

The Publications Board joined with TAB in sponsoring a review of conference publication procedures. Such publications fill a need but are not a substitute for publications of important results in the Transactions and Journals. Because of this and other considerations, the joint study committee concluded that a digest format was preferred for conference publications.

The editors of all IEEE technical publications have been brought together by the Publications Board as a Panel of Editors. The panel will assist in the development and implementation of uniform editorial policies and procedures.

The Standards Committee approved 15 new or revised standards, which have been published. Work on the IEEE dictionary was started; Publication no. 270, "Proposed Standard Definitions of General (Fundamental and Derived) Electrical and Electronics Terms," provides the basic terms that will be used by the technical committees in developing special terms.

Meetings. A changing pattern of meeting activities was apparent in 1966. Attendance was generally strong, but except for a few special technical areas, exhibit interest had the weakness that was apparent in 1965. Factors external to and beyond the control of IEEE contribute to this situation. In addition, as the IEEE technical interests broaden, there is a tendency to inaugurate more special conferences and symposia. Because these meetings are sharply limited in technical content, any exhibits associated with them will not be on the same scale as the exhibits for a general interest meeting. Thus, the exhibits at any particular conference may be limited in number but the total of all such exhibits constitues an important part of the conference activity.

II. IEEE membership by region

	Total	Percentage
Region 1	39 871	25
Region 2	26 512	17
Region 3	14 436	9
Region 4	18 338	11
Region 5	13 422	8
Region 6	31 411	20
Region 7	7 382	5
Region 8	3 938	2
Region 9	1 416	1
Region 10	2 509	1½
U.S. overseas military	825	½
U.S. possessions	10	
Total	160 070	100

The entire IEEE meeting complex includes those meetings sponsored by Sections and Chapters, Regions, and Groups. A new support policy was evolved to encourage Sections to sponsor one-day symposia. Attention was also focused on the evening meetings, sponsored by Sections and Chapters. Attendance at such meetings varies widely and is part of the problem of determining the interests, needs, and desires of a significant fraction of the IEEE membership that apparently takes little part in IEEE activities.

Membership. IEEE Group membership statistics reflect both the expanding technical base of modern society and the varied socioeconomic factors that compete for the attention of the individual and influence his actions. Many organizations provide their employees with publications and conference attendance support, thus removing one of the incentives for professional society membership and the lower rates reserved for members. The dues increase is another factor against membership growth. On the other hand, for one active in a particular field, membership in IEEE and one or more Groups has distinct personal advantages. All these factors appear to be roughly balanced but somewhat favoring Group membership, and as 1966 closed, the total IEEE Group memberships of 127 000 showed a strong and healthy situation.

Organization. Several organizational changes were adopted in 1966. With the conversion to a consolidated billing on January 1 of each year, the significance of the July 1 date to Group administration and operations largely disappeared. Accordingly, it was voted by TAB to shift all Group administrative years to coincide with the IEEE administrative and fiscal year, which is the calendar year. This transition is to become effective on January 1, 1968.

As a consequence of action initiated in 1965, all of the active Technical Committees (Standards) were merged into appropriate Groups during 1966. The two TC(S)'s not involved in mergers will be terminated, unless detailed investigation reveals that failure to merge before the deadline was for some sufficient reason other than inactivity.

At the request of the IEEE Executive Committee, TAB OpCom drafted revisions for the bylaws pertaining to the General Committees. In the course of the preparatory work, a merger was made between the Basic Sciences Committee and the New Technical Activities Committee to form a single New Technical Scientific Activities Committee. The Executive Committee, in accepting this report, requested a review of all General Committee roles and missions and performances.

Jointly with the IEEE Sections Committee, TAB established an *ad hoc* committee to review and recommend steps to clarify and improve the Group/Chapter/Section relationship. The *ad hoc* committee very early concluded that the appropriate Group should be brought into the approval cycle on the establishment of a new Chapter. Other aspects of the relationship problem continue under study.

The biomedical field has received special attention from the IEEE Directors and TAB OpCom has joined in the effort to provide a better organizational arrangement. The affiliate plan has not been as successful as originally hoped, i.e., to bridge the interdisciplinary interests in the biomedical field. A few Groups in other fields appear to have gained from the affiliate plan, and an *ad hoc* committee has been established to review the plan and recommend how it might be improved.

Finances. As a part of a thorough examination of IEEE finances by the Directors, TAB focused on the two categories of support of technical activities: the funds managed by the Group; and the funds managed by IEEE, including both direct cash support of Group printing and the indirect (so-called invisible) support of Group and other technical activities. For the first time, detailed information for both categories of support was assembled and made available to the Directors and Group officers.

The detailed study of Group finances strongly suggested that a few Groups will have very serious problems unless sources of support in addition to Group fees may be found. The TAB supported a Publications Board recommendation that display advertisement in Group publications be considered under prescribed circumstances; TAB was sharply divided, and balanced, on the question of page charges. The need to publish more pages at less cost will receive further attention with the advent of new publication procedures.

Long-range Planning. In March 1966, TAB OpCom met for two days with especially invited representatives from other IEEE areas, to review the progress that had been made since 1963 in developing a unified IEEE technical activities program and supporting organization, and to outline steps that needed to be taken.

A direct consequence of the meeting was the establishment of five TAB Standing Committees, each represented by a subheading of the above report. The TAB Finance Committee did an outstanding job under unusual pressures of time and total budgetary planning limitations. The other committees initiated measures that will bear fruit in the next and succeeding years.

The Long Range Planning Committee set for itself the task of projecting the IEEE technical activities to a 1986 baseline. The committee recognized that long-range planning becomes pure fantasy if the known factors are exceeded by and masked by the unknown factors. Nonetheless, the committee did venture to suggest that solid-state and microelectronic developments would produce economic pressures for the acceptance of complex devices in applications now reserved for human perception and action. In particular, computers of varying degrees of simplicity will find their way into almost all forms of human activity; computer applications may become as commonplace as the electric motor is today.

The image of electrical and electronic engineering appears to be changing in a manner to erase the traditional areas and replace them with interdisciplinary domains, not clearly belonging within the purview of any present organization. The IEEE must meet this challenge, working with its sister societies in science and engineering, to insure the efficient and effective support that should be forthcoming from a great professional society.

The Joint Technical Advisory Committee (JTAC), sponsored by the IEEE and the EIA (Electronic Industries Association), held six regular meetings during 1966 and one special meeting at which the Director of Telecommunications Management, James D. O'Connell, reviewed the problems in the field of communication satellites.

Publication activities

The year 1966 was one of continued growth in editorial activity and further strengthening of the publications management structure of the Institute. It was a year that saw the addition of a new quarterly publication, approval of a Spanish-language publication, and a greatly increased emphasis on secondary publications and other information services.

The total 1966 editorial program, excluding translated journals and the Membership Directory, resulted in the publication of 2986 papers and 1315 correspondence items, making up a total of 29 414 editorial pages.

A change in the IEEE Constitution to make the Chairman of the Publications Board the IEEE Vice President for Publication Activities was approved by the voting membership in late 1965 and was implemented in January. Dr. F. Karl Willenbrock of Harvard University served throughout the year in this new office.

The Panel of Group Editors, which in 1965 was formalized as a standing committee of the Publications Board, was expanded in 1966 to include the Editors of IEEE SPECTRUM, the PROCEEDINGS OF THE IEEE, and the STUDENT JOURNAL, and its name was changed to the Panel of Technical Publications Editors. This expansion makes the panel a truly representative body for providing advice on and implementing overall editorial policies.

Approval was given for the establishment in 1967 of a

Spanish-language publication to serve the Latin American Region of the IEEE. The publication, to be called IEEE ELECTROLATINA, will be quarterly, carry advertising, and contain technical articles on subjects of interest to members in Latin America. It will be produced in Mexico City.

The Institute took a stronger stand on the use of metric units than it had heretofore. The March issue of SPECTRUM carried a Standard entitled "IEEE Recommended Practice for Units in Published Scientific and Technical Work," which states the official policy of the Institute as recommending the use of the International System of Units in all publications. The International System has been adopted for use in SPECTRUM, the PROCEEDINGS, and the STUDENT JOURNAL, and its use in Group publications has been strongly encouraged. As a matter of editorial style, the "hertz" was adopted as the unit for frequency in all IEEE publications.

Information services. This is the first time that "Information Services" has appeared as a separate subject in the Secretary's Report. The rapidly growing importance and long-term significance of this area of activity to the Institute is the reason for its recognition as a separate entity. The Institute will have to do more in the future to satisfy the information needs of its members than simply improve and expand its primary publications. Technical information is being published at such an increasing rate that the present methods of disseminating this information are becoming increasingly inadequate. In recognition of this fact, the Board of Directors at its August meeting passed a resolution establishing as a matter of policy that the Institute is concerned not just with primary publications, but with all of the technical information needs of its members, and should take the initiative in providing meaningful, modern supplementary information services to meet the needs of its members as it becomes possible to do so.

Upon the advice of the Information Processing Committee, several other actions were taken in 1966. Dr. Howard Tompkins of the University of Maryland was retained as IEEE Consultant in the information services area to assist Engineering Index with their electrical/electronics pilot project. This effort will entail working with IEEE editors and authors on the improvement of abstracting and indexing methods for IEEE publications.

Late in the year, an invitation was accepted from the British Institution of Electrical Engineers for IEEE to participate in the publication of *Science Abstracts* by naming members to its Editorial Advisory Committee. Part B of *Science Abstracts* is now entitled *Electrical and Electronics Abstracts*, and is the most comprehensive journal devoted to the bibliographic citation of our field.

In addition, the IEEE is cooperating with the American Institute of Physics in the development of indexing terms in the laser field and is exploring other avenues of joint effort with that organization. Finally, the Executive Committee authorized the acquisition of a full-time staff director for information services in 1967 and Dr. Tompkins will assume that post in July.

IEEE Spectrum. SPECTRUM completed its third year of publication in 1966 and is now firmly established as the core publication of the Institute. The most important development of the year was undoubtedly the strengthening of the management structure of SPECTRUM. In March the IEEE Board of Directors appointed C. Chapin Cutler of Bell Telephone Laboratories as its Editor; a distinguished Editorial Board was subsequently appointed to assist and advise Mr. Cutler. This step places SPECTRUM under the direct guidance of dedicated people who are broadly representative of the Institute's membership. All contributions for publication consideration are reviewed under the cognizance of Mr. Cutler and the Editorial Board.

A new department called "IEEE forum" was begun with the July issue. Members are encouraged to submit letters for publication in this department expressing their opinions on any phase of IEEE affairs. Letters in "IEEE forum" are often followed by comments by the Editor or other appropriate IEEE official so that a two-way communication channel is established giving information on important questions. Thirty-three letters were published during the six months of 1966 that "IEEE forum" was in existence.

A total of 98 articles were published in SPECTRUM during the year, as compared with 81 in 1965. Most of these were invited or contributed, but 13 were written by members of the editorial staff. Although the number of articles published increased, the average article length was decreased in an effort to make each article more useful to the busy engineer. In addition to the letters published in "IEEE forum," 38 technical letters were published in "Technical correspondence."

The total pages published in IEEE SPECTRUM in 1966 numbered 2190. Of these, 1371 were devoted to technical and editorial material, and 819 consisted of advertising and related matter.

Proceedings of the IEEE. The PROCEEDINGS was guided throughout 1966 by its appointed Editor and Editorial Board. One of the most important innovations instituted was a revised review procedure whereby the reviewers for each contributed paper are selected by a member of the Editorial Board who is particularly familiar with the subject area of the paper. This procedure was adopted to assure that papers are sent to the best reviewers available. With the active assistance of the Editorial Board, a program of publishing invited papers from leading specialists was launched. Three papers in this series were published during the year, and the groundwork was laid for a greater number to appear in 1967.

The PROCEEDINGS year was highlighted by the appearance of four special issues devoted to the subjects of frequency stability, the millimeter-wave region and beyond, optical electronics, and computers. Especially noteworthy was the optical electronics issue, which was a unique joint undertaking with *Applied Optics*, a publication of the Optical Society of America; the papers for this special issue appeared in both journals in October.

In 1966 the typesetting for the PROCEEDINGS was shifted from conventional "hot type" to a photographic technique; the first issue using photographic composition was September. In January the printing had been changed from letterpress to offset lithographic printing to make it possible to adopt this modern typesetting technique.

Two changes were instituted in response to the increasing use and importance of letters for quickly and briefly announcing new research results. First the letters section was changed to a more readable and attractive two-column format and was renamed "Proceedings Letters." Second, the review procedure was tightened so that all letters are subjected to speedy reviews. During the year

642 pages were devoted to the printing of 592 letters. As a comparison, 692 letters were published in 1965.

The year saw the appearance of a grand total of 2502 pages in the PROCEEDINGS OF THE IEEE, of which 2097 were editorial pages and 405 were pages containing advertising and other noneditorial material. The total number of papers published was 139, of which 99 appeared in special issues.

Group publications. As in previous years, the Group publications encompassed the major share of the IEEE publication output. A total of 152 issues, constituting 16 852 pages, were published. This represents an increase of nearly 10 percent over the 15 356 pages published in Group publications in 1965.

Since there were no Group mergers during 1966, the number of Transactions being published remained at 31. The quarterly IEEE JOURNAL OF SOLID STATE CIRCUITS was launched in September to fill a need for a publication outlet for papers in the general area of solid-state circuits. This, together with the previously established IEEE JOURNAL OF QUANTUM ELECTRONICS, brings the total number of Group publications to 33.

The IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, previously issued bimonthly, became a monthly publication effective with the January 1966 issue, thus increasing the number of Group publications issued monthly to four. During 1966 seven Group publications were issued bimonthly, 13 were issued quarterly, and nine appeared aperiodically.

During the year the printing schedules and editors' deadlines for all Group publications were reorganized with the result that there was a marked improvement in the mailing of issues on time.

IEEE Student Journal. The bimonthly student magazine of the IEEE served the student membership during 1966 by publishing 288 pages of technical material and other career information, including 34 signed articles. As is customary, an extra 20 000 copies of the September issue were sent to IEEE Counselors in colleges and technical institutes for distribution to potential Student Members.

Translated Journals. The Institute continued its program of translating and publishing papers from four Russian and two Japanese technical journals. This project is carried out with the support of the National Science Foundation. The year 1966 saw the appearance of 4648 pages translated from Russian and 3285 translated from Japanese. Advance tables of contents of issues to be translated were carried each month in SPECTRUM, as were signed critical reviews of selected papers that had been published in English.

Special publications and preprints. The papers presented at the 1966 International Convention, held in New York City in March, were published in a 12-part, 2368-page *Convention Record*, which was available at the Convention. In addition, five special Conference Records were published, comprising 137 papers and 1416 pages.

An IEEE Membership Directory, consisting of 832 pages, was issued early in 1966.

Finally, a total of 340 papers, amounting to 5022 pages, were individually preprinted by photo-offset means for four meetings.

Report of the Treasurer—1966

J. V. N. Granger

It is my privilege to present on the following pages the IEEE Financial Report for 1966, including the financial statements, as audited and certified by Price Waterhouse & Co. The net deficit of $212 568 was approximately $30 000 less than the deficit of the preceding year, and the results detailed in the report follow very closely the budgeted projections for the year, published when the dues increase was announced. Your Board of Directors has officially commended the Headquarters staff for the accuracy of its forecasts and for the manner in which expenses were controlled in accordance with the established budget.

I would request that all members read the report and compare it with the statements made by Past President Shepherd in the June (p. 42) and October (p. 59) issues of IEEE SPECTRUM. The 1966 Financial Report confirms beyond any doubt the conclusions reached by the Board of Directors as to the financial needs of the IEEE. I am happy to report that the renewal of membership at the increased dues rate, thus far reported in 1967, is on budget and may in fact exceed our expectations in future months. This fact assures the financial soundness of our operations. The other Directors join me in expressing thanks for this endorsement of their plans by the membership.

During 1966 a number of new procedures were instituted in our financial operations. These include programming the computer to produce a composite bill for dues, fees, and subscriptions payable at the option of the member in two equal installments; a new and thoroughly detailed method of reporting income and expenses of each Headquarters Department; a procedure for accepting reserve funds in Section treasuries (at the Section's option) in the Headquarters investment portfolio; and the preparation of specifications of a new computer system using random-access (disk-oriented) files. The new computer, when installed, will permit much faster and more flexible selections of Group and Section lists from the master file, and will permit many new services to be offered to the membership.

Conditions in the stock market affected all portfolios, and the Institute's was no exception. During 1966, the market value of the Institute's holdings of stocks and bonds decreased 8.7 percent. This record compares with 15.1 percent decrease in the Dow Jones average, and 13.2 percent in Standard and Poor's Index.

The possible impact of taxation is mentioned in President MacAdam's introduction. In all other respects, the financial outlook of the Institute is excellent.

Auditors' report

Price Waterhouse & Co.

60 Broad Street
New York 10004
March 8, 1967

To the Board of Directors of The Institute of Electrical and Electronics Engineers (Incorporated)

In our opinion, subject to the final determination of the Institute's income tax liability, if any, as referred to in Note 1, the accompanying statement of financial position, the related statement of income and operating fund, and the statement of changes in restricted funds present fairly the financial position of The Institute of Electrical and Electronics Engineers (Incorporated) at December 31, 1966 and the result of its operations for the year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year. Our examination of these statements was made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Price Waterhouse & Co.

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (INCORPORATED)

COMPARATIVE STATEMENT OF INCOME AND OPERATING FUND

	For the year ended December 31, 1966	1965*
Income:		
Membership, entrance fees and dues	$1,971,608	$1,902,669
Advertising	1,072,194	997,188
Periodicals subscriptions	745,289	721,618
Other publications and sales items	393,716	325,666
Convention and technical conferences	1,043,826	1,111,347
Investments, including gain on sale of securities	252,188	237,846
Miscellaneous other	211,309	187,590
Total income	5,690,130	5,483,924
Expenses:		
Headquarters services to members	829,184	815,776
Support of Sections and Branches	424,551	438,076
Support of Groups	846,725	848,714
Periodicals publication	1,677,025	1,571,943
Other publications and sales items	403,187	329,703
Convention and technical conferences	792,220	824,519
General administration	929,806	899,127
Total expenses	5,902,698	5,727,858
Excess of expenses over income for the year	(212,568)	(243,934)
Operating fund balance, January 1	2,817,465	3,061,399
Operating fund balance, December 31	$2,604,897	$2,817,465

* Certain amounts have been reclassified for comparative purposes.

COMPARATIVE STATEMENT OF FINANCIAL POSITION

	December 31	
Operating Fund	1966	1965
Current assets:		
Cash including $1,602,000 in certificates of deposits and a savings account (1965—$600,000)	$2,167,117	$1,066,575
Marketable securities, at cost, market value $4,261,000 (1965—$4,617,000) (Note 2)	3,731,323	3,467,152
Notes and accounts receivable, less doubtful accounts	297,423	338,429
Prepaid expenses, inventory, etc.	235,604	254,292
Total current assets	6,431,467	5,126,448
Less—Current liabilities:		
Accounts and accrued expenses payable	590,008	663,102
Funds held for the use of Professional Groups	895,916	530,887
Deposits by Sections (Note 2)	59,953	
	1,545,877	1,193,989
Deferred income:		
Dues	1,760,404	794,371
Subscriptions	397,066	255,489
Convention	637,125	663,766
	2,794,595	1,713,626
Total current liabilities	4,340,472	2,907,615
Working capital	2,090,995	2,218,833
Note receivable, 6%, installments due after 1967	65,710	116,656
Fixed assets:		
Office equipment and leasehold improvements, at cost, less accumulated depreciation and amortization $288,385 (1965—$221,661)	448,192	481,976
Operating fund balance (accompanying statement) (Note 1)	2,604,897	2,817,465
Property Fund		
Advance to United Engineering Trustees, Inc. (Note 3)	265,000	265,000
Restricted Funds		
Cash	82,140	74,257
Marketable securities, at cost, market value $133,321 (1965—$154,395)	98,206	98,231
Restricted funds balance (accompanying statement)	180,346	172,488
Total funds	$3,050,243	$3,254,953

STATEMENT OF CHANGES IN RESTRICTED FUNDS FOR THE YEAR ENDED DECEMBER 31, 1966

Restricted Fund	Fund balance January 1, 1966	Receipts from contributions and marketable securities	Disbursements for awards and related costs	Fund balance December 31, 1966
Life Member Fund	$ 75,251	$14,130	$ 5,704	$ 83,677
International Electrical Congress—St. Louis Library Fund	6,686	162	138	6,710
Edison Medal Fund	13,661	1,219	557	14,323
Edison Endowment Fund	8,521	267		8,788
Lamme Medal Fund	9,391	345	330	9,406
Mailloux Fund	1,038	42	43	1,037
Volta Memorial Fund	17,203	646	2,355	15,494
Kettering Award Fund	2,376	81		2,457
Browder J. Thompson Memorial Prize Award Fund	5,745	157		5,902
Harry Diamond Memorial Prize Award Fund	1,150	39		1,189
Vladimir K. Zworykin Television Award Fund	4,957	113	500	4,570
W. R. G. Baker Award Fund	9,378	457		9,835
William J. Morlock Award Fund	5,442	221		5,663
W. W. McDowell Award Fund	10,884	430	832	10,482
William D. George Memorial Fund	805	8		813
Total	$172,488	$18,317	$10,459	$180,346

NOTES TO FINANCIAL STATEMENTS

NOTE 1: In 1964 the Institute was notified by the Internal Revenue Service that the Institute's annual convention involved the operation by the Institute of an unrelated trade or business and that the net income therefrom, if any, is subject to federal tax. If the Service's position, which should be applicable to 1954 and subsequent years, were ultimately sustained, the amount of potential liability for taxes and interest would be material.

The Institute has filed both a tax return with respect to the test year 1954 and claims for refund in the amount of the taxes shown to be due thereon. Most of the claims for refund have been denied and the Institute presently intends to sue to recover the amounts in controversy.

NOTE 2: Marketable securities include $59,953 invested by certain IEEE Sections. Such funds with pro rata share of income and unrealized gains or losses can be withdrawn by the Sections concerned at the end of any fiscal year or quarter.

NOTE 3: In accordance with a Founder's agreement between the Institute and the United Engineering Trustees, Inc., the Institute has agreed to maintain permanently its principal offices in the United Engineering Center, which currently involves an annual lease payment of approximately $180,000. The $265,000 advanced to United Engineering Trustees, Inc., is repayable only out of available reserve funds on dissolution of United Engineering Trustees, Inc., and carries interest at an annual rate of 4 percent.

NOTE 4: The Institute has voluntary noncontributory pension plans covering its employees. No vested benefits accrue until retirement. The pension cost for the year for such plans was $68,874 which included amortization of past service cost over 20 years. Unfunded past service cost at December 31, 1966 is approximately $190,000.

An amendment to the present plan to provide for vested benefits for employees who are 40 or more years of age and with five or more years of service is awaiting qualification by the Internal Revenue Service.

IEEE publications

scanning the issues
advance abstracts
translated journals
special publications

Scanning the issues

Keeping Things Working. As long as men have made things, they have had the problems of keeping them repaired and working. With growing and ever more complex technology, the problems of keeping things working have also grown more complex, until today we have "maintenance concepts." A special issue of the IEEE TRANSACTIONS ON RELIABILITY on the subject of maintainability requirements and methods has just been assembled. It contains a set of five papers that cover the broad bases for maintainability control, description, and quantification, and a second set of five papers that cover specific applications. Leading off the papers is a short and worthy account of the evolution of maintenance concepts by Clair E. Cunningham.

Mr. Cunningham sketches the idea of maintenance from military rifles, through nuts and bolts, up to the Model A Ford. Who could not, he asks, fix it with just a few tools, baling wire, and very little training? Perhaps he is stretching a point about that (surely there have always been, God help us, some people who have been pretty awkward even with baling wire), but we surely must agree with him that the more recent decades of the 20th century have not been calculated to make life any easier for those people who like to keep things fixed, but who grew up in the baling wire era, and have never been able to forget it.

As Cunningham puts it, the acceleration of the use of electronics for warfare during the early 1940s created the need for a vast number of electronic technicians. But maintenance concepts had not changed appreciably from the 1930s (creating what, if President Kennedy were still with us, might be called a "maintenance gap").

Anyway, despite those bad times, man's ingenuity prevailed over the maintenance gap. For instance, Cunningham cites how the metal vacuum tube posed a problem since visual detection (i.e., looking to see if the filaments were burning red) was out. The problem was surmounted by running a hand over the tubes until a cold one was found. The really great advance, of course, was not in trying to fix the bum tube with baling wire, but in just chucking the tube out and putting in a brand-new one.

Moreover, in the 1950s a new maintenance concept appeared like a vision from heaven before maintenance men's eyes. This new concept, which was to change forevermore design and packaging concepts, was to remove and replace whole functional elements of an equipment. The equipments became modularized and test points were brought out at the module level so that localization of faults became somewhat easier. Then two things happened that are still the root of today's maintenance problems—one was transistors and subminiaturization and the other was digital circuits and computers. Complexity pyramided, but maintenance didn't. Once again, there was a maintenance gap, and if such things could be compared, it was almost as serious as the credibility gap suffered by the Johnson administration. Things got so bad in military maintenance that in 1956 a special Office of Maintenance Engineering (later called the Office of Engineering Management) was set up by the Pentagon. Result: by the 1960s, techniques of maintainability (M) measurement were developed and tested, and this is what the special issue is about.

As a coda to this scan, we must apologize to Mr. Cunningham for this slightly fractured history (his isn't) about how men keep things working. (*IEEE Trans. on Reliability*, May 1967.)

Superconducting Superpower. What amounts to a bold and quite fantastic scheme for the transmission of vast amounts of power over great distances by superconductors is put forward in an article in the recent issue of the PROCEEDINGS OF THE IEEE. The authors, R. L. Garwin and J. Matisoo, propose the design of a power transmission line that would carry 100 GW (10^{11} watts), which is equal to half the total present peak power generating capacity of the entire United States. This power would be in the form of direct current, to be transmitted over high-field, high-current superconductors over a distance of 1000 km. The authors state that their proposal is not an engineering study, but rather a preliminary exploration of feasibility. Nonetheless, their proposal provides design details on the transmission line, including an estimate of the investment costs that would be involved in its construction.

In developing their arguments for the transmission of such large blocks of power, the authors provide a concise interpretative history of what has been happening in the power industry that in itself should prove interesting to those who have had little contact (aside from the great blackout of November 1965) with events and developments in the power field. Garwin and Matisoo point out that before World War II, there was little incentive for the electric utilities to develop means of long-distance transmission of electric energy. In fact, the only high-voltage long lines in existence were those required to transport power from hydroelectric sources to population centers. Electric energy transmission over long distances was avoided mostly because of the high cost of transmission over lines, which in fact constituted a compromise between power loss in small conductors and the capital expense of building large-diameter lines. It was more economical to build generating stations near the major consumption centers, and to transport the energy to the generating stations in some other way—for example, as coal by barge or by railway. This procedure, the authors reason, was also consistent with the structure of the electric utility industry, which not long before had consisted of many comparatively small local companies, each serving its own area, and quite independent of one another.

However, the recent and projected growth of the utility industry has forced a re-examination of the economics of this past practice. Although the costs of coal transportation by rail have been declining, they are still substantial. Furthermore, the utilities have now become aware of the advantages of power pooling. By tying together formerly independent power systems, they can save in reserve capacity (particularly when the systems are in different regions of a large country), because peak loads, for example, occur at different times of day, or in different seasons. To take advantage of these possible economies, the authors argue, facilities must exist for the transmission of very large blocks of electric energy over long distances at reasonable cost.

Should it be possible to transmit large amounts of electric energy with negligible loss, fossil-fuel as well as nuclear plants could be placed so as to offer no hazard to urban areas, and the choice of location could be made entirely on economic considerations. In particular, the authors say, mine-mouth operation of steam plants would lead to large savings in coal transportation costs.

The line they propose, in contrast to one made of ordinary metal, would dissipate none of the power transmitted through it, although it would be necessary to tap power from the line itself for refrigeration. The consequences of this negligible transmission loss are substantial—power transmission would be economical, thermal and air pollution problems could be minimized because of the location of the plants, and novel power sources could be considered.

The power line would be made of Nb_3Sn and would be refrigerated to 4°K. The power is transmitted as dc rather than as ac, because the comparatively large ac losses would require excessive refrigeration capacity.

The design discussed is for a line at 200 kV carrying 0.5×10^6 amperes. The investment in the line would be approximately \$806 million, or \$8.06/kW. Of this, some \$6.06/kW is line cost, the remainder being converter cost, which, Garwin and Matisoo remind us, is the same for an ordinary dc line. In comparison with the shipping of coal, the investment cost would be repaid in ten months.

Garwin and Matisoo are careful to say that although the technical discussion is probably correct, the cost figures do not include engineering expenditures and do not consider in detail the costs involved in providing the redundancy and safety factors for, say, a failure rate of one per ten years with a time of a few seconds to restore power.

Provided satisfactory superconducting cable of the kind described by the authors can be developed, they conclude that the use of superconducting lines for power transmission appears feasible. Whether it is necessary or desirable, they point out, is another matter entirely. However it turns out, the proposal is a fascinating one. (R. L. Garwin and J. Matisoo, "Superconducting Lines for the Transmission of Large Amounts of Electrical Power Over Great Distances," *Proc. of the IEEE*, April 1967.)

Resonator Gate Transistor. An article describing in detail a novel approach to the problem of fabricating frequency-stable monolithic integrated circuits appears in a recent issue of the IEEE Transactions on Electron Devices. The authors describe how mechanically resonant structures are integrated directly on a semiconductor chip. They have demonstrated batch-fabricated transistors exhibiting high-Q tuning characteristics in the range 1–100 kHz, and have constructed both single- and multiresonant structures.

The new device, which is described as essentially an electrostatically excited tuning fork employing field-effect transistor readout, is called a resonant gate transistor (RGT). The device is quite small, the typical volume of its mechanical resonator being about 10^{-9} cubic inch. Even including the volume of the necessary silicon chip to contain the field-effect transistor detector, the device represents quite a considerable decrease in volume at a given frequency and Q over existing state-of-the-art means of achieving high-Q tuning. Since the fabrication process is basically compatible with silicon-based technology, the authors feel that it is possible that eventually not only size but substantial cost savings may be realized once optimum fabrication methods are developed.

The development is regarded as important in light of the classic problem that has hindered the entry of integrated circuits into many nondigital systems, namely, the lack of a compatible tuning element. This device promises to solve the tuning problem over the frequency range from about 0.5 kHz to 1 MHz. (H. C. Nathanson *et al.*, "The Resonator Gate Transistor," *IEEE Trans. o Electron Devices*, March 1967.)

A Disillusionment. An article tha reports on a disillusionment may be re garded as something of a "sleeper" i that it may often be more instructiv than reports of successes. A recent re port on a six-month evaluation of th potentialities of an existing compute aided instruction system in an engineer ing education environment is a case i point. Considering the interest in com puter-aided instruction nowadays, th authors' low-key conclusion that "th system showed small promise at th time" seems a bit understated.

The system studied by the authors wa IBM's Coursewriter, and it was con sidered strictly for the engineering clas room situation. Thus, the authors di not consider the broader questions c system research and development to ward future goals, or the value of com puter-aided instruction as an exper mental tool for research in education c learning, or the possibilities of usin computer terminals for classroom in formation retrieval or problem solving.

Computer-aided instruction aims t make use of a computer as a sophist cated teaching machine for the admini tration of programmed material. Th material is held in computer memo and presented in appropriate sequenc to the student. The sequencing may tak a branching path determined by student's performance if the autho provides the correspondingly structure course material, together with the nece sary branching criteria. In this sense, th system can adapt to the needs of the in dividual student. The computer als keeps track of, records, and possib analyzes information related to eac student's progress and performance.

The four main causes of the author disillusionment with the techniqu which they discuss in their article, are a follows: poor man/machine communica tion; inability of the system to interpr student answers; the immense effo required to prepare course material fo the system; and the high cost of hard ware and of program preparation.

The upshot of the authors' disillusion ment is that they have abandoned th computer-aided instruction approa and have been, in lieu thereof, develop ing and using programmed instructio in book format. (R. D. Strum and J. Ward, "Some Comments on Compute Assisted Instruction in Engineerin Education," *IEEE Trans. on Educatio* March 1967.)

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. 6
IEEE Transactions on	
Audio and Electroacoustics	Vol. AU-15, no. 2
Automatic Control	Vol. AC-12, no. 3
Broadcast and Television Receivers	Vol. BTR-13, no. 1
Circuit Theory	Vol. CT-14, no. 2
Communication Technology	Vol. COM-15, no. 3
Education	Vol. E-10, no. 2
Electronic Computers	Vol. EC-16, no. 3
Instrumentation and Measurement	Vol. IM-16, no. 2
Magnetics	Vol. MAG-3, no. 2
Microwave Theory and Techniques	Vol. MTT-15, no. 6
Parts, Materials and Packaging	Vol. PMP-3, no. 2
IEEE Journal of Quantum Electronics	Vol. QE-3, no. 6

Proceedings of the IEEE

Vol. 55, no. 6, June 1967

(Special Issue on Radio Measurement Methods and Standards)

Measurement Accuracy at Radio Frequencies, *A. V. Astin*—The interdependence of science and technology and measurement capability is especially significant in measurements at radio frequencies. The example cited of this symbiotic relationship involves microwave spectroscopy and quantum electronics. It is pointed out that accuracy of measurements at radio frequencies is highly critical in satellites and similar craft. Growing international cooperation in the exploitation of satellites for research and other peaceful uses has developed concern over compatibility of international radio-frequency measurements. Accordingly, the International Bureau of Weights and Measures in 1965 initiated a program to improve the techniques of measuring electrical quantities at radio frequencies.

The International Scientific Radio Union—URSI, *M. G. Morgan*—The history, purpose, and function of URSI, and the relationship of the United States National Committee of URSI to the IEEE, are described. A few examples demonstrating the interest of the Union in the field of this special issue are given.

The Functions of Commission I of the International Scientific Radio Union, *J. M. Richardson*—The distinctive task of Commission I of the International Scientific Radio Union (URSI) is to extend the ability of all radio scientists to make valid measurements as a necessary means for the international exchange of scientific and engineering results. The Commission concentrates on: improved measurement methods applicable either to new phenomena or to closer tolerances for familiar phenomena, the highest national and international levels of accuracy, and progress for the long term. The Commission functions by surveying both progress and deficiencies in radio measurements and standards, by evaluating new results for their lasting contribution to the measurement structure of radio, by recommending the general adoption of proved advances and the pursuit of further research to remove deficiencies, and by giving its recommendations force and effect through the efforts of its members. A sketch of the international and national URSI organizations and operations is given. The functions are performed mainly by organizing technical meetings devoted to measurement and instrumentation, by encouraging pertinent publications, and by committee interactions with other international organizations having related interests. The organization has exerted significant impact on time and frequency standards, on international uniformity of radio standards, and on precision coaxial connectors as an aid to more accurate radio techniques.

International Comparison of HF and Microwave Electromagnetic Quantities, *M. C. Selby*—Activities to establish international agreement on measurements of high-frequency electrical quantities have been in progress since 1957 at the initiative of URSI and the International Committee of Weights and Measures. Results accomplished and the overall up-to-date status are presented.

Worldwide Control of Industrial Radio-Electronic Measurement Accuracy, *C. E. White*—Economic expansion of industrial countries is dependent upon production and export of well-qualified and reliable products. National industrial controls, through a single unified measurement system, establish compatibility of an export-nation's products with an import-nation's requirements, as well as supplying internal national needs. A survey was conducted in 1966 to determine the extent to which certain selected nations have established legal measurement systems. For comparison purposes, the measurement system maintained in the United States is briefly outlined, and a presentation is made of the measurement capabilities of several industrial measurement laboratories taking part in an audit by the National Conference of Standards Laboratories in 1964–1966.

Radio-Frequency Standardization Activities, *F. D. Lewis, R. A. Soderman*—Adequate standards are essential to the practice of engineering. In no other field is this requirement more pressing than in the radio-frequency portion of the spectrum. The organizations involved and the processes followed in the generation, adaptation, and dissemination of Standards Documents concerned with RF measurements are described. A listing of organizations engaged in this activity, current Standards Documents, and work in progress is included.

Universities and RF Measurement, *M. A. Mason*—RF measurement offers an excellent opportunity to university students and practitioners to advance knowledge. Progress in the field requires better RF measurements, especially for improvement of systems.

A Systems Concept of Electromagnetic Measurements in the U.S.A., *G. E. Schafer*—A systems concept of the measurement activities in the United States is briefly reviewed. This concept is the one recently proposed (1966) by R. D. Huntoon and named by him the "National Measurement System." His description of the role of the Institute for Basic Standards and its parent organization, the National Bureau of Standards, as a functional element of the system is summarized. The Radio Standards Laboratory, an organizational unit of the Institute for Basic Standards, is described as a functional element in the system. Some benefits of considering the Radio Standards Laboratory as an element of the system are given.

The Role of the NBS Radio Standards Laboratory, *H. A. Altschuler*—Three major roles played by the NBS Radio Standards Laboratory in the field of electromagnetic measurements are described. The primary technical areas of the Laboratory are highlighted with specific examples of the work involved, and the various services that the Laboratory provides to the nation are mentioned. The dynamic character and wide range of research in radio metrology at a national standards laboratory are also described.

The Conference on Precision Electromagnetic Measurements, *H. A. Altschuler*—The character and scope of the biennial Conference on Precision Electromagnetic Measurements (CPEM) are described. Some of its history is recounted and its increasing international coverage is noted.

Quartz Frequency Standards, *E. A. Gerber, R. A. Sykes*—Progress made over the past few years in the field of quartz crystal frequency standards is reviewed. Several accomplishments thought to be of special importance are discussed in detail. These subjects include quartz vibrator enclosures, modes of motion including the "trapped-energy" concept, and studies of quartz material. It has been demonstrated that the Q of synthetic quartz can be improved to a value equivalent to natural quartz. Progress made in the field of long-term stability of precision crystal units is described and the various reasons for aging of such units is discussed. The characteristics of precision crystal oscillators are reviewed, including temperature compensation and the influences of severe environment. The properties of high-precision crystal frequency standards are described with specific emphasis on aging, and the problem of short-term stability of such standards is discussed. Precision crystal standards are available today with a daily drift rate as low as a few parts in 10^{11} and a short-time stability better than a

:w parts in 10^{10} for a period of one milli-
:cond.

. Historical Review of Atomic Frequency :tandards, *R. E. Beehler*—An attempt is nade to trace the historical development of ne leading contenders in the atomic frequency tandards field—cesium and thallium atomic eam devices, rubidium gas cell standard, and ne hydrogen maser. Many of the important xperiments leading to the development of echniques basic to the various types of tandards, such as the magnetic resonance nethod, optical pumping, buffer gases and vall coatings, and maser techniques are riefly described. Finally, the application of nese basic techniques to the development of ne specific types of atomic standards is iscussed.

'he Relative Merits of Atomic Frequency :tandards, *A. O. McCoubrey*—The relative nerits of atomic frequency standards based pon resonances in hydrogen, rubidium, or esium depend upon the particular application nd the specific requirement for each of several erformance factors combined with physical haracteristics. Although the properties of n ideal atomic frequency standard may be stablished, practical instruments depart from he ideal as the result of compromises in the pparatus design and construction. The esonance line sharpness is an important ictor that is dependent upon the apparatus; owever, others may have a greater influence pon the essential characteristics. These include istrumental offsets due to atomic collisions vith neighboring atoms or walls and magnetic elds. The intensity of the resonance signal is lso essential in the determination of merit. 'hese factors are discussed in relationship to ydrogen maser rubidium gas cell and cesium eam atomic frequency standards and the nerits of each are compared. The possible nerits of frequency standards based upon hallium beams are also discussed; however, a ick of extensive operating experience limits he knowledge in this case.

;ome Characteristics of Commonly Used Time ;cales, *G. E. Hudson*—Various examples of lealy defined time scales are given. Realiza-ions of these scales occur with the construction nd maintenance of various clocks, and in the roadcast dissemination of the scale informa-ion. Atomic and universal time scales dis-eminated via standard frequency and time ignal broadcasts are compared. There is a iscussion of some studies of the associated roblems suggested by the International Radio 'onsultative Committee.

'he Development of an International Atomic 'ime Scale, *J. A. Barnes*—The methods of enerating atomic time and the errors inherent 1 the resulting scales are reviewed briefly. An tomic clock consists of an atomic frequency tandard and an "integrator" to accumulate he phase of the signal. Because of noise per-urbing the instantaneous frequency, an en-emble of identical atomic clocks will show a istribution of (epoch) times that is unbounded s the system evolves in time. The recognition f this problem has important consequences in ational and international coordination of time cales and the construction of average atomic me scales. Also of significance is the not ompletely resolved question of weighting of ndividual standards in the construction of verage time scales. In spite of these difficulties is pointed out that through coordination and roper data handling, most of the advantages f astronomical time scales can be realized by tomic time scales. A statement of some of the roblems facing any attempts at coordination ; presented without any suggested solutions.

)istribution of Standard Frequency and Time ;ignals, *A. H. Morgan*—The present methods f distributing standard frequency and time signals (SFTS), which include the use of high-frequency, low-frequency, and very-low-frequency radio signals, portable clocks, satellites, and RF cables and lines, are reviewed. The range of accuracies attained with most of these systems is included along with an indication of the sources of error. Information is also included on the accuracy of signals generated by frequency dividers and multipliers. Details regarding the techniques, the propagation media, and the equipment used in the distribution systems described are not included. Also, the generation of the signals is not discussed.

Radio-Frequency Power Measurements, *A. Y. Rumfelt, L. B. Elwell*—The need for improved accuracy in and understanding of all kinds of measurements has come with the recent rapid advances in modern technology. Radio-frequency power measurement is no exception to this requirement. The basic principles of bolometric, calorimetric, and certain other types of power meters are reviewed. The methods for making accurate RF power measurements are discussed in detail. Emphasis is given to the techniques for eliminating or accounting for the errors due to mismatch, dc or LF substitution, and bolometer mount efficiency.

Measurement of RF Peak Pulse Power, *P. A. Hudson*—The principal methods developed during the past 20 years for the measurement of RF peak pulse power are surveyed. The basic principles involved for each method are described, together with accuracies attainable under normal operating conditions. General techniques for pulse power measurement and precautions to be observed are also given.

The Measurement of Baseband Pulse Rise Times of Less than 10^{-9} Second, *N. S. Nahman*—A review is presented of the measurement of fractional nanosecond pulse rise time in which the following subjects are discussed: oscillographic systems, pulse comparison techniques, a basic instrumentation system, and the distortion of pulses by transmission lines. Extensive references are provided. Included in the discussion is a delineation of equivalent-time oscillographic sampling systems and a classification into three sampling categories: sequential, random, and multiple. Also considered are single transient oscillographic systems employing either traveling-wave deflection-structure cathode-ray tubes or multiple sampling methods. In order clearly to present the rise-time limitations caused by TEM transmission lines, attention is given to the distortion incurred by pulses upon passing through such lines. Some suggestions and predictions relating to future work are presented.

Noise Standards, Measurements, and Receiver Noise Definitions, *C. K. S. Miller, W. C. Daywitt, M. G. Arthur*—Four sections are included: (1) basic principles of noise measurement, (2) the switching radiometer, (3) a survey of noise sources, and (4) concepts of noise factor and noise temperature. The first part presents basic formulas used in analyzing radiometers. The second discusses the switching radiometer, briefly tracing its development and usage in the standards field. The third surveys the development of hot and cold thermal noise sources, noise diodes, and gas-discharge noise generators. The last section presents the basic definitions of receiver noise performance.

Voltage Measurement at High and Microwave Frequencies in Coaxial Systems, *M. C. Selby*—The progress and up-to-date state of the art in measuring voltages at frequencies to 10 GHz and higher are briefly described. The trend toward higher frequencies in voltmeter design is indicated. Advantages of voltage measurements and standards over computation of voltages from power and impedance measurements are briefly discussed. Some pending development problems are indicated and major steps are proposed to improve the application of voltmeters at frequencies above 30 MHz.

Peak Pulse Voltage Measurement (Baseband Pulses), *A. R. Ondrdjka*—Several methods are presently being used for the measurement of pulse voltage. Oscilloscopes are particularly useful because they provide information concerning the shape of the pulse, besides a measure of the peak voltage. In addition to the oscilloscope, several peak voltmeter circuits are mentioned. These include pulse stretching, sampling, and the slideback method. A standard pulse generator is described that provides a calibrated pulse voltage suitable for voltmeter calibration and other uses.

The Measurement of Current at Radio Frequencies, *W. W. Scott, Jr., N. V. Frederick*—The state of the art of radio-frequency current measurement is reviewed with emphasis on the most useful standards. In particular, thermocouple and electrodynamic ammeters are discussed in detail. Reference is made to photo-ammeters, air thermometer milliammeters, and other types of current-measuring apparatus, some of which deserve additional development. Extensive referencing is included for the convenience of investigators interested in an intensive review of radio-frequency current measurements.

Definitions of v, i, Z, Y, a, b, Γ, and S, *D. M. Kerns*—Concepts and conditions underlying the establishment and use of immittance- and scattering-matrix descriptions of waveguide *n*-ports are discussed. TEM modes are considered and no restriction to high or microwave frequencies is implied. The discussion is intended to be critical and intensive rather than general. Needed results of electromagnetic (and waveguide) theory are assumed. Emphasis is placed on defining basic quantities needed in the matrix scheme. These include: generalized voltage and current, v and i, for waveguide modes; modal impedance; modal characteristic impedance; the immittance matrices, Z and Y; traveling-wave amplitudes, a and b; reflection coefficient, Γ; and the scattering matrix, S. Properties of Z, Y, and S are not discussed; applications are indicated but not discussed.

Lumped-Parameter Impedance Measurements, *L. E. Huntley, R. N. Jones*—A tutorial review is given in the specific area of lumped-parameter immittance measurement at radio frequencies. Included is a brief background discussion with particular emphasis upon the important recent developments of precision coaxial connectors and coaxial air dielectric transmission lines as immittance standards. Special emphasis is given to precision coaxial connectors and their necessity in achieving highest accuracies. Standards, techniques of measurement, and instruments are also discussed. The present state of the art is presented in graphical form wherein the accuracies attainable by best practices are compared with the best capabilities found in specifications for commercial instruments. The state-of-the-art presentation includes two-terminal as well as three-terminal measurements. Some recommendations are given for improving the state of the art in this measurement area.

Impedance Measurements in Coaxial Waveguide Systems, *R. L. Jesch, R. M. Jickling*—A tutorial review is presented of impedance measurements and standards in coaxial waveguide systems propagating a TEM wave. The development of coaxial air lines as impedance standards are described, representative measurement methods are reviewed, and the errors and measurement techniques of the slotted line are discussed in detail.

Standardization of Precision Coaxial Connectors, *B. O. Weinschel*—Previous work in precision coaxial connectors for air lines and improvement of coaxial cable connectors is reviewed. The current philosophies and resulting Standards of the United States of America Standards Institute's Subcommittee C83.2 and the IEEE Subcommittee on Precision Coaxial Connectors are discussed. Techniques for improved VSWR measurements needed in the development of precision coaxial connectors are described. Applications, development plans, and unresolved problems are mentioned.

Impedance Measurements and Standards for Uniconductor Waveguide, *R. W. Beatty*—A tutorial review is presented of the measurement of impedance and reflection coefficient in uniconductor waveguide. Normalized impedance in a waveguide operating in a particular mode is defined and related to measured quantities such as the reflection coefficient and the VSWR. Emphasis is given to the rectangular waveguide operating in its dominant mode and to the tuned reflectometer as an instrument for achieving the most accurate results. The evolution of the tuned reflectometer at NBS is outlined and recent techniques are discussed. Different types of standards of reflection coefficient are described.

RF Attenuation, *D. Russell, W. Larson*—A tutorial review of RF attenuation measurement methods and standards is presented. Accepted and proposed definitions and attenuator models are discussed. Commonly used standards operating from direct current through most waveguide bands are compared with the "ideal" interlaboratory standard. Characteristics of fixed resistive, waveguide-below-cutoff, and rotary-vane standards are included. Measurement methods are classified and described, including comments concerning convenience and accuracy of various methods, and references are given that cover most of the basic and important research in the field.

UHF and Microwave Phase Shift Measurements, *D. A. Ellerbruch*—A phase shift standard, a measurement system, and the techniques for determining the corresponding limit of uncertainty are all required for obtaining the phase shift characteristics of UHF and microwave components. Differential phase shift standards, measurement techniques, and measurement uncertainties are all discussed in a general sense and a comprehensive bibliography is included to supplement the general discussion.

NBS Field-Strength Standards and Measurements (30 Hz to 1000 MHz), *F. M. Greene*—A description is given of the various CW field-strength standards and associated measurement instrumentation and techniques developed during the past 25 to 30 years at the National Bureau of Standards. These are used for the calibration of both commercial and military field-strength meters in various frequency bands of the overall range from 30 Hz to 1000 MHz. The techniques used are applicable only for evaluating the strength of steady-state, ac fields varying sinusoidally in time, and are not intended for use in broadband applications of any kind. Two principal types of field-strength standards and a prototype near-zone field-strength meter are described: (1) Magnetic-Field-Strength Standards (30 Hz to 30 MHz) for the calibration of CW field-strength meters employing small-loop receiving antennas; (2) Electric-Field-Strength Standards (30 to 1000 MHz) for the calibration of CW field-strength meters employing half-wavelength self-resonant dipole receiving antennas; and (3) Near-Zone Electric-Field-Strength Meter and Interim Field-Strength Standards (150 kHz to 30 MHz) for the evaluation of hazards of high-level electromagnetic radiation to ordnance devices and other uses.

Field Strength Above 1 GHz: Measurement Procedures for Standard Antennas, *R. R. Bowman*—To calibrate antennas for state-of-the-art field-strength measurements above 1 GHz, standard antennas are needed that have gain values known to within ±0.1 dB. Since this requirement exceeds the verified accuracy of calculated gain values, these standards must be established by making absolute gain measurements. The discussion primarily concerns absolute gain measurements for horn antennas by the two-antenna method. However, much of the discussion is pertinent to high-accuracy field-strength measurements in general. The two-antenna method is considered to be essentially an insertion-loss measurement (with many additional problems and sources of error), and this concept is used to derive a working formula that is suitable for high-accuracy gain measurements. The two problems that are most intractable—insufficient antenna separation and multipath interference—are discussed in detail. Some important experimental details are included that previously have been overlooked or inadequately discussed, and it is concluded that previous error estimates of less than ±0.1 dB for horn-gain measurements have been somewhat optimistic. To facilitate the design and evaluation of high-accuracy gain measurements, some simple terms, concepts, and formulas are provided that are useful in analyzing multipath interference.

Swept-Frequency Techniques, *P. C. Ely, Jr.*—Swept measurement techniques are developing rapidly and have demonstrated their crucial importance in advancing the microwave state of the art. The key components of swept measurement systems are discussed and the development of reflection coefficient measurements on a swept basis is examined in detail. Reflectometer and slotted-line accuracies are analyzed using signal flow graphs. The results are compared to illustrate that, in the typical laboratory, swept-frequency measurements offer accuracy equivalent to the slower, more tedious, fixed-frequency systems. A significant step forward has been the development of instrumentation completely to characterize high-frequency networks by means of the complex scattering matrix. The new techniques for sweep-measuring the amplitude and phase of microwave parameters are explained and the *s*-parameter design procedures that have evolved are referenced.

Measurements in the Millimeter to Micron Range, *R. G. Fellers*—Measurement techniques and measuring instruments in the millimeter and submillimeter wavelength range are described. Included are discussions of devices in dominant (TE_{10})-mode rectangular waveguide such as a bolometer, which possesses an efficiency of 95 percent, a gas absorption wattmeter with an accuracy of 5 percent and a sensitivity of 10^{-6} watt, and isolators and variable attenuators. Components in circular TE_{01}-mode waveguide are described, including a standing-wave indicator with a residual VSWR of 1.02 and an adjustable attenuator with 30 dB of attenuation and a VSWR of 1.08. Devices for use in free space include a pair of dielectric prisms for use as an adjustable directional coupler, a hybrid junction, and an adjustable attenuator. Attenuation is readily adjustable from 0 to 30 dB with directivity in excess of 15 dB. Also described are dielectric slab filters and calorimetric power meters with accuracies of 0.5 percent in the power range 1–50 mW. Interferometers for use as wavemeters with accuracy as good as 0.04 percent and for use as cavities with Q as high as 10^6 are described. They can be used in the measurement of dielectric constant with accuracies of 2 percent. Measurements of the characteristics, attenuation, field distribution, and loss per iteration of beam waveguides and reflecting beam guides have been made that yield good confirmation of theoretical predictions. Measurements of focal length, aberrations, and other characteristics of gas lenses for use in free-space waveguides are described. Measurements are carried out using the lateral shear interferometer and the Mach–Zehnder interferometer.

Frequency Stabilization of Gas Lasers, *G. Birnbaum*—Methods of frequency and wavelength stabilization of gas lasers are reviewed, with emphasis on principles of operation and results of stability measurements rather than experimental details or apparatus design. Most of the stabilization work has been done with the He-Ne laser. The best long-term stability is about 1 part in 10^9. Various absolute wavelength measurements of stabilized He-Ne lasers by interferometric comparison with standard lamps give agreement to about two parts in 10^7. Wavelength shifts due to variations of gas pressure and gain are important factors in limiting the absolute wavelength stability of gas lasers. Optical standards of length and their use in length measurements are considered.

Measurement of Laser Energy and Power, *G. Birnbaum, M. Birnbaum*—Measurements of laser energy and power are discussed with emphasis on those methods that attempt to establish the accuracy or standards for such measurements. Methods to attenuate laser radiation are summarized. The principles and limitations of the methods are stressed rather than design details of the apparatus. It is found that standards for the measurement of laser power and energy are yet to be definitely established. Thus caution should be exercised in accepting stated accuracies for laser output measurements.

RF Measurements of the Speed of Light, *R. C. Baird*—Modern RF measurements of the speed of light are reviewed, with emphasis on those methods capable of attaining an accuracy of 1.0 km/s or better. The geodimeter and microwave interferometer methods are discussed in some detail because of the significant role they have played in arriving at our present value for *c*. Serious limitations of the microwave resonant cavity method are pointed out and brief mention is made of the electrical units and band spectrum methods. A recent measurement by Karolus and Helmberger, who obtained the value 299 792.1 ± 0.2 km/s, is mentioned. Some experimental factors that should be considered in planning future speed-of-light measurements are presented, and an experiment involving lasers, now in progress at the Joint Institute of Laboratory Astrophysics, is described briefly. The conclusion is that the presently accepted value of 299 792.5 ± 0.3 km/s is still valid. Only two or three measurements have been completed since its adoption nearly ten years ago and they are not of sufficient accuracy to warrant a re-evaluation of *c*.

Laser Measurements of Long Distances, *P. L. Bender*—The extension of radio-frequency techniques to the optical region of the spectrum has made possible many types of measurements not feasible before. One area in which important scientific contributions can be expected during the next few years is the use of lasers to measure long distances with high accuracy. Three types of distance measurements that have been discussed in the literature and that are now being investigated actively are: (1) interferometric measurements over distances of up to hundreds of meters through evacuated or sealed-off tubes, (2) measurements with modulated laser beams over distances of perhaps 1 to 50 km with corrections made for the atmospheric index of refraction along the path, and (3) range measurements to artificial satellites and to the moon using laser radar. Some of the possible geophysical and geodetic applications of such measurements are also discussed.

Measurement of RF Properties of Materials, A Survey, *H. E. Bussey*—Methods for radio and microwave measurements of dielectric and magnetic properties of materials are discussed and referenced. The reference period extends to mid-1966. Measurement errors are analyzed where appropriate.

Electromagnetic Compatibility Measurements, *R. M. Showers, O. M. Salati*—Standards extending the frequency range of both instrumentation and techniques up to 100 MHz are being developed. Along with the spectrum signature concept, the use of automated instrumentation is becoming increasingly important. Techniques for measurement of harmonic power in a waveguide, near fields of antennas, line current, the Poynting vector, and device radiation at frequencies above 50 MHz are discussed.

Accuracy Charts for RF Measurements, *W. A. Wildhack, H. L. Mason, R. S. Powers, Jr.*—The general factors involved in the estimation of uncertainties in calibration or measurement are reviewed briefly. Twenty-five accuracy charts are presented showing the estimated uncertainties in National Bureau of Standards calibrations of laboratory standards or measuring instruments for electrical and radio-frequency quantities.

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 June issue of PROCEEDINGS. The list will appear in the next issue of SPECTRUM. Listed below are the letters from vol. 55, no. 5, May 1967.

Electromagnetics and Plasmas

A Useful Matrix Inversion Formula and Its Applications, *H. C. Chen, D. K. Cheng*
Generation of Submillimeter Radiation by a Racetrack Microtron Beam in a Fabry-Perot Resonator, *E. Brannen, V. Sells, H. R. Froelich*
On "Conjugate Solutions of Laplace's Equations," *G. Eichmann, D. T. Paris*
Coupled Wave Equations for Propagation in Generally Inhomogeneous Compressible Magnetoplasmas, *R. Burman*
Energy-Transport Velocity Under Lorentz Transformation, *I. Sugai*
On Waveguides and Cavities Containing a Hot Gyrotropic Plasma, *F. E. Gardiol*

Circuit and System Theory

Comments on Time-to-Frequency and Frequency-to-Time Domain Matrix Formulations, *D. C. Fielder*
Effects of Parameter Quantization on the Poles of a Digital Filter, *C. M. Radar, B. Gold*
Evaluating the Transient Response of a Network Function, *R. I. Ross*
An Optimum Bandlimited System with Monotonic Step Response, *W. A. Michael, P. A. Szego, G. C. Temes, H. J. Orchard*
The Relationship Between Impedance Matching and Gain Sensitivity to the Active Component Variations in a Low-Pass Negative-Resistance Amplifier, *G. Martinelli, A. Roveri*
Nullator-Norator Equivalent Networks for Controlled Sources, *A. C. Davies*
Normalized Equations for Two-Mode Feedback Oscillators, *T. Saito, T. Takagi, K. Mano*

Electronic Circuits and Design

Injection Locking of Pulsed Avalanche Diode Oscillators, *M. I. Grace*
Experimental Results of a Frequency Doubler Using a Varactor Array, *D. Parker, A. I. Grayzel*
Active Directional Couplers, *B. Pellegrini*

Electronic Devices

MOS Transistors with Anodically Formed Metal Oxides as Gate Insulators, *W. Witt, F. Huber, P. Delivorias*
GaAs Avalanche Microwave Oscillator with 1-Watt Power Output, *S. G. Liu*
Control of the Surface Potential of Evaporated CdS Layers, *R. R. Haering, J. F. O'Hanlon*
New Microwave Emission Effect in Indium Antimonide, *A. N. Kohn*
All-Garnet-Substrate Microstrip Circulators, *B. Hershenov*
Current-Dependent Modes in Pulsed Avalanche Diodes, *F. K. Manasse, J. S. Shapiro*
Frequency Changes in Reflex Klystrons During Square-Wave Amplitude Modulation, *C. Weil-Malherbe*
Controlled Bulk Semiconductor Current Pulse Generator, *M. Shoji*
The Tolerance Spread of the Transistor-Base-Emitter Voltage and Its Temperature Coefficient, *M. Milkovic*
High-Power Operation of CdS Thin-Film Transducers, *W. A. Crofut*
Comment on "A New Negative-Resistance Device," *H. Mac Juneau*
Linear Millimeter-Wave Amplification with GaAs Wafers, *H. W. Thim, H. H. Lehner*
Bulk Semiconductor High-Speed Current Waveform Generator, *M. Shoji*
The Resonant Iris as a Diode Mount—Broad-band Multidiode p-i-n Modulator, *I. El-Hefni, G. M. Blair*
Electron Beam Recording in SiO_2 with Direct Readout Using the Electron-Beam-Induced Current at a p-n Junction, *C. J. Varker, E. M. Juleff*
Conditions for Space-Charge-Wave Growth and Differential Negative Resistance in "Two-Valley" Semiconductors, *A. Sasaki, T. Takagi*
Spatial Distribution of Excess Carriers in Electron-Beam-Excited Semiconductors, *D. F. Kyser, D. B. Wittry*

Optics and Quantum Electronics

Effects of Magnetic Field on Pulse and CW Operation of the Large-Bore Ionized Gas Laser, *S. A. Ahmed, T. J. Faith, G. W. Hoffman*
Thermal Effects Observed in Ultrasonic Diffraction Experiments with Rutile Crystals, *J. K. Parks, C. S. Tsai*
An Infrared Detector Utilizing Internal Photoemission, *D. W. Peters*
Photoelastic Properties of YAG, *V. R. Johnson, F. A. Olson*
Silicon and Chlorine Laser Oscillations in $SiCl_4$, *W. C. Carr, R. W. Grow*

Communication Theory

Automatic Channel Equalization Algorithm, *C. W. Niessen*
On Detection of Sparsely Sampled Data, *T. Berger, E. Brookner*

Computers

UHF Subharmonic Parametric Oscillator, *T. Williams, R. H. Mitchell, W. D. Ryan*

Communication Technology

The Transfer Characteristic of a Linear Phase Detector when Its Input Signal-Noise Ratio Is Small, *E. H. Sheftelman*

Miscellaneous

Variable Magnetoelastic Delay to 50 μs at L-Band and Room Temperature, *R. C. Addison, J. H. Collins, H. R. Zapp*
Comparator for Calibration of Inductive Voltage Dividers, *S. H. Tsao*
Waveform Stretching Using Time-Varying Memories: A Sample Approach, *D. H. Cooper*

IEEE Transactions on Audio and Electroacoustics

Vol. AU-15, no. 2, June 1967

(Special Issue on the Fast Fourier Transform)

What is the Fast Fourier Transform? *G-AE Subcommittee on Measurement Concepts*—The fast Fourier transform is a computational tool that facilitates signal analysis such as power spectrum analysis and filter simulation by means of digital computers. It is a method for efficiently computing the discrete Fourier transform of a series of data samples (referred to as a time series). The discrete Fourier transform of a time series is defined, some of its properties are discussed, the associated fast method (fast Fourier transform) for computing this transform is derived, and some of the computational aspects of the method are presented. Examples are included to demonstrate the concepts involved.

Modern Techniques of Power Spectrum Estimation, *C. Bingham, M. D. Godfrey, J. W. Tukey*—The effect of the fast Fourier transform on complex Fourier analysis is discussed in detail. It is shown that the computationally fastest way to calculate mean lagged products is to begin by calculating all Fourier coefficients with a fast Fourier transform and then to fast-Fourier-retransform a sequence made up of $a_k^2 + b_k^2$ (where $a_k + ib_k$ are the complex Fourier coefficients). Also discussed are raw and modified Fourier periodograms, bandwidth versus stability aspects, and aims and computational approaches to complex demodulation. Appendixes include a glossary, a review of complex demodulation without fast Fourier transform, and a short explanation of the fast Fourier transform.

Spectrum Analysis in Speech Coding, *J. L. Flanagan*—In the process of hearing, the human ear develops a short-time spectrum of its acoustic input, obviously retaining information-carrying features of the signal. It is shown that an understanding of the process by which the human auditory system preserves perceptually significant features is valuable in developing speech-transmission techniques. An example of effort in this direction is the phase vocoder.

The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short, Modified Periodograms, *P. D. Welch*—The use of the fast Fourier transform in power spectrum analysis is described. Principal advantages of this method are a reduction in the number of computations and in required core storage, and convenient application in nonstationarity tests. The method involves sectioning the record and averaging modified periodograms of the sections.

Historical Notes on the Fast Fourier Transform, *J. W. Cooley, P. A. W. Lewis, P. D. Welch*—The fast Fourier transform algorithm has a long and interesting history that has only recently been appreciated. The contributions of many investigators are described and placed in historical perspective.

Application of the Fast Fourier Transform to Computation of Fourier Integrals, Fourier Series, and Convolution Integrals, *J. W. Cooley, P. A. W. Lewis, P. D. Welch*—The fast Fourier transform is a computational procedure for calculating the finite Fourier transform of a time series. The properties of the finite Fourier transform are related to commonly used integral transforms, including the Fourier transform and convolution integrals. The relationship between the finite Fourier transform and Fourier series is also discussed.

Fast Fourier Transform Method of Computing Difference Equations and Simulating Filters, *H. D. Helms*—Two methods for using the fast Fourier transform to reduce the number of arithmetic operations and, therefore, the time required for computing discrete, preformulated, and finite convolutions are listed and justified. Under the idealistic assumption that the impulse response of a preformulated difference equation terminates, a theorem is

roved that these two methods can be modi-ed to compute such difference equations. his theorem makes plausible the application f these methods when the impulse response oes not terminate, provided that the impulse esponse decays to a small value. In such ases, the fast Fourier transform can be used compute approximations to the solutions, though usually this use offers no reduction the amount of time required for computing he definition of the difference equation. How-ver, if a filtering operation is specified as a equency response, the fast Fourier transform an be used to compute the filtering operation irectly without need of formulating a differ-nce equation, although this simplification is chieved at the cost of a moderate increase .g., twice) in the amount of computation me.

Method for Computing the Fast Fourier ransform with Auxiliary Memory and imited High-Speed Storage, ***R. C. Singleton***—method is given for computing the fast ourier transform of arbitrarily large size sing auxiliary memory files, such as magnetic pe or disk, for data storage. Four data files re used, two in and two out. A multivariate omplex Fourier transform of $n = 2^m$ data oints is computed in m passes of the data, nd the transformed result is permuted to ormal order by $m - 1$ additional passes. Vith buffered input-output, computing can e overlapped with reading and writing of ata. Computing time is proportional to $n \log_2$ The method can be used with as few as three es, but file passing for permutation is re-uced by using six or eight files. With eight es, the optimum number for a radix 2 trans-orm, the transform is computed in m passes ithout need for additional permutation asses. An Algol procedure for computing he complex Fourier transform with four, six, r eight files is listed, and timing and accuracy est results are given. This procedure allows n arbitrary number of variables, each dimen-on a power of 2.

igital Determination of Third-Octave and ull-Octave Spectra of Acoustical Noise, ***. C. Maling, Jr., W. T. Morrey, W. W. ang***—The spectrum of the acoustical noise roduced by typical sources such as business achines is usually measured with analog filter anks. The objective of this study was to per-orm spectral analysis using digital rather than nalog methods. The Cooley-Tukey algorithm as been used to compute the Fourier coeffi-ents of noise samples obtained with the aid of digital recording system. The resulting oefficients have been used to compute octave and and third-octave band spectra of the oise samples. The digital spectral estimates re in good agreement with analog measure-ents. Emphasis is placed on the filter char-cteristic or "window" used for the analysis, nd the spectral fluctuations that occur in hort (65-250-ms) samples of the noise. For ne machine studied, the spectral fluctuations re larger than would be expected for samples f random noise. Spectral analysis of impulsive oise produced by a second machine (a anual, key-entry card punch) indicates that pectral fluctuations occur even when the nvelope of the pressure-time pattern is ob-erved to be repetitive.

pectral Analysis of the Call of the Male Killer Vhale, ***R. C. Singleton, T. C. Poulter***—Poulter reviously presented sonagram analyses of nderwater sound recordings of various sea ammals, calling attention to the apparent armonic progression of components of these gnals. Other workers have questioned the resence of these harmonics in the original ata and have suggested that they may instead e introduced during the analysis. Underwater ound recordings of the male killer whale Namu were taken with equipment flat within ±2 dB to beyond 18 432 Hz, the upper limit of the analysis, to show by means of digital spectral analysis methods that a harmonic progression exists. In the signals analyzed, peaks on the estimated spectrum were observed at each integer multiple of the fundamental frequency. In view of the broad frequency response to the recording equipment and the precision of the subsequent digital analysis, it can be said that these harmonics were actually present in the whale's call. For the analysis, portions of an audio recording were converted to digital form. In the conversion, a bandpass filter was used to attenuate power below 40 Hz and above 10 kHz. Digital analysis techniques similar to those proposed by Bingham, Godfrey, and Tukey were then used. For each time span of data to be analyzed, a windowed Fourier transform was first computed, using a fast Fourier transform program. The power spectrum was next computed, as the squared modulus of the windowed transform, and a correction was made for the attenuation of high frequencies during analog to digital conversion. The autocorrelation function was estimated by computing the inverse transform of the power spectrum. A moderate amount of digital smoothing was then applied to the spectrum to reduce irregularities due to noise. The resulting smoothed spectrum is used as an estimate of the power spectral density function.

Correspondence

Informal Comments on the Uses of Power Spectrum Analysis, *B. P. Bogert, E. Parzen*

IEEE Transactions on Automatic Control

Vol. AC-12, no. 3, June 1967

Optimal Attitude Control of a Spinning Space Body—A Graphical Approach, ***G. Porcelli, A. Connolly***—A simplified mathematical model of a rigid, long space body, spinning at constant rate about an axis of symmetry, is presented. From a heuristic analysis of the vehicle trajectories in the pitch-yaw plane, obtained by application of impulsive control effort, the minimum-fuel two-impulse control law for the case of unlimited thrust is readily deduced. This yields the absolute lower bound on fuel consumption. For the case of limited thrust, based on the minimum fuel two-impuse control scheme, two suboptimal control laws are determined and illustrated with examples. An approximate graphical construction of the trajectories in the pitch-yaw plane is given, from which the total fuel spent and the total time for control can be evaluated.

Minimum-Energy Control of a Second-Order Nonlinear System, ***J. J. Bongiorno, Jr.***—The bounded control function $u(t)$, which minimizes the total energy expended by a submerged vehicle (for propulsion and hotel load) in a rectilinear translation with arbitrary initial velocity, arbitrary displacement, and zero final velocity, is established. The motion of the vehicle is determined by the nonlinear differential equation $\ddot{x} + a\dot{x}|\dot{x}| = u$, $a > 0$. The performance index to be minimized is given by $S = \int_0^T (k + u\dot{x})dt$, with T open and $k > 0$. The analysis is accomplished with the use of the Pontryagin maximum principle. It is established that singular controls can result when $k \leq 2\sqrt{U^3/a}$, where U is the maximum value of $|u(t)|$.

Optimal Control of Systems with Pure Time Delays Using a Variational Programming Approach, ***D. MacKinnon***—A variational programming algorithm of an iterative nature is developed. It generates an optimal feedback control for systems with pure time delays in the plant dynamical equations. The computational approach is based on the theory of weak relative minima of the classical calculus of variations and may be applied in situations where the plant is nonlinear and/or the performance index is nonquadratic.

Nonlinear Filtering: The Exact Dynamical Equations Satisfied by the Conditional Mode, ***H. J. Kushner***—The signal x_t is a stochastic process satisfying the stochastic differential equation $dx = f(x)dt + dz$. Observations $\dot{y} = g(x) + \xi$ are taken, where ξ is white noise. The exact dynamical equation for the mode of the conditional density of x_t is derived.

Error Bounds of Continuous Kalman Filters and the Application to Orbit Determination Problems, ***T. Nishimura***—The effect of errors due to incorrect a priori information on initial states as well as on noise models in continuous Kalman-Bucy filters has been investigated. A conservative design criterion has been established, and a convenient formula for computing error bonds has been derived that will allow parametric studies of the error effect. The results are applied to typical orbit determination problems of the spacecraft subject to random acceleration having noise-contaminated Doppler or range data.

Methods for Injection Error Analysis and Their Comparison, ***J. D. Irwin, J. C. Hung***—Statistical techniques for the analysis of missile injection errors are studied in detail. The commonly used direct and adjoint methods are reviewed and extended. It is shown that the determination of the covariance matrix is equivalent to the determination of two transformation matrices for both methods. In general, the adjoint method is more efficient. But for a special case, the direct method could be preferable depending upon the relative dimension of the system state and the error source. Two examples are given to verify the results. The techniques presented can be applied equally well to a wide variety of control system problems.

A Learning Method for System Identification, ***J. Nagumo, A. Noda***—A method for system identification is proposed that is based on the error-correcting training procedure in learning machines, and is referred to as "learning identification." This learning identification is nondisturbing, is applicable to cases where the input signal is random and nonstationary, and can be completed within a short time, so that it may be used to identify linear quasi-time-invariant systems in which some parameters vary slowly in comparison with the time required for identification. This merit also makes it possible to eliminate noise disturbances by means of the moving average method. Computer simulation of the learning identification was carried out and the times required for identification were obtained for various cases. Some modifications of the learning identification were also investigated together with their computer simulations.

Correspondence

The Minimum Number of Inputs Required for the Complete Controllability of a Linear Stationary Dynamical System, *W. G. Vogt, C. G. Cullen*

A Note on Sensitivity of System Observability, *R. A. Monzingo*

Discussion on "Parametric Relations for the α-β-γ Filter Predictor," *S. R. Neal, T. R. Benedict*

On Suboptimal Linear Filter Design, *J. R. Huddle*

On Increasing Sampling Efficiency by Adaptive Sampling, *D. Ciscato, L. Mariani*

A Note on Multirate Sampled-Data Systems, *E. I. Jury*

Quadratic Performance Criteria with Linear Terms in Discrete-Time Control, *G. B. Kleindorfer, P. R. Kleindorfer*

On a Classical Variational Formulation of a Multidimensional Control Process, *H. R. Martens, S. J. Asseo, J. R. Tou*

Control Problems with Linear Dynamics, Quadratic Criterion, and Linear Terminal Constraints, *S. E. Dreyfus*
Further Results on the Sensitivity of Optimally Controlled Systems, *J. C. Dunn*
Comments on a Linear Pursuit-Evasion Game, *P. A. Meschler, S. Baron, L. Ho*
On Controlling a String of Moving Vehicles, *J. D. Pearson*
A Note on the Computation of Optimal Control, *P. Dyer*
On Optimal Nonlinear Feedback Control, *A. Debs, R. W. Bass, R. F. Webber*
On the Optimal Control of Plants with Saturation Nonlinearity, *T. C. Hsia*
On Equivalent Systems in Optimal Control and Stability Theory, *N. H. McClamroch, J. K. Aggarwal*
Liapunov's Method for Adaptive Control System Design, *R. V. Monopoli*
Stability of Linear Time-Invariant Systems, *M. A. L. Thathachar, M. D. Srinath, K. S. Narendra*
Explicit Stability Criteria for the Damped Mathieu Equation, *G. J. Michael*
Comment on "An Extension of Pell's Method of Phase-Trajectory Construction," *P. P. Wang*
On Aizerman's Conjecture and Boundedness, *W. G. Vogt, J. H. George*
An Extension of "Comments on a Stability Inequality for a Class of Nonlinear Feedback Systems," *J. L. Willems*
Comment on "Finite-Time Stability Under Perturbing Forces and on Product Spaces," *P. Dorato, L. Weiss, E. F. Infante*
On the Step Response of a Class of Third-Order Linear Systems, *G. A. Jones*
Improving Transient Response of Control Systems Using Switching Techniques, *M. S. Michail*
A Note on the Parameter Plane in the Design of Control Systems, *E. J. Davison, D. D. Siljak*
Correction to "Hidden Modes and Pole-Zero Cancellation," *H. D. Albertson, B. F. Womack*

Book Reviews

"An Introduction to the Theory and Its Application" by M. Athans and P. Falb, *reviewed by S. J. Kahne, E. B. Lee*
"Introduction to Dynamic Programming" by G. L. Nemhauser, *reviewed by R. E. Larson*
"Biological Control Systems Analysis" by J. H. Milsum, *reviewed by E. A. King-Smith*

IEEE Transactions on Broadcast and Television Receivers

Vol. BTR-13, no. 1, April 1967

An AC/DC Line-Operated Transistorized TV Receiver, *C. F. Wheatley*—An all-transistor television receiver that incorporates many design innovations is described. Several of these innovations are directed toward better performance or lower cost. Some merely indicate a different way of serving a function. It is intended that each innovation be evaluated on its own merit, rather than as part of an integrated system. The primary objective of the receiver is to demonstrate ac/dc operation of the horizontal-deflection circuit. This objective is accomplished by use of a relatively low-voltage transistor in an economical configuration. Although the power supply is regulated, the cost of regulation is offset by the following factors: (1) a large filter choke may be eliminated, as well as its magnetic fields; (2) many large electrolytic capacitors are eliminated; (3) horizontal retrace time is increased to 14 microseconds in conjunction with the regulation (at no sacrifice in presented raster); the required voltage–current product of the deflection transistor is thus reduced to half that required without regulation; (4) the very low ripple content of the supply permits signal-coupling and biasing techniques that eliminate additional electrolytic capacitors; (5) regulation for partial load variation permits the vertical and audio circuits to operate directly from the supply without need for decoupling; (6) receiver performance is maximized independently of line voltage; (7) the problem of oscillator stability with line-voltage variation is eliminated (in VHF, UHF, vertical, and horizontal oscillators). Each function of the receiver is described, and design innovations are pointed out.

Computer-Aided Circuit Design, *D. G. Mark*—The computer-aided design technique called "design for reliability" is not a rigidly fixed push-button procedure into which the engineer feeds design requirements at one end and from which he receives a schematic diagram and a "jewel-like" production prototype at the other end. It is rather a *modus operandi*—a method of attacking and solving design problems that yields top-quality results. If the design for reliability approach could be summarized in one short phrase, this phrase might be "modernized craftsmanship," implying the classic concept of highly developed skills and careful attention to detail, plus the application of modern tools and techniques. The design for reliability philosophy originated in the mid-1950s during the Terrier missile program. Basic techniques discovered at that time for considering the effects of component part variability on performance have since been expanded and implemented so that their use is routine and their results are indispensable.

A New Video and Noise-Immune Sync Tube and Circuit, *T. E. Deegan, E. F. Kashork*—A newly developed multifunction tube, the RCA Dev. No. A55280, that should achieve widespread acceptance by designers of advanced television circuits, is described. One section of the tube may be used to provide improved video and noise-immune sync amplification and a second section is being used as a vertical oscillator or a sound IF amplifier. A modification of a conventional production-type television receiver circuit is described that makes use of the A55280 to improve circuit performance, particularly in regard to noise immunity.

A Comparison of Solid-State and Electron-Tube Devices for TV-Receiver RF and IF Stages, *L. S. Baar, S. Reich*—Today's circuit designer, realizing that either electron tubes or solid-state devices can provide satisfactory performance in television tuners, is faced with deciding which of the many available devices he should choose to achieve an optimum performance-to-cost ratio. A summary and comparison of device capabilities for RF and IF stages are given, and it is shown how each capability can be applied to the attainment of realistic receiver performance objectives. The devices compared are bipolar transistors, MOS field-effect transistors, and both frame-grid and conventional-grid electron tubes. All except the MOS transistor are commercially available entertainment types that appeal to a television-receiver manufacturer from an economic viewpoint. The MOS transistor is included in the comparison for completeness, although performance data on this relatively new device are still somewhat limited. Comparisons involving MOS devices are limited to measurements made in an RF-amplifier stage and to some theoretical performance figures.

IEEE Transactions on Circuit Theory

Vol. CT-14, no. 2, June 1967

Synthesis of Active and Passive Compatible Impedances, *C. W. Ho, N. Balabanian*—The following problem is discussed. Given two rational functions $Z_1(s)$ and $Z_0(s)$, otherwise arbitrary but for which $R + Z_1(s)$ has no zeros in the right half plane, $Z_1(s)$ is to be realized as the driving-point impedance of a lossless coupling two-port terminated in the impedance $Z_0(s)$. This problem had been previously considered and solved by Schoeffler and by Wohlers when $Z_1(s)$ and $Z_0(s)$ are positive real functions and the coupling network is reciprocal. Necessary and sufficient conditions are given here for realizability in the contemplated form when neither of the two impedances is necessarily positive real and when the coupling network may be reciprocal or nonreciprocal, but still lossless. A realizaton procedure is developed and examples are given to illustrate the approach.

Transfer Function Realizability of Grounded URC Networks, *J. D. Rhodes*—Necessary and sufficient conditions for the realization of a short-circuited transfer admittance by means of a grounded $\overline{U}$RC network are presented. The approach used to determine the realizability conditions is similar to that employed in lumped transformerless networks but, in this case, the conditions upon realizability are directly related to the short-circuited transfer admittance (y_{12}) rather than the open-circuited voltage transfer ratio. Similarly, if y_{12} satisfies the realizability conditions, surplus factors may have to be used before synthesis can be performed. Finally, the procedure used in testing for realizability and synthesis is demonstrated by a nontrivial worked example.

Synthesis of RC Bandpass Filters, *K. L. Su*—The technique of the conformal transformation is used in the design of *RC* bandpass filters. An elliptic-function transformation that transforms the complex-frequency plane into a rectangle is used. In the transformed plane, poles and zeros can be located to produce several useful bandpass characteristics. Key quantities, such as the passband ripple, the equal-ripple bandwidth, and the half-power bandwidth, of these filters can be calculated in terms of a few parameters in closed form. Some design charts are presented. Several design examples and experimental filters are given.

High-Q Bandpass and Band-Elimination Resistance-Capacitance Ladder Structures, *G. Prabhavathi, V. Ramachandran*—Bandpass and band-elimination structures are considered. These *RC* structures are also expected to fulfil the two conditions, viz., (1) the factor $Q = (w_0/2)\ (d\phi/dw)_{w=w_0}$ (where ϕ is the phase-shift between the input and the output, and w_0 is the frequency at which $\phi = 180°$) shall be a maximum possible, and (2) the open-circuit input impedance and the short-circuit output admittance shall be simultaneously maximized.

On Unistor Graphs, *G. G. Dodd*—There are a number of applications of graph theory to the solutions of problems in electrical networks, switching circuits, and communication nets. These applications involve modeling a system by a graph and describing the properties of the system in terms of this corresponding graph. It is shown that a linear system can be modeled by a graph of unistors; that is, an oriented edge with flow proportional to the initial vertex. The solution of the system is then obtained by means of products of directed trees. There is no calculation of cofactors as an intermediate step, and no extra calculation to determine the sign of the solution. In order to achieve the result, the relationships between the directed trees forming a unistor graph and their associated incidence matrices are developed and techniques for calculating determinants and cofactors of linear systems by means of directed trees and directed two-trees are given.

Non-Series-Parallel Realization of Symmetrical and Bisymmetrical Two-Element-Kind Two-

Ports to Minimize Multiparameter Sensitivity, *S. C. Lee*—A non-series-parallel synthesis procedure is introduced to realize a class of two-element-kind two-port symmetrical and bisymmetrical network function specifications. Necessary and sufficient conditions for the realizability of the network functions are given. The multiparameter sensitivities of the non-series-parallel realizations and their equivalent conventional realizations are discussed. In particular, *RC* ladder networks (series-parallel networks) are compared with respect to multiparameter sensitivity with non-series-parallel networks that realize the same network functions. It is shown that the new networks always have smaller values of multiparameter sensitivity than two classes of equivalent ladder networks for all frequencies. Numerical examples computed on the CDC 1604 and the IBM 7094 illustrate the method.

A Systematic Method of Finding All Directed Circuits and Enumerating All Directed Paths, *T. Kamae*—A method of obtaining all directed circuits is presented by using a connection matrix. Also obtained is the number of directed paths of each length from any one vertex to another. Finally, it is extended to the non-oriented case.

A Topological Method of Generating Constant-Resistance Networks, *P. M. Lin*—Zadeh has shown that any self-dual network, fixed or linear time-varying, is a constant-resistance network. To date, the only known constant-resistance networks with self-dual structures are the classical lattice and bridged-T networks. The topological aspect of the problem is investigated, with the aim of obtaining new constant-resistance network configurations. Let $G\rho$ be a self-dual one-terminal-pair graph with respect to vertices (i,j), and with the degrees of (i,j) both equal to ρ. It is proved that for $\rho \geqq 2$, $G\rho$ can be realized with $8\rho - 11$ edges, but not with fewer edges, if the union of $G\rho$ and an edge joining (i,j) is to be triple connected. Using these graphs as the basis, a class of constant-resistance networks is generated, which includes the classical lattice and bridged-T networks as special cases for $\rho = 2$. The generation of a contant-resistance network for $\rho = 3$ is shown in detail, with a numerical example illustrating its application in transfer function synthesis.

Active RC Synthesis for Significant Reduction in Magnitudes of Reactive Elements, *I. M. Horowitz*—Active elements may be used to reduce significantly the total reactance required in a network. Two active *RC* synthesis techniques for this purpose are presented. One method employs a negative-impedance-converter to realize any number of system poles and reduces the total required capacitance to any desired extent. The resulting design is, however, very sensitive to active and passive parameter values. The second method also permits any prescribed total capacitance but employs a cascade of isolated second-degree sections. Two such sections are presented and optimized with respect to a figure of merit C_tAS_A, being the product of total capacitance, required active element gain, and system sensitivity to the last. System transmission zeros may be accommodated to a certain extent.

Simplified Multiple-Parameter Sensitivity Calculation and Continuously Equivalent Networks, *J. V. Leeds, Jr., G. I. Ugron*—A method of efficiently calculating the sensitivity functions of a single output variable with respect to all the parameters in a reciprocal network is described. The method reduces the problem of obtaining these sensitivity functions to the simple problem of solving one additional network easily derived from the given network. A distinct advantage of the method is that current available digital computer network analysis programs can be used with little modification and calculation of the sensitivity functions. Next, the frequency dependence of the sensitivity of continuously equivalent networks is examined. The results of this study allows one to make three hypotheses about continuously equivalent networks: (1) that the continuously equivalent network resulting from a minimization of the sum of the magnitudes squared of the sensitivity functions at a given frequency is the network with minimum sum of the magnitudes squared of the sensitivity function at all frequencies, (2) that the sum of the magnitudes squared of the sensitivity functions decreases as the number of elements increases in continuously equivalent network, and (3) that the sum of the sensitivity functions is invariant with respect to the various equivalent networks. The most important hypothesis is the first, since if it is true for all continuously equivalent networks, then a great simplification of the computation problem results. Even if a limited class of continuously equivalent networks exhibits this property, the result is worthwhile. Experimental results show that such a class does exist. These exerimental results do not prove that all continuously equivalent networks have these three properties.

Analysis and Synthesis of Multivalued Memoryless Nonlinear Networks, *L. O. Chua*—A simple but general method is presented—the iterative piecewise linear method—suitable for the analysis and synthesis of multivalued memoryless nonlinear networks that may contain multivalued nonlinear resistors, controlled sources, ideal transformers, gyrators, negative impedance convertors, etc. The method itself is an algorithm, and therefore it can be easily programmed in a computer. Part I, Analysis of Multivalued Memoryless Networks, considers the operating point problem and the determination of driving-point and transfer characteristic plots. Part II, Piecewise Linear Synthesis of DC Memoryless Nonlinear Networks, describes a simple procedure to synthesize a nonlinear lattice network having a prescribed driving point, and transfer as well as nonlinear load characteristics.

Statistical Properties of Ramplike Random Processes, *R. Nash, Jr.*—The work of Lampard and Redman on the statistical properties of the integral of a binary random, process is generalized and extended to include more general ramplike random processes $z(t)$. These ramplike processes are defined to be ramps of random slope that switch slope at random times. Both the intervals between switching times and the slopes of the ramp segments are assumed to be independent random variables. The general properties of the one and multidimensional probability density functions of $z(t)$ are discussed. A Laplace transform technique is employed to obtain the Laplace transform of the characteristic function of these probability density functions in terms of the Laplace transform of the characteristic function of the ramp slopes multipled by the probability functions of the switching times. For Poisson switching times, these expressions are relatively compact. However, the inversion problem is formidable, and closed-form results are presently available only for a binary slope probability density function (a previously known result). Due to the properties of characteristic functions, the moments of $z(t)$ are obtained by a single Laplace inversion of the derivative of the Laplace transform expressions. These moments may be used to characterize the probability density functions of $z(t)$ with a series expansion involving the Gaussian density function and its derivatives. Examples are given for the cases of Gaussian and rectangular slope probability density functions with Poisson switching times.

High-Q Resistance-Capacitance Ladder Phase-Shift Networks, *G. Prabhavathi, V. Ramachandran*—Resistance-capacitance ladder low-pass networks, to obtain a phase shift (ϕ) of 180° between the input and the output, are examined. It is found that there exists a theoretical maximum value of Q, defined by

$$\frac{w_0}{2}\left|\frac{d\phi}{dw}\right|_{w = w_0}$$

where w_0 is the frequency at which the phase shift is 180°. This theoretical limit can be approached in actual practice, but never reached. It is attempted to synthesize such networks having as high a Q as possible. In addition, the resulting network possesses the property that the open-circuit input impedance and the short-circuit output admittance are simultaneously maximized. A transformation enables one to get the corresponding high-pass structure from the low-pass one.

Correspondence

Computation of the Step Response of a General Nonuniform *RC* Distributed Network, *E. N. Protonotarios, O. Wing*

Circuit Transformations for Crystal Ladder Filters, *E. Christian*

Transient Response of Equal-Element Band-Stop Filters, *H. J. Hindin, J. J. Taub*

Generation of Concave Node-Weighted Trees, *M. A. Tapia, B. R. Myers*

Hamilton Circuits in Directed-Tree Graphs, *Wai-Kai Chen*

Constant-Resistance, Wide-Sense Solvability, and Self-Duality, *C. A. Desoer, R. W. Newcomb, K. K. Wong*

A Simple Calculation of the Determinant Polynomial of General Networks, *C. F. Kurth*

Nonlinear Distortion in Periodically Time Variable Circuits, *J. Lenkowski*

Visualizing the Operation of Electronic Circuits, *R. M. Lee*

IEEE Transactions on Communication Technology

Vol. COM-15, no. 3, June 1967

A Multicomputer Message Switching Data Processing Systems, *E. U. Cohler, H. Rubinstein*—A number of new techniques for data processing in a message switching center are described that will improve system reliability and increase system availability. This data processing system contains several processor equipment pools introduced to avoid costly duplexing, yet it will keep equipment failures from interrupting operation. The system uses list-processing techniques for memory allocation, which result in efficient memory usage and allow each processor access to the entire message store. Direct access to memory interface is used to permit automatic switch-over of service from one processor to another if the processor fails, and to minimize the use of per-line equipment. Techniques are described for message accounting, routing, and processor scheduling, which are independent of machine configuration.

Telecommunications in Sweden, *B. Bjurel*—The main tasks of the Swedish Telecommunications Administration—telephone, telegraph, and telex services—are described. The staff of the Administration includes about 40 000 persons. About 3½ million telephones are serviced. Each year 250 000 new telephones are installed. Data transmission is a rapidly expanding new branch of activity. Switching equipment is of the crossbar type, or based on the 500-line switch, and switching equipment of stored-program-controlled semi-electronic type is under development. For long-distance traffic, coaxial cables and microwave links are used. The Swedish Telecommunications Administration has resources for technical development and factories for manufacturing telephone sets and switching equipment.

The Australian Telecommunications Network, *T. Z. Housley*—The Australian Telecom-

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munications Network, which is operated by the Government through the Postmaster-General's Department, is among the world's more advanced systems. Telephone, telegraph, and television services are provided to virtually all settled areas of the vast Australian continent. In very sparsely settled areas, outpost radio telephone services provide essential communication. The manner in which the Australian network is being extended and modernized to meet the demands of the future is described. Reference is made to Australia's overseas telecommunications services and to the measures taken in the national system design to ensure compatibility with the world system.

The Italian Telephone Long-Distance Network, *M. Mazzarella, D. Gagliardi, F. Vallese*—A description is given of the Italian long-distance network, which interconnects the 21 "transit regional centers" of the country and the international and intercontinental telephone networks. In particular, the characteristics of coaxial cables and radio links are detailed, as well as the criteria to be adopted in order to guarantee a grade of service acceptable to subscribers. Fundamental outlines are also described for functional and design standardization of equipments, and problems arising with interconnection on a full European and world basis.

Telecommunication Expansion in India, *C. P. Vasudevan*—The problems and methods of development of telecommunications in India from 1949 to 1966, and plans for 1966 to 1971, are examined. Statistical information is given on the financial investment and the physical targets together with the features and the nature of development. The orientation necessary to achieve this high rate of development is discussed. Keeping the network financially viable is a problem. The technical features and an outline of the systems and equipment, which includes new coaxial and microwave routes and common control crossbar systems, are described. The range of manufacture undertaken in the country is also covered. A review of the research organization and its vital contribution to the development is included.

Air Traffic Control G/A/G Channel Loading Investigation, *R. L. Podell, G. Scharf*—Data and results of importance in communications systems design are presented from a recent survey characterizing ground–air–ground communication channels in air traffic control. Channel utilization is studied because it is a measure of the controller's communication work load. Relationships between channel utilization and air traffic parameters are derived from the data for various controller positions. The utility and validations of the relationships are discussed. Observed channel utilization distributions, average values of contact lengths and number of contacts per aircraft, and relationships between contact lengths and air traffic parameters are also presented.

DISCOSE—A New Tool for Communications Studies, *H. J. Crowley*—A unique laboratory facility, which has been set up for automated evaluation of digital communication systems, is described. This facility contains a large-scale, stored-program communication processor interconnected to a number of experimental transmitting and receiving sites and telephone transmission facilities. By interconnecting the processor and the communication facilities to experimental digital devices, it is possible quickly to perform real-time, on-line evaluation of these equipments. The stored-program processor generates the necessary test messages, analyzes transmission errors, and prints out results on a continuous basis during a given test. Facilities are available for simultaneous evaluation of several equipments and transmission links operating in tandem combinations to form a communication system.

The Scheduling Problem in Satellite Communications Systems, *C. Ahara, J. Rossbach*—In satellite communications systems, the assignment of communications channels to users is a separate function from that of satellite acquisition and the establishment of actual communications circuits. A discussion of this scheduling problem is presented with emphasis on system analysis and mathematical formulation. Computational procedures that have been developed for schedule generation are identified. Also discussed is a simulation study designed to evaluate a linear programming algorithm for scheduling specific configurations of medium-altitude communications satellites and trunks. The simulation was programmed in Fortran and run on the IBM 7090 computer.

Evaluation of Error-Correction Block Encoding for High-Speed HF Data, *K. Brayer, O. Cardinale*—Error-pattern data gathered from an operational HF digital data transmission system are shown to have characteristics that permit their direct classification into predominantly burst, random, and periodic error categories. These data are useful in a proposed method for effectively evaluating and designing forward error-detection and -correction devices using interleaving and block error-correcting codes. The method is based on the strategy of transforming channel burst error patterns into easily corrected randomly distributed errors. The measure of randomness of observed errors is established by comparison with distributions of known random error data derived from a computer program simulation. A valid method is established that permits the quantitative evaluation of interleaver performance in terms of effective randomization of burst error patterns.

Data Communication Through the Atmospheric Burst Error Channel, *N. S. Jayant*—Simple and easily utilized techniques are suggested for reliable transmission of binary data in the presence of atmospheric noise bursts. The techniques utilize the time statistics of the noise bursts, now known to be log-normal, and operate on one-way channels. Two modes of transmission are distinguished. The first mode involves double or triple transmission of an error-detection code word. The second mode of transmission is based on burst error correction, provided either by a majority count principle or by the recurrent codes of Hagelbarger. Numerical calculations indicate the superior performance of the error-detection techniques.

Forced-Erasure Decoding and the Erasure Reconstruction Spectra for Group Codes, *R. M. Heller*—Forced-erasure decoding, an easily implementable technique for realizing the fullest capability of a code, is presented and discussed. This type of decoding combines the implementation simplicity of digital decoding with the performance enhancement expected of correlation decoding techniques. Adaptive versions, with and without interleaving for fading channels, are described. An exact expression for word-error probability in white Gaussian noise is derived. The concept of a code erasure reconstruction spectrum is introduced and several new results presented, along with a review of applicable, known ones.

The Performance of Forced-Erasure Decoding, *R. G. Marquart*—Forced-erasure decoding is described and evaluated. Adaptive versions, with and without interleaving for fading channels, are also treated. The simulation of representative channels is described, and the performances of forced-erasure decoding, correlation decoding, and digital decoding on these channels are determined and compared.

A Stochastic Model of Message Interchange on a Channel with Transmission Delay, *P. T. Brady*—A technique for analyzing the statistical behavior of a two-way communication system with transmission delay (D) is discussed. Messages are transmitted and received by means of servers located at the terminal stations. If $D > 0$, each server is uncertain of the present state of the other, and may initiate transmission when the other has already begun to transmit, thus causing message interference. Interference is measured as the amount of one server's transmission that arrives at the other server when it is already transmitting. The relationship between the size of the delay and the amount of interference is studied, as well as other quantities that describe the system behavior. The exact solution is available only for $D = 0$, but an approximate solution is found for very small D with respect to the lengths of idle periods of the servers, and the asymptotic solution is obtainable for very long D. The particular communication system analyzed is a very simple one, but the mathematical technique of handling the delay can be applied to more elaborate systems.

On Coded Partially Phase-Coherent Communication Over a Gaussian Channel, *C. Chen*—Error probabilities for 2^n orthogonal signals under partially phase-coherent reception are derived by a simple method and then illustrated. The amount of phase coherence is related to the effective signal energy per bit to noise density ratio. The joint effect of timing error and noisy phase reference on system performance is examined in detail.

Cycle Slipping in Phase-Locked Loops, *R. Tausworthe*—It is shown that the expected first-slip time of a phase-locked loop of arbitrary order can be found as the solution of a first-order linear differential equation, to which formal solutions are easily written. Computation of an exact solution involves being able to evaluate a certain conditional expectation, which, for the first-order loop, is readily done and yields the exact known result. For higher order loops, an approximate evaluation of the expectation is presented and compared with experimentally obtained data of the second-order loop. The first-slip time based on this approximation also compares favorably with measured times.

Digital Transmission Capabilities of a Transportable Tropo-Scatter System, *H. L. Smith*—The digital transmission performance of a transportable tropo-scatter station is evaluated as a function of path length. Equipment parameters are chosen to be representative of a compact full-scale terminal capable of serving a major switching facility. Although error-rate evaluations for tropo-scatter transmission have been made, they have generally corresponded to the conditions of specific systems. Here, a reasonable path model and set of transmission parameters, thought to be representative of practical situations, have been chosen to allow performance evaluations to be made over the full gamut of range, propagation frequency, and bit rate conditions that are of interest. The two modes of digital transmission considered are direct-carrier modulation and subcarrier modulation within an FDM-FM baseband. The error-rate estimates finally determined reflect error contributions from all causes, with enhancement achieved from diversity operation.

The Lunar Orbiter Telecommunications System, *W. T. Bundick, C. H. Green, E. A. Brummer*—The Lunar Orbiter is an unmanned lunar reconnaissance satellite that takes high-resolution photographs of large areas of the lunar surface to assist in selecting a landing site for

Apollo. Because of various mission aspects and the fact that the Orbiter employs a film-type camera, the requirements placed on the telecommunications system are different from those of previous U.S. spacecraft. The design of both the spacecraft and ground equipment of the Lunar Orbiter telecommunications system is described. Some of the unique features of the design include the use of vestigial sideband modulation for transmission of the picture data, a full-verification command system, a low-gain antenna system whose pattern approaches that of an isotropic radiator over a large portion of the radiation sphere, and a dual-power-level transmission system that does not use RF switching. Included is a link-design chart that shows the SNRs and performance margins obtained for all operating modes.

A New Data-Gathering and Control System, *R. P. Sanders*—The Automatic Electric C-2000 Data-Gathering and Control System, which represents recent innovations in the field of industrial control, is described. The system consists of a master station complex located at the hub of a communication network, linking it to a number of remote stations. An unusually efficient communication message structure is employed, which, when used in conjunction with a high-speed data set, results in an exceptionally high information rate. An efficient and effective message security scheme is employed. The system is modular on both a functional and a per-point basis, allowing it to be efficiently employed in installations of all sizes.

Carrier Transmission on Voice-Loaded Loops, *M. J. Birck*—A new telephone line-loading scheme is reported that permits application of subscriber carrier systems to voice-loaded cable pairs with practically no degradation to either voice or carrier transmission. This scheme, termed "super-loading," makes use of a bifilar wound toroidal inductor having both windings center tapped, with an *LC* network joining the center taps. This arrangement produces a device that acts as a one-to-one transformer at frequencies where the *LC* network presents a low impedance and a series inductor when the network impedance is high. Data are presented comparing the transmission characteristics of nonloaded, nominally loaded, and superloaded cable pairs at voice and carrier frequencies.

Transistorized Line Equipment of V 2700 Carrier System, *H. Keil*—A transistorized system has been developed for transmitting 2700 voice channels, or 1200 voice channels simultaneously with a television program. It has the same repeater spacings and the same low noise power as hitherto supplied systems with tube amplifiers. Outstanding details described are the underground line amplifiers, the combination of temperature compensation and automatic pilot control of level stabilization, and the equalization of frequency response nonlinearity.

IEEE Transactions on Education

Vol. E-10, no. 2, June 1967

The Curriculum and the Education of Engineers, *S. Seshu*—The purpose of education of the electrical engineer is explored, especially as it relates to the division of responsibility between the teaching machine and the faculty. Arguments are presented for making the cirriculum more flexible and better suited to individual students, especially gifted students.

The Mathematical Representation of Physical Entities, *C. H. Page*—Mathematics comprises abstract operations upon abstract elements. For the application of mathematics to the sciences, one not only must know the rules for manipulating symbols, but also must define the correspondences between the mathematical abstractions and the concepts to which application is made. Certain basic postulates about physical observables yield the structure of their mathematical representation. An understanding of this structure yields an understanding of measure equations, quantity equations, measurements units, abstract units, and the mathematical nature of dimensional analysis. Writing equations in a dimensionally homogeneous form is often convenient, but not necessary; sometimes an inhomogeneous formulation is more useful.

Introduction of Electrical Engineering Systems, *T. Horrocks*—A course is described in which the attempt is made to introduce first-year electrical engineering students to the basic principles upon which their chosen discipline is founded and to establish early the concept of a system. It is contended that an undergraduate course need not lag a decade behind current practice and current thinking but that, rather, the techniques taught and, indeed, the entire mode of approach can and should be completely up to date.

Procedures for the Automated Synthesis of Logical Networks, *C. C. Carroll, H. Mott*—Numerical procedures are presented that can be programmed in a generalized manner to accomplish the logical design of various logical networks with the use of a general-purpose digital computer. Some programming techniques are discussed to indicate just how the procedures are performed in the computer. Several elementary designs are mentioned with regard to the relationship between the network input–output information and the necessary input information for the automated procedures. Also, the results obtained with the performance of each step of the procedures are tabulated for the automated design of a code translator that represents a basic logical design problem. The elementary nature of these designs is not indicative of the type of design problems that make an automated procedure worthwhile; however, they clearly demonstrate the versatility that a single computer program may have in accomplishing very sophisticated designs.

An Approach to Senior Technical Electives, *S. J. Kahne*—Senior technical electives in electrical engineering should provide the student with an opportunity to synthesize knowledge gained throughout his undergraduate years. An excellent vehicle for such synthesis is a design project, including a detailed written and oral report. Such a project is discussed and its effectiveness in achieving these goals is discussed.

Report

G-E "Goals of Engineering Education" Questionnaire, *M. P. Smyth*

Short Papers

Approaches to Nonconventional Energy Conversion Education, *E. T. B. Gross*
Probability Theory and the Laplace Transform, *T. J. Healy*
An Example of State-Variable Analysis from Physiology and Medicine, *F. M. Patterson, D. M. Levy*
Mesh/Star and Star/Mesh Conversions, *E. Wilkinson*
Finding Generalized Forces by Use of Partial Derivatives of Energy Functions, *J. W. Rogers*
Application of Desk-Top Computers as Aids in Teaching Mathematics, *M. T. Ung, R. A. MacDonald*
Teaching Transistor Circuit Design to Undergraduate Engineers, *D. J. Comer*
The Mechanics of the Bilinear Transformation, *H. M. Power*
On a Theorem Used in Determining a Driving-Point Immittance from Its Phase Specifications, *S. C. Dutta Roy*

Correspondence

Comment on "An Experiment with Support Programming of a Textbook," *R. K. Moore*
Coincidence of Poles and Zeros, *S. F. Crumb, K. R. Rao*
A Classroom Reactance Network Determination Method, *D. C. Fielder*
Temperature Compensation of Strain-Gage Bridges, *R. J. Distler, P. J. Graham*
Let's Schwa, *C. A. Ranous*

IEEE Transactions on Electronic Computers

Vol. EC-16, no. 3, June 1967

Random-Pulse Machines, *S. T. Ribiero*—A new kind of machine is proposed, in which the continuous variable is represented as a probability of a pulse occurrence at a certain sampling time. It is shown that threshold gates can be used as simple and inexpensive processors such as adders and multipliers. In fact, for a random-pulse sequence, any Boolean operation among individual pulses will correspond to an algebraic expression among the variables represented by their respective average pulse rates. Thus, any logical gate or network performs an algebraic operation. Considering the possible simplicity of these random-pulse processors, large systems can be built to perform parallel analog computation on large amounts of input data. The conventional analog computer has a topological simulation structure that can be readily carried over to the processing of functions of time and of one, two, or perhaps even three, space variables. Facility of gating, inherent to any form of pulse coding, allows the construction of stored-connection, parallel, analog computers made to process functions of time and two space variables. This technique of random-pulse computation and its potential implications are considered. Problems of realization, application examples, and alternate coding schemes are discussed. Speed, accuracy, and uncertainty dispersion are estimated. A brief comparison is made between random-pulse processors and biological neurons.

Synthesis of Resistive Digital-to-Analog Conversion Ladders for Arbitrary Codes with Fixed Positive Weights, *M. R. Aaron, S. K. Mitra*

Basic Properties and a Construction Method for Fail-Safe Logical Systems, *H. Mine, Y. Koga*—"Fail-safe" properties of logical systems are studied, and, the conditions found that the basic logical functions of fail-safe logical systems should satisfy; also, the allowable failures for the basic logical function circuits are identified. With these results, a systematic representation of fail-safe logical systems and an effective method of logical design for fail-safe systems are presented.

New Classes of Synchronous Codes, *D. J. Clague*—New classes of codes with similar application to Gilbert's code are defined. Weakening of his synchronizing condition is given higher efficiency in the new codes. One class (the *F* codes) is shown to be the most efficient possible among those codes that use Gilbert's method of achieving synchronization, i.e., the "position fixing" method. The other classes use a basically different method of achieving synchronization, and have even higher efficiencies than the *F* codes. The codes are compared mainly with regard to efficiency, but some idea of the hardware required is also given. The efficiency is compared to that of the bound on Golomb's comma-free code, but evidence is supplied that codes that are constructed to carry information will never reach this limit.

A Theory of Adaptive Pattern Classifiers, *S. Amari*—Error-correction adjustment procedures for determining the weight vector of linear pattern classifiers under general pattern distribution are described. The intention is to clarify theoretically the performance of adaptive pattern classifiers. In the case where the loss depends on the distance between a pattern vector and a decision boundary and where the average risk function is unimodal, it is proved that, by the procedures proposed, the weight vector converges to the optimal one even under nonseparable pattern distributions. The speed and the accuracy of convergence are analyzed, and it is shown that there is an important tradeoff between speed and accuracy of convergence. Dynamical behaviors, when the probability distributions of patterns are changing, are also shown. The theory is generalized and made applicable to the case with general discriminant functions, including piecewise-linear discriminant functions.

Generation of Polynomial Discriminant Functions for Pattern Recognition, *D. F. Specht*—A practical method of determining weights for cross-product and power terms in the variable inputs to an adaptive threshold element used for statistical pattern classification is derived. The objective is to make it possible to realize general nonlinear decision surfaces, in contrast with the linear (hyperplanar) decision surfaces that can be realized by a threshold element using only first-order terms as inputs. The method is based on nonparametric estimation of a probability density function for each category to be classified so that the Bayes decision rule can be used for classification. The decision surfaces thus obtained have good extrapolating ability (from training patterns to test patterns) even when the number of training patterns is quite small. Implementation of the method, both in the form of computer programs and in the form of polynomial threshold devices, is discussed, and some experimental results are described.

Memory Protection in Multiprocessing Systems, *J. Roder, A. F. Rosene*—In a multiprocessor system where a bank of processors share a bank of memories, it becomes necessary to equip a processor with the capability periodically to deny to other processors access to certain memory locations. This is called the memory protection problem because the processor that has gained access to the data must protect it from others. The type of data contained in the memory locations to be protected dictates the characteristics of the protection techniques that are applicable. The techniques as they apply to four classes of data that are defined for multiprocessor systems are outlined. In those cases where special hardware is required, such hardware is described. The programming implications and the error control problems are discussed.

A Mathematical Model for Diagnosing System Failure, *W. W. Chu*

Portable Electronic Keyboard for Computer Input by Telephone, *M. H. Lewin*—The device described, which may be acoustically coupled to any conventional telephone handset, generates coded tone sequences representing alphanumeric characters. The full ASCII character set, coded with parity, is used, and all 128 symbols available for selection are displayed on the device in a small electronic "keyboard." The transmitted tone sequences correspond to those generated by most Teletype–Dataphone terminals in typical time-sharing systems. In operation, the user dials the remote machine and then inputs messages, character by character, by pointing at the selected symbols on the keyboard with a hand-held selection "pen," in a hunt-and-peck fashion. It is assumed that this device would be used to communicate with a machine with voice answer-back capabilities.

High-Speed Plated-Wire Memory System, *S. Waaben*—The plated-wire memory, combined with functional circuit integration, is a strong contender for economic, high-speed, large-capacity memory systems. Important attributes of the plated-wire are high-speed DRO and NDRO capability, low digit WRITE current, high output sense signal, and low word-to-digit-line crosspoint capacitance. Design and operational results for a 1024-word by 80-bit store model are reported in detail. Utilizing transformerless diode matrix for high-speed word selection, an access time of 75 ns and a READ-WRITE cycle time of 150 ns have been realized.

Solenoid-Coupled Variable-Frequency READ-Only Memory, *Y. Hsia*—A variable-frequency READ-only memory utilizing the mutual coupling of two solenoids for information storage is described. The properties of the proposed memory element and the batch-fabricated memory array are discussed. Experimental results on a 256-word, 36-bit-per-word memory stack operating at memory cycle frequency varying up to 10 MHZ are reported. A proposed full-size 256-word, 288-bit-per-word, READ-only memory is evaluated together with cost analysis to demonstrate its economic practicability.

IEEE Transactions on Instrumentation and Measurement

Vol. IM-16, no. 2, June 1967

Ground Instrumentation for Mariner IV Occultation Experiment, *G. S. Levy, T. Y. Otoshi, B. L. Seidel*—The Mariner IV occultation experiment imposed unique requirements upon the NASA/Jet Propulsion Laboratory Deep Space Instrumentation Facility. It was necessary to measure extremely small deviations in the rate of change of frequency to a few parts in 10^9. The instrumentation used and the results obtained are described.

Active Filters Operating Below 1 Hz, *G. G. Bloodworth*—Second-order *RC* filters are synthesized using two voltage amplifiers with gains A_1 and A_2. As the natural frequency depends on A_1 only, and the damping factor depends on A_1 and A_2, these factors can be chosen consecutively by varying the two gains. The passive components need not have variable or accurate values. As described, this feature is particularly useful in the realization of filters operating below 1 Hz, and cut-off frequencies down to at least 10^{-3} Hz can be obtained by exploiting the high input resistance of MOS transistors.

A Strip-Chart-to-Punched-Tape Translator, *G. F. Jenkinson*—The strip-chart translator described was developed to convert complex strip-chart records (for example, those obtained from radio propagation tests) into digital format, on punched tape, to allow analysis by electronic computer. An operator is required to follow the chart trace with a cursor mark, but the translation process is otherwise automatic. The detail contained in such record traces has so far precluded the use of a fully automatic translation process.

A Pseudo-Superheterodyne Receiver for Measuring Phase and Amplitude, *B. B. O'Brien*—A simple high-sensitivity receiver for simultaneously measuring the amplitude and phase of signals at radio and microwave frequencies is described. The receiver is built, for the most part, with standard (microwave) components and employs a modulation technique. The receiver sensitivity, depending on the information bandwidth, is of the order of −100 dBm. Information bandwidths ranging from a few hertz to several megahertz are easily achieved.

A New Wide-Band True RMS-to-DC Converter, *P. Richman*—A new wide-band true rms-to-dc converter is described, covering the ranges of 20 Hz to 100 kHz and 30 mV to 1 kV full scale, with crest factors in excess of 7 to 1. Operation is based on use of two precision dual-heater thermistors in an automatic double bridge, by means of which the temperatures of both thermoelements are maintained constant to better than 0.002°C. Converter linearity is 0.02 percent over a four-to-one input range, with response typically 2.5 seconds to settle within 0.1 percent of final value. Applications range from ac signal conditioning for digital voltmeters to 0.01 percent ac–ac transfer work—with nonsinusoidal waveforms as well as the quasi-sinusoids typical in field measurement situations.

Another Zero-Crossing Principle for Detecting Narrow-Band Signals, *A. J. Rainal*—A zero-crossing principle for detecting weak narrow-band signals immersed in Gaussian noise is described. This principle leads to a zero-crossing detector (detector II), which is also relatively insensitive to system gain fluctuations. Moreover, for the detection of a weak sine wave in noise, zero-crossing detector II performs only 1.2 dB worse than the time-honored square-law detector. An application of the zero-crossing principle to the problem of incoherent detection of a stationary radar target in clutter is discussed.

A Design of a Period-to-Frequency Analog Converter, *R. N. Sato, R. G. Suchannek, D. Valiquette*—A method for designing a period-to-analog converter is described. The device accepts input signals of varying frequency and converts the period of the waveform to a time inverse voltage *Vi(t)*. This voltage is sampled at the end of the period, and this information is held over the following interval. The analog derived from the input signal is a voltage proportional to the repetition rate. The approach to generating the time inverse voltage is based on Willer's general method of approximating decaying functions with a sum of exponential functions. The described method has been utilized to develop a device for monitoring physiological signals. Results demonstrating the performance of the instrument are presented. The method is directly applicable to function generation in general and could be of importance for analog computers.

A Precision Current Comparator, *C. M. Allred, R. A. Lawton*—A technique capable of precise comparison of currents in different parts of a network or between currents in different networks is discussed. With proper conditions, this comparison can be done with negligible perturbation of the networks under measurement. Experiments on a coaxial system at 30 MHz are discussed.

High-Voltage Pulse-Reflection-Type Attenuators with Subnanosecond Response, *R. J. Thomas*—Significant advances have been achieved in high-voltage pulse attenuation and measurement fidelity by utilizing the principle of traveling-wave reflection at an abrupt impedance mismatch along a transmission line. Such "reflection-type" attenuators allow practically distortionless attenuation of the signal, independent of voltage level. Their rise-time response and attenuation factor can be known very accurately because they are free from voltage and temperature effects, making them especially suited as high-voltage pulse calibration standards. The rise-time response for such attenuators can attain 100 ps or less, a practical limit being 30 ps.

Orientation Measurement of Circular Plates of Crystals, *K. T. Tang, M. C. Mahajan*—

A method that can be used to check the orientation angle of circular crystal plates to a high degree of accuracy is described. The method involves making two readings on an X-ray goniometer, determining a correction from a curve, and applying this correction to one of the goniometer readings.

Enhancement of Signal-to-Noise Ratio of Turbulence Measurements by Cross-Correlation, *I. Kidron*—A novel method for the measurement of very low turbulence intensities in fluids, based on a dual heat-transfer transducer and a cross correlator, is described. The minimum measurable turbulence intensity is shown to vary with the square root of the minimum detectable cross-correlation coefficient ρ. The effects of finite additive noise correlation and finite lateral separation between the transducer halves are studied. Details are given of an instrument measuring the normalized cross-correlation coefficient between two time-dependent signals in the frequency range 2 Hz–300 kHz with an accuracy of ±0.05, ± 0.01. The described correlator is particularly suitable for measurements of quasi-stationary processes. A variation of 10 percent in the level of either input signal results in a correlation error of less than 0.6 percent.

Alternating-Current Solenoid of Finite Length in a Medium with Hall Conductivity, *S. Selamoglu*—The electric field of an ac solenoid of finite length in conducting media is investigated. The first-order (Hall) effect of an externally applied, constant, axial magnetic field on the electric field is considered. The coil impedance and the electromotive force induced in a certain closed path are calculated numerically for small frequencies.

Progress in the United States on Electromagnetic Standards and Measurements at 30 kHz to 1 GHz, 1963 Through 1965, *M. C. Selby*—A digest of highlights is presented on the most significant U.S. contributions to the measurement of attenuation, impedance, phase, field strength, thermal noise, current, and voltage at 30 kHz to 1 GHz. Approximately 30 contributions are digested, including the following accomplishments: a supersensitive detector for a complex-insertion-ratio measurement system having accuracies of about 0.0005 dB/10 dB at 30 MHz; exact equations for mutual and self-inductance of various combinations of filaments, tapes, and bars; a modified twin-T bridge for measuring resistances of 100 to 10 000 ohms to 15 MHz; a set of Q-factor standards for frequencies to 45 MHz based on data and experience accumulated over five years; a unique adjustable characteristic-impedance coaxial line; measurement of Q's greater than 100 000 of cryogenic circuits at frequencies to 300 MHz; a novel T-junction to enable calibrations of voltmeters of any practicable input impedances with VSWRs ranging from 1 to 200, to 1 GHz and higher; a miniaturized dipole-antenna field strength meter, employing a semiconducting plastic transmission line, to measure complex near-zone fields of 0.1 to 1000 volts per meter, from 150 kHz to 30 MHz; and a prototype 3-MHz model of precision thermal noise-power comparators for an equivalent noise-temperature range of 75 to 10 000°K at accuracies of 0.2 to 1 percent.

IEEE Transactions on Magnetics

Vol. MAG-3, no. 2, June 1967

Magnetic Scan Head for High-Frequency Recording, *M. Comras*—As described, stationary magnetic head scans the width of a record magnetically, enabling successive lines of video information to be recorded on a slowly moving tape. The head contains a large number of laminations. All except one of these are blocked from transducing action with the tape, by currents through sweep windings. As the sweep currents are changed, every lamination becomes active in succession. For playback, such a head operates on a magnetic-modulator principle, which is sensitive to flux rather than to its rate of change.

On the Dynamic Properties of Cascaded Self-Saturating Magnetic Amplifiers, *W. Torbicz*—The influence of some parameters of the two-stage self-saturating magnetic amplifier on its steady-state and transient properties is described. It is shown that applying an RC filter between both stages ensures proper operation of the amplifier. On the basis of the difference equations describing the single-stage self-saturating magnetic amplifier the discrete transmittance of the circuit can be described. It is pointed out that the back reaction of the second stage on the first appears in cascade. The time constants of the cascade are not equal to the time constants of stages working separately. The influence of the electric and magnetic feedback loop over both stages on the stability of the circuit is considered. Conditions are given under which, when the transient state is caused by a jump change of control voltage, the cascade output voltage appears as an exponential function with two time constants, damped oscillations, or self-sustained oscillations. Characteristic parameters of the cascaded magnetic amplifier are determined. Theoretical results were compared with laboratory investigations.

Stability Analyses of Self-Saturating Magnetic Amplifiers with Capacitive Load, *Y. Sakurai, T. Kusuda, Y. Morita*—Analyses of self-saturating magnetic amplifiers are generally restricted to the pure resistive load cases. There are a few reports related to capacitive loads and some others on inductive loads. The possibility of occurrence of abnormal phenomena in the self-saturating magnetic amplifier with capacitive load has been reported, but their mechanism of circuit behavior is not yet clear. The circuit operation is analyzed in detail from the stability point of view and the mechanism of peculiar modes is investigated. The circuit operation is represented by the nonlinear difference equations that are derived from the continuity of both charge and flux linkage. Linear difference equations for small disturbances occurred at the equilibrium state directly suggest the stability of the equilibrium state and possibility of occurrence of the peculiar modes. Further, the control characteristics and the transient responses are calculated and the criteria for prevention of the peculiar modes are found in simple forms. The theoretical analyses show good agreement with experimental results.

Polyphase Multivibrators, *K. Harada*—A new type of polyphase multivibrator is introduced in which saturable cores are the timing elements and transistors the switching elements. The basic units are like the multivibrators invented by Royer and others, but, in the new polyphase circuit, several single-phase multivibrators with a common dc source are constrained by a loop connection of windings on the cores in such a way that polyphase output voltages are obtained. Detailed analysis of a typical three-phase circuit leads to conclusions regarding the frequency of oscillation and the output voltage waveforms that conform to experimental observations. Novel arrangements are presented by means of which two-phase voltages can be obtained from a three-phase multivibrator.

Analysis of Minor Loop Behavior During Alternating Flux Reversal in Rectangular Loop Toroidal Cores, *M. Gabler*—The analysis of minor hysteresis loop behavior during partial alternating flux reversal in toroidal cores with a rectangular hysteresis loop is considered. A simple flux-reversal model is proposed on the basis of which, with the aid of dimensionless units, the asymmetry of minor hysteresis loops is derived. The drift of minor hysteresis loops during alternating flux reversal is investigate on the basis of loop asymmetry and by means of a proposed indirect method. The method involves compensation of the minor-loop drift by means of a dc component of the exciting field, the magnitude and sense of which are a measure of the drift. The experimental section deals partly with a qualitative comparison of the character of the actual asymmetry of a minor loop with that derived from the flux reversal model, and partly with comparing the actual minor-loop drift with the drift derived theoretically on the basis of the indirect method. Experimental results indicate that in the case of the 50 percent nickel-iron alloy, cold-rolled at a great reduction, there appear additional factors that affect the instability of the minor loop. This effect is further investigated, and a simplified mechanism is proposed for its simulation. Finally, the proposed mechanism is verified experimentally.

Design of Half-Million-Bit Wire Memory, *J. H. Kefalas*—A high volumetric density wire memory stack of 12000 bits/in^3 was designed. The high bit density was obtained by the introduction of a novel and continuous digit line printed circuit, which is also used to separate and support the plated wires. The printed circuit is also used for interconnecting the planes of the memory stack. Analysis of digit current and signal coupling is given. The advantages of the proposed memory stack configuration are apparent. These include low digit current and digit signal coupling along with good word and digit noise cancellations and high bit density.

Magnetization Creep in Magnetic Films, *W. Kayser*—Magnetization reversal in planar magnetic films can occur for field amplitudes well below the static treshold. Repeated field transitions parallel to a film's hard axis in the presence of an easy axis field can cause slow motion or "creeping" of the domain boundaries. Experimental observations of magnetization creep and proposed creep mechanisms are reviewed. Creep was studied in slow-rising sine-wave and pulsed hard-axis fields. The effective creep thresholds obtained for these cases are compared. In an operating mode in which a bipolar easy axis pulse and a unipolar word pulse are used, creep is reduced and the effective creep threshold is improved. Examples of domain growth in unipolar and bipolar hard axis fields are shown in a series of Kerr optical photographs demonstrating the creep process.

The Effects of Metallic Underlayers on Properties of Permalloy Films, *K. Y. Ahn, J. F. Freedman*—Thin Permalloy films of zero-magnetostrictive composition were evaporated on a variety of metal film underlayers of various thicknesses (which were deposited on glass substrates) and also on smooth metallic substrates. In contrast to Prosen *et al.*, however, the observed uniaxial magnetic anisotropy is not zero. In thin Permalloy films (100–1000 Å) deposited on high-melting-point metal films (Mo, Ti, Pd, and Cr), essentially the same anisotropy field is obtained as is normally observed on glass substrates. In these films the coercivity and the angular dispersion increase slightly as the underlayer thickness increases. Permalloy properties on low-melting-point metals (Au, Ag, Cu, and Al) depend strongly upon the underlayer thickness. At a given substrate temperature, a maximum in coercivity and angular dispersion is found in $\sim$100 Å thick underlayers of Au, Ag, and Cu. In Al underlayers, the values of coercive force along the easy and hard axis increase rapidly as a function of thickness. Large values of the easy-axis skew are obtained in all metal underlayers where the direction of the skew depends upon the geometrical arrangement of the vapor source (Permalloy) and the substrate. These effects are attributed to the microstructure and morphology of the underlayers. Electron microscopy studies are presented in confirmation of these surface geometrical effects.

Mathematical Models for Loss Measurements in Thin Permalloy Films with Ramp Drives, *H. C. Bourne, Jr., C. N. Causey*—Uniaxial thin Permalloy films are driven with a large amplitude sinusoidal H field in order to approximate a ramp drive. The H field is characterized by rise times that exceed 3×10^6 Oe/sec. Two mathematical models are suggested to represent the loss measurements obtained in a domain wall motion region and in an incoherent rotation region. A normalized loss threshold is determined that characterizes the transition between the two regions. In the slow reversal or wall motion region, the normalized losses are proportional to the square root of α where $H = \alpha t$. In the relatively fast reversal or incoherent rotation region, the normalized losses are proportional to α. In both cases the inverse switching time is proportional to the coercive force in excess of the static value. Experimental data verify the reasonableness of the mathematical models.

A Study of Noncoherent Rotation Switching for Thin Magnetic Films, *J. H. Hoper*—Thin magnetic film switching was investigated for fields near those needed for pure rotation. Experimentally the films were switched using <0.4-ns rise-time field pulses. The resulting flux changes were detected in the easy and hard direction with a response time of 0.6 ns. Measurements were made for pulses both longer and shorter than the magnetization switching times. By analyzing the voltage waveforms and flux changes, it was concluded that instabilities and rapid rearrangements of the magnetization can occur within a few nanoseconds,causing anomalous results during switching. Equations of existing quantitative switching models—pure rotation, spin-wave, and stripe domain—were solved with a digital computer. To better compare theory and experiment, the solutions were modified to account for the sense system's finite rise time. It was found that none of the existing models adequately described the switching processes for low amplitude magnetic fields. However, qualitatively, the stripe domain model best fits the experimental data.

IEEE Transactions on Microwave Theory and Techniques

Vol. MTT-15, no. 6, June 1967

Resonant Frequency of Open-Ended Cylindrical Cavity, *N. C. Wenger*—The TE_{011} mode of oscillation in an open-ended circular cylindrical microwave cavity is analyzed. The cavity consists of a circular waveguide that is terminated at each end with a thin cylindrical partition coaxial with the circular waveguide. The resonant frequency of the cavity is computed by using Laplace transform and Wiener–Hopf techniques. Numerical values for the resonant frequency are presented.

Theory of Direct-Coupled-Cavity Filters, *R. Levy*—A new theory is presented for the design of direct-coupled-cavity filters in transmission line or waveguide. It is shown that for a specified range of parameters the nsertion-loss characteristic of these filters in case of Chebyshev equal-ripple characteristic is given very accurately by the formula

$$\frac{P_0}{P_L} = 1 + h^2 T_n^{\,2}\left[\frac{\omega_0}{\omega}\,\frac{\sin\left(\pi\dfrac{\omega}{\omega_0}\right)}{\sin\theta_0'}\right]$$

where h defines the ripple level, T_n is the first-kind Chebyshev polynomial of degree n, ω/ω_0 is normalized frequency, and θ_0' is an angle proportional to the bandwidth of a distributed low-pass prototype filter. The element values of the direct-coupled filter are related directly to the step impedances of the prototype whose values have been tabulated. The theory gives close agreement with computed data over a range of parameters as specified by a very simple formula. The design technique is convenient for practical applications.

A Frequency Transformation for Commensurate Transmission-Line Networks, *E. G. Cristal*—The frequency transformation $W = 1/S$, where $S = \tanh(\gamma L)$, is investigated for commensurate transmission-line networks consisting of stubs, resistors, ideal transformers, and unit elements. This transformation takes transmission-line transformers into transmission-line low-pass filters and vice versa, low-pass (or bandstop) filters into high-pass (or bandpass) filters and vice versa, and elliptic-function bandstop filters into elliptic-function bandpass filters and vice versa. The practicality of the transformation lies in the fact that element values of the transformed network are easily related to the corresponding element values of the original network. The transformation is useful because it provides an alternative viewpoint for synthesis, and because it reduces the number of tables of designs needed for various filter types. Several examples of designs using the transformation are given. One design is an unusual narrow-band 3-dB directional coupler.

Current Distribution and Impedance of Lossless Conductor Systems, *R. L. Brooke, J. E. Cruz*—A general method for determining the characteristic impedance of uniform, lossless, transmission systems is developed. The current distribution within the system is determined by means of a matrix equation programmed for computer solution. Once the current distribution is known, the inductance per unit length and characteristic impedance are determined. The results obtained by applying this method to several rectangular coaxial systems are compared with the predictions of an approximate analytic expression. The reflection coefficient of a variable characteristic impedance coaxial line is measured on a time-domain reflectometer, and the results are compared with both the matrix method and the approximate analytic expression.

Radiation from an Infinite Array of Parallel-Plate Waveguides with Thick Walls, *S. W. Lee*—A semi-infinite array of parallel-plate waveguides with walls of finite thickness is excited by incident TEM modes in every waveguide identically. By proper application of the boundary conditions, two Wiener–Hopf equations are obtained, which, however, cannot be solved by the standard techniques. A method originated by Jones is applied to recast these two equations so that the forms of the solutions are found. The solutions involve constants to be determined by an infinite set of linear simultaneous equations which converge absolutely. When the thickness of the walls b is small compared with the wavelength λ, explicit solutions of the order of $O(b/\lambda)$ are found in very simple forms.

Propagation in Rectangular Waveguide Filled with Skew Uniaxial Dielectric, *J. R. Davies*—A solution is given for propagation in rectangular waveguide fully loaded with a uniaxial dielectric, with the c-axis lying anywhere in the transverse plane. This problem arises in the design of particular traveling-wave masers. By application of the Rayleigh–Ritz method to Berk's variational expression, the problem is reduced to a matrix eigenvalue problem, and in a form suitable for direct evaluation on a digital computer. An explicit approximate solution is, however, shown to give accurat results. The analysis can be interpreted d rectly in terms of mode coupling of the usua rectangular waveguide modes, and the possibl extension is indicated to general tensor medi and to circular or elliptical waveguide.

IEEE Transactions on Parts, Materials and Packaging

Vol. PMP-3, no. 2, June 1967

Analysis of Transient Loading and Heating o the Electronic Transformer, *N. R. Grossner*—Electronic transformers are often subject t intermittent or transient electrical loading As a consequence there are a variety of therma waveforms that alter, in differing degrees, th aging rate of the transformer. Certain bas parameters—the thermal time constant, dut ratio, and relative aging—are defined and va ious load waveshapes are described. It shown how the concept of relative aging ca be employed so as to permit either an increas in the steady-state volt-ampere rating or reduction in the size of the electronic tran former, without jeopardizing the transformer life expectancy.

Correspondence

A Practical Method of Heat Computations i Electronic Equipment, *G. Rezek*

IEEE Journal of Quantum Electronics

Vol. QE-3, no. 6, June 1967

(Abstracts of the IEEE Conference on Las Engineering and Applications, Washingto D.C., June 6–9, 1967)

Atmospheric Modulation Noise in an Optic Heterodyne Receiver, *D. L. Fried*—Atmo spheric modulation noise in an optical hetero dyne receiver, as measured by σ_M^2, the no malized variance of the signal power, and b $\langle(\Delta f)\rangle$, the mean-square frequency spread what would otherwise be a monochromat signal, are evaluated. The analysis is based o the statistics of optical propagation in a ra domly inhomogeneous medium, and pa ticularly on results for the wave-structure fun tion. It is shown that to avoid a large signa power variance, the receiver–collector diam eter should be no larger than r_o (r_o is the diam eter associated with saturation of receiv performance as measured by the average si nal-to-noise ratio). It is found that the rms fr quency spread due to atmospheric effects small enough that, even under worst cond tions, such a frequency spread will not serious affect the velocity resolution on an optic Doppler radar.

Laser Mode-Locking with Saturable Absorbe *E. Garmire, A. Yariv*—A mode-locked laser described in terms of traveling pulses of ligh It is shown that the energy absorbed by saturable absorber is a minimum if the pul length is a minimum and that two pulses a essentially as favorable as one if they meet the position of the dye cell. Under steady-sta pulsing conditions, however, the pulses w have a width that depends on their energ It is found that for parameters appropriate present Nd:glass experiments, the expect length is about 10^{-11} second, in agreement wi observations. Finally, the rather surprisi result that a linearly dispersive medium do not broaden the mode-locked laser pulses first order is demonstrated.

Correspondence

Megawatt Line Radiator Using Sequent Inductive Discharges, *A. Papayoanou, G. Buser*

Translated journals

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Tables of Contents

Electrical Engineering in Japan

(Journal of the Institute of Electrical Engineers of Japan)

Vol. 87, no. 1, January 1967

Electronics and Communications in Japan

(Journal of the Institute of Electrical Communications Engineers of Japan)

Vol. 50, no. 1, January 1967

Lecture

Contributed Papers

Engineering Cybernetics

Vol. 5, no. 1, January–February 1967

Control Problems and Operations Research

System Reliability and Maintenance

***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 Electronica should apply to the IEEE Special Subscription Department.**

Radio Engineering and Electronic Physics

the Directivity of Large Antennas, *Ya. S. Shifrin, L. G. Kornienko*

Synthesis of Phase Correctors Forming a Given Field, *B. Z. Katzenellenbaum, V. V. Semenov*

Diffraction of a Plane Electromagnetic Wave from a Dielectric Layer with a Grid Antenna, *V. A. Kaplun*

Symmetrical Waveguide Circulators, *I. P. Tyukov*

Light Propagation in a Stable Medium with Negative Absorption, *L. A. Rivlin*

Distortion of Nonlinear Signals by Saturation of a Quantum Paramagnetic Amplifier, *N. V. Karlov, T. I. Kuznetsova*

A Quantum Paramagnetic Amplifier Delay System Partially Loaded with an Active Substance with Anisotropic Specific Inductive Capacitance, *Yu. V. Abazadze, E. G. Solovyev*

New Methods of Measurement of Hall Electromotive Force, *Yu. F. Ogrin, V. N. Lutzkiy*

Impedance of the Surface Region of a Semiconductor, *V. N. Dobrovolskiy, O. S. Zinets*

Pulse Properties of Gallium Phosphide Light Sources, *I. M. Matusevich, N. F. Nedelskiy*

High-Frequency Microstructural Polarization of Semiconductors, *Ye. Z. Meylikhov*

Design of Waveguide Y-Circulators on the Basis of Their External Characteristics, *A. K. Stolyarov, I. P. Tyukov*

Plasma Diagnostics by a Plasma Beam, *V. P. Chirkov*

Conservation of Energy in TWT and Maximum Efficiency of this Tube, *N. M. Sovetov, A. N. Shestoperov, G. T. Razakov*

The Theory of TV Camera Tubes, *A. Frishman*

Smoothing Properties of Nonlinear Filters Using the Capacity of the p-n Junction, *G. I. Ilyin, V. A. Lossovskiy*

Telecommunications and Radio Engineering Part I—Telecommunications

Vol. 21, no. 2, February 1967

Basic Laws of Error Distribution in Discrete Communication Channels, *L. P. Purtov, A. S. Zamriy, A. I. Zakharov*

Reliability of Discrete Information Transmission in the Presence of Pulse Interference, *S. P. Vol'fbein, N. G. Veksler*

Choice of Optimum Parameters in a Phase Telegraphy System with Signal Fading, *V. V. Sokolov, M. I. Pelekhatyi*

The Distribution of Errors in the Incoherent Reception of Binary Signals in Relative Phase Telegraphy, *N. P. Khvorostenko*

Optimum Representation of Signals with Limited Spectrum by a Truncated Kotel'nikov Series, *A. Yu. Lev, V. A. Kisel'*

Experimental Characteristics of a Reflex Klystron Amplifier and Synchronized Oscillator with Automatic Phase Control, *L. A. Belov et al.*

Doppler Effect in a Rotating System Radiating and Reflecting EM Waves, *L. I. Bogin, V. O. Kobak*

Interdependence of the Autonomous Parameters of a Transistor in Different Circuit Configurations, *V. I. Anisimov*

Some Time and Spectral Characteristics of the Overall Radio Interference in Large Cities, *V. I. Glinka, G. M. Myaskovskiy*

Two-Sided Inductive Coupling in Factories, *B. A. Shvarts*

Features of Thermal Compensation of the Frequency of Controlled Quartz Oscillators, G. B. Al'tshuller

Radio Interference of Low-Lying Radio Communication in Cities, *P. M. Trifonov, V. N. Makarov, E. V. Martsinkovskiy*

Optimum Distribution of Redundancy in Fixed-Length Codes, *G. V. Lavinskiy*

Determination of the Reflection Coefficients in a Circuit with Uniformly Distributed Loads, *A. F. Zenevich*

Part II—Radio Engineering

Vol. 22, no. 2, February 1967

Optimum Characteristics of Low-Pass Filters, *A. A. Lanne*

Determination of the Pull-In Range of a PAFC System with Inertia in the Presence of Fluctuation Noise, *V. V. Shakhgil'dyan*

Method of Calculating the Selectivity Characteristic of a Tuned Circuit Containing a Nonlinear Capacitance, *A. M. Mallyar*

Broadband Miniature Bridge for the UHF and Microwave Bands, *L. G. Dorfman*

Power Transmitted by the E_{00} Wave in a Surface-Wave Line, *N. A. Semenov*

Statistics of a Linear Antenna Array Field When Periodically Correlated Phase Errors Are Present, *V. Yu. Rudin, V. V. Sazonov*

Effect of Combined Signal and Noise on Differential Frequency Discriminators, Part 1, *Yu. M. Davydov*

Threshold Relationships in FM Signal Reception, *E. S. Elinson, A. S. Larionov*

Gain of a Converter Using a Variable Admittance, *V. M. Meshchankin*

Simple Harmonic Quartz Meter Wave Transistor Oscillators, *T. D. Gavra, M. M. Pruzhanskiy, Yu. V. Shabanov*

Bridge Phase Shifters with Constant Input Impedance, *V. L. Danilov, V. A. Rodionov*

Analysis of Optimum Reception of Signals Which Have Passed Through a Channel with Random Parameters, *V. M. Smol'yaninov, L. I. Filippov*

Standardization of Angular Error Signals in Monopulse Radar with Single-Channel IFA, *N. I. Chertkov*

Reflection of a Plane Electromagnetic Wave from an Ideally Conducting Ellipsoid of Revolution, *Yu. V. Pimenov, V. A. Kravtsov*

Effect of the Finite Dimensions of the Antenna Aperture in the Vertical Plane on the Conditions for Line-of-Sight Propagation of USW, *M. P. Dopukhanov*

Comparison of the Noise Immunity of Discrete Synchronization Systems with Various Additional Devices, *M. I. Romanovskiy*

Operation of a Cathode Follower Under Pulsed Conditions, *A. P. Pershin, Yu. V. Sal'gin*

A Method of Constructing Delay Devices, *M. I. Finkel'shtein*

Parameters of a Tee Substitution Circuit Taking the Impedances Shunting the Transistor Into Account, *M. D. Shterk*

Stroboscopic Distortions for Equiaccelerated Motion ("Blind" Accelerations), *P. V. Makovetskiy*

Some Technical Applications of the Polynomial Method of Extrapolation, *A. V. Mozgalevskiy, D. V. Gaskarov*

Reviews

Electrical Engineering in Japan

Vol. 86, no. 6, June 1966

Equivalent Circuit of a Power System by the Mesh Method, *M. Hayashi, N. Noda*—This paper explores the possibilities of network reduction and solution of various power system problems by mesh matrix manipulation. The equations formulated are specifically suited for solution on a digital computer. Using Lagrangian network topology, the authors propose a method for reduction of the system mesh matrix utilizing sectionalization techniques to speed solution. Several types of problems are solved using the equivalent mesh matrix, both in general and with numerical examples. These include: power flow, transmission loss, transmission loss factor, and line faults.

The authors provide a good deal of information relative to digital computer timings for their method. These, however, are for extremely small power systems. Optimistic projection of these timings for system sizes normally studied indicate excessive length for the equivalent calculations. In certain cases the mesh method may prove superior to nodal solution. The authors do indicate that for any application, both nodal and mesh methods should be compared to determine the best to use.—*W. W. Maslin*

Analysis of Hysteresis Motors Considering Eddy Current Effect, *S. Miyairi, T. Kataoka*—The authors have discovered the need to consider the torques produced by eddy currents in the hysteresis ring in the asynchronous modes of the hysteresis motor. The characteristics of the machine in this mode are analyzed. Means for analysis of the eddy currents are suggested. The flux and eddy current distributions in the rotor are described. A method is proposed for calculating the hysteresis and eddy current losses. All of the above analytical work is brought together by offering an equivalent circuit for the hysteresis motor. Experimental results are compared with calculations made from the equivalent circuit in the asynchronous mode of operation. This information appears useful to the motor-design engineer.—*R. P. Boynton*

Analysis of Single-Phase Induction Motor, *A. Ozawa*—This paper deals with performance calculations on single-phase motors. It derives equations for such performance calculations, making use of the cross-field approach. It discusses the parameter k, defined as the ratio of rotor reactance to resistance (the reciprocal of r_2/X, used by many writers.) The paper also discusses calculation of circuit constants from test values. Further, it develops a circle diagram. It leans quite heavily upon tests to determine magnitudes of constants to be used in calculations.

Topics covered by the paper have, in general, been covered more fully and more comprehensively by many articles, technical papers, and books from 1918 to date. It is to be doubted that those who are familiar with the literature on the subject (unfortunately not cited or referenced by the author), will find much, if any, new material.—*C. G. Veinott*

Vol. 86, no. 7, July 1966

Minimum Phase-to-Phase Electrical Clearances of Substation Bus for Switching and Lightning Surges, *T. Udo*—Mr. Udo, in a well-documented article, has explored the pertinent considerations for determining minimum phase-to-phase clearances for substation busses. He deduces that although many factors influence the minimum clearance, any study should assume surges of opposite polarity on each electrode. The clearance for stations operated at 287 kV and below should be determined by lightning considerations whereas those operated above 287 kV are controlled by switching surge voltages. In the clearance ranges from 2-4.5 meters (6.5-15 feet) rod-to-rod and conductor-to-conductor gap spacing have almost identical voltage withstands. A procedure is set forth for determining minimum clearances that should be useful to all persons making decisions concerning bus clearances.—*J. A. Rawls*

Analysis of Brushless Self-Excited-Type Single-Phase Synchronous Generator, *S. Nonaka, I. Muta*—This paper presents an analysis of an improved brushless self-excited single-phase synchronous generator. A previous paper covered this type of machine, in which a condenser was connected to the single-phase stator winding in parallel with the load. In this case, the authors report improvement in characteristics and performance by adding a second winding in quadrature with the original load winding. The condenser is removed from the original load winding and connected across the second winding. The stator then contains unbalanced two-phase windings, one of which is connected to a condenser as an exciting winding and the other used as the load winding.

As in the original machine, the self-excitation of the rotating field is obtained by rectifying the second-harmonic voltage induced in the field winding by the negative-sequence rotating field due to armature reaction of the load winding. Moreover, the MMF of the positive sequence loading current in the condenser exciting winding increases the self-excitation effect. The generator has the compound characteristics consisting of the series-generator characteristic due to the load current and the shunt-generator characteristic due to the condenser current. The initial voltage buildup is caused by a leading current flowing in the condenser exciting winding as a result of the induced voltage caused by the residual magnetism. Self-excitation of this winding will then continue by the increasing magnetism of this leading current. The improved generator has a greater output power ability than the original generator and the voltage fluctuation due to the resistive load is almost zero. In addition, the voltage buildup can easily be made under load and the generator has excellent load characteristics.

An excellent analysis and determination of no-load and loaded characteristics is made taking into account the effects of saturation for both the original and improved machines. Voltage and current waveforms and harmonics are also studied.

The chief value of this paper is its academic excellence. There is probably no great practical use for this type of synchronous generator since other types of brushless synchronous generators afford better performance and more voltage and load control. The exciting winding, condenser, and the rotating rectifier do not appear to offer much advantage over the conventional brushless exciters. However, this paper does add to the knowledge of single- and polyphase synchronous motors under capacitor self-excited conditions.—*P. J. Tsivitse*

Method of Calculating Optimum Terminal Values of Water Storage for Economical Operation of Hydrothermal Power Systems, *S. Tsuzuki*—The paper contains a very readable description of the technique used and the application of a digital computer program to the problem of calculating the optimum terminal values of water storage for economical operation of hydrothermal power systems. The optimization techniques used are well known in the United States, however, the demonstration of the saving in volume of computation in this method of application is unique and well worth consideration by those involved with hydrothermal scheduling. —*P. M. Davidson*

Radio Engineering and Electronic Physics

Vol. 11, no. 4, April 1966

Optimum Reception of Signals in Nongaussian Noise, *R. L. Stratonovich, Yu. G. Sosulin*—The problem of the detection of the presence of a signal in nongaussian noise is considered in this paper. The equations for optimum detection are derived for the general case in which signal and noise are assumed to be functions of continuous Markov processes. Added to the nongaussian noise is a white Gaussian noise component. A three-dimensional Markov process is formed using the signal, the nongaussian portion of the noise, and the integral of the observed waveform, from which, using the theory of conditional Markov processes, the equations for the logarithm of the likelihood ratio are developed. The optimum receiver is realized as consisting of optimum nonlinear filtering, formation of the likelihood ratio, and comparison with a fixed threshold.

The general results are applied to a special case consisting of a known sinusoidal signal and phase-modulated interference in which the modulating waveform is white Gaussian noise. The equations for the operating characteristics, in the form of the probabilities of error of the first and second kinds, are derived for this special case.

The results of this paper should be of interest to those working in the area, particularly because of the relatively straightforward manner in which the equations can be applied to specific problems, as is evidenced by the example given in the paper.—*A. R. Cohen*

Angular Noise, *R. V. Ostrovityanov*—The paper deals with the angular noise or scintillation of the reflection center of a radar target. The discussion is based on a two point model of the target. It is shown that the variation of the angle of the resultant Poynting vector at the receiver is confined to $\pm\pi/2$. The author then develops the probability density function for the angular noise, and compares his results to those of an earlier paper.[1] The earlier results show considerable discrepancy from these, except when the probability densities of the reflected amplitudes from the two point sources are equal. The variance of the angular noise is then evaluated and it is demonstrated that the variance is finite, contrary to the references. (It should be noted, however, that in reference 1, while an infinite result was obtained for variance, it was recognized that the calculation violated the basic assumptions.)

Finally, the effect of a limited-beam-width receiver is examined, and it is shown that this reduces the tracking error. The results should be of value in radar location and tracking.—*T. T. N. Bucher*

1. The author's reference [1] would appear to correspond to and is probably a reprint or translation of: DeLano, R. H., "A theory of target glint or angular scintillation in radar tracking," *Proc. IRE*, vol. 41, p. 1778, Dec. 1953.

Discontinuities in Rectangular Waveguides, Higher-Mode Waves, *V. P. Shestopalov, V. V. Shcherbak*—This is an extension of earlier work by the same authors. They have applied a "rigorous" theory to cast the problem of diffraction by a planar, aperiodic array of strips in rectangular waveguide into a form amenable to numerical computation. By "rigorous" the authors apparently mean that the approximations are those of numerical analysis, and presumably the accuracy is estimable. The mathematical methods are given in this paper, but numerical methods are not. References are given to earlier work.

As the quantitative behavior of reflection and transmission coefficients of strips in waveguides is, by now, reasonably well known, it can be seen that the numerical results given as graphs in the paper appear to be correct, displaying the Wood's anomalies in the expected places. Since no specific motivation or application for the results is suggested, this reviewer is left with the impression that the work may have been undertaken purely as an exercise in computer applications.—*R. B. Kieburtz*

Vol. 11, no. 6, June 1966

Two-Stage Detection Procedure Without Level Quantization of Signals, *Yu. B. Sindler*—The author considers a problem in sequential hypothesis testing where a second test is performed based on the outcome of a first test. In particular, the "signal power" allocated to the second test depends on the outcome of the first test. The likelihood ratio arising from the first test, z_1, is compared with two preset levels, z_l and z_u. If $z_1 \leq z_l$, the null hypothesis (H_0) is accepted. If $z_l — z_u$, hypothesis H_l is accepted. If $z_l < z_1 < z_u$, a second test is performed with signal power functionally related to z_1. The likelihood ratio arising from the second test is z_2. Then the hypotheses are distinguished depending on whether $z_1 + z_2$ exceeds or is less than another threshold, c.

It is desired to maximize the detection probability (the probability that H_1 is correctly accepted) subject to a preset false alarm probability (the probability that H_0 is incorrectly rejected) and preset second-stage average energy expenditure conditional on H_0. The maximization is with respect to the thresholds z_l and z_u (which are set independent of z_1) and c (which may be a function of z_1). The maximization is also with respect to the functional dependence on z_1 of the second test's signal energy.

The problem is set up in considerable generality. It is shown that, in general, the final threshold c should be independent of z_1. The complete solution is obtained for a known signal in additive Gaussian noise and for a signal with Rayleigh amplitude distribution and unknown phase in additive Gaussian noise. The average energy implied by the latter solution is numerically compared with the energy required in single-pulse detection for the same detection and false alarm probabilities. The ratio of energies, called efficiency, is calculated for several signal-to-noise ratios and false alarm probabilities. Also compared is the efficiency of a two-step test with quantization, which had been discussed previously. (There is an apparent inversion of column headings in the table on page 873.) The computations show the effectiveness of the two-level test (efficiencies range from 1.2 at low signal-to-noise ratio to 3.8 at high signal-to-noise ratio). Also shown is the fact that quantization in two-level tests does not lower efficiency much at low signal-to-noise ratio, but does lower efficiency considerably at high signal-to-noise ratios.—*B. Reiffen*

Vol. 11, no. 8, August 1966

The Use of Methods of Control of the Surface of Optical Telescopes for the Adjustment of Pencil-Beam Radio Telescopes, *B. V. Braude, N. A. Yesepkina, V. Yu. Petrun'kin, S. E. Khaykink, V. N. Umetskiy*—The authors outline the difficulties encountered when the methods employed for adjusting the surface of optical telescopes are applied to the adjustment of large, parabolic reflector antennas. Foucault knife-edge techniques are reviewed and found to be incapable of providing the accuracy required for measuring antenna reflectors.

The authors propose the use of a radio-frequency measurement technique that involves: (1) the illumination of the reflector by a radio-frequency signal source located outside of the normal focal point to provide a convergent wavefront in the near field, (2) the placement of a number of small, movable antenna elements, each with a microwave modulator, on the surface of the reflector to be measured, and (3) a pickup receiver near the second focal point of the antenna to detect the phase of the signal reflected from one of the modulated antenna elements on the reflector surface. In this technique, the relative phase of the reflected signal after demodulation is directly related to the surface contour of the reflector.

Related phase-modulation techniques for measuring antennas have been explored at the Stanford Research Institute and the M.I.T. Lincoln Laboratory. This technique has been successfully used on the Soviet GAO movable-plate telescope to detect surface displacements of fractions of a millimeter. It will be more difficult to employ on large, fully steerable paraboloids with shorter f/D (0.3–0.4).—*H. G. Weiss*

Special publications

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.

Publication		Prices M	Prices N
S-135	Power Cable Ampacities, Volumes I and II (Sold in sets only)—1962	15.00	15.00
	Radio Spectrum Utilization (book)	10.00	10.00
3 C 38	International Symposium on Antennas & Propagation—Dec. 5–7, 1966	4.00	6.00
6 C 64	Vehicular Communications Conference Record—Dec. 1–2, 1966	2.50	5.00
7 C 50	1967 Symposium on Reliability—Jan. 10–12	8.00	8.00
10 C 22	1966 Aerospace Systems Conference—July 11–15 (Transactions Supplement)	7.50	15.00
10 C 34	1966 Aerospace & Electronic Systems Convention Record (Supplement to AES-2, no. 6, Nov. 1966)—Sept. 26–27	7.50	15.00
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
	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
	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 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
	14th Annual Joint Engineering Management Conference—Sept. 26–27, 1966	10.00	10.00
	19th Conference on Engineering in Medicine and Biology—Nov. 14–16, 1966 (Hardbound)	12.00	18.00
	International Solid-State Circuits Conference—Feb. 15–17, 1967	6.00	6.00
F 72	Southwestern IEEE Conference (SWIEEECO)—April 19–21, 1967	6.00	9.00
	1966 Electron Devices Meeting—Oct. 26–28 (Abstracts)	2.00	2.00
15 C 63	**8th Conference on Tube Techniques—Sept. 20–22, 1966 (Record)**	**6.00**	**9.00**
	(Digest)	**1.00**	**2.00**
26 C 68	**Conference on Improving the Strategy of Oral Presentations—Feb. 6, 1967**	**2.00**	**4.00**
	INTERMAG, International Conference on Magnetics—April 5–7, 1967 (Digest)	**2.50**	**2.50**
F 71	**Region 3 Meeting—April 17–19, 1967 (Record)**	**5.00**	**10.00**
	Electronic Components Conference—May 3–5, 1967 (Proceedings)	**7.00**	**7.00**
31 C 69	**PICA, Power Industry Computer Application—May 15–17, 1967**	**10.00**	**10.00**
34 C 55	**Industrial and Commercial Power Systems Technical Conference—May 22–25, 1967**	**5.00**	**7.50**

of the fluorescent CRT image, which is incompatible with existing microfilm reproduction equipment.

An experimental device was built that develops the full-reversal white-on-black images of the CRT in 13½ seconds using only four processing solutions—developer, bleach, redeveloper, and rinse. Full reversal is accomplished by re-exposure through the film base at the redevelopment station.

The rapid-access full-reversal process was especially adapted for optimum use with the information density, line widths, and contrast of CRT displays. Image densities were evaluated to determine optimum development time and temperature, and modifications to processing formulas. Film velocity for the processor was 24 inches (approximately 61 cm) per minute, which produces a developed picture every two seconds.

Laser technique detects metal traces in human cells

Scientists can now detect tiny traces of metals in a single human cell or part of a cell by making it go up in a puff of smoke—through a new application of the laser. The laser beam is focused through a microscope on a minute piece of tissue. The tissue is vaporized at a temperature of about 18 000 degrees over a period of a few millionths of a second.

The light from the minute brilliant cloud is made up of many wavelengths that produce a spectrum of the cell's chemical composition. The intensity of the color at each wavelength depends on the quantity of a particular metal present in the original sample. The intensity is measured by a very sensitive photoelectric tube attached to a spectrograph.

In recent experiments, a Stanford University School of Medicine research team (Drs. David Glick, E. S. Beatrice, and I. Harding-Barlow) succeeded in detecting metals such as iron and zinc in single human red and white blood cells, sperm cells, and liver and kidney cells. Metals necessary for human life as well as those that could possibly be dangerous to health can now be identified as a result of the technique, which simplifies measurement of a few million trillionths of an ounce of metal in a sample the size of a very fine pollen grain.

The research is being supported by the National Institutes of Health.

Technical correspondence

Patent recommendations

In February (pp. 57–64) and April (pp. 64–69), IEEE Spectrum published articles discussing the U.S. President's Patent Commission's recommendations for revisions in the present patent system. The following is from a report of a special subcommittee of the New York Patent Law Association commenting on some of these recommendations. In its present form, this is only a draft report representing the views of the special subcommittee; it has not yet been acted on or approved by the Board of Managers of the Association.

The large compass and the still larger implications of the Report of the President's Commission have made it impossible for the subcommittee to consider all aspects of the Report. Those thought to be of greatest importance are the first three recommendations.

The committee opposes Recommendations I, II, and III, for we believe great harm would come from the proposal to determine priority of invention only upon the dates of the filing of applications in the Patent Office and from the proposal to extend the bar of "prior art" to knowledge, use, or sale anywhere in the world before the filing date of a patent application.

The principal advantage urged for the proposed system is that it would enable interference proceedings to be abolished. Although the committee agrees that the present interference practice is undesirable, we believe that the first-to-file system would create practical problems, expenses, uncertainties, and injustices far exceeding in importance those encountered in the relatively small number of cases put into interference by present practice.

The automatic award of priority to the man who wins the race to the Patent Office, save for proved derivation, would undeniably change the basic concept upon which the protection of inventive property has promoted the outstanding progress of the useful arts in the United States. The proposed system would, in many cases, prevent the real contributor from obtaining patent protection commensurate with his contribution. It would invite speculative concepts and disclosures for the purpose of blanketing an art, which would deter further research and development. It would promote a tendency to file a patent application before any work has been done and to make such filing of speculatively broad legal consequence. It would promote a new breed of "theoretical inventors" and would create new hazards for the works of those uninformed as to their legal rights. It would create a powerful discrimination in favor of the prosperous corporation against the individual inventor and the small company of limited means who cannot participate effectively in a contest to get to the Patent Office first. It would also promote the filing of preliminary applications on undeveloped, untried, and useless concepts.

Our law for over 130 years has rightly encouraged the person conceiving an invention to disclose it promptly to others, to test it, and to demonstrate its value under conditions of practical use, all with the aid and counsel of others, before undertaking the work and expense of a patent application. In this way, many impractical and valueless conceptions are weeded out, so U.S. patent applications for the most part have been directed to inventions of demonstrable worth. The law has also encouraged care and thoroughness in the preparation of patent applications.

In those countries in which a first-to-file rule prevails, anxious inventors submit applications that are sketchy and often merely speculative. It is a weakness of such patent systems that they work to the obvious detriment of the public and of inventors who are bound by premature and frequently inaccurate or unduly narrow specifications. Alternatively, an inventor who takes time to complete and present his invention in accordance with the high standards of disclosure that have hitherto been enforced here will be penalized by the risk of a rival's hasty filing.

The inventor in the United States who requires financial or technical assistance or advice from others not bound to him by ties of secrecy, or who needs proof of the worth of this work under commercial conditions, is assured that his rights will be secure for a limited period after public divulgence of his work. He can be advised not to spend money or apply for a patent before knowing his 'nvention is worthwhile; he can trust his neighbor and his consultants. He can accept the attendant risk of a pre-emptive application being filed by another, which is a small risk seldom hurtful under existing law, because his acts of making and perfecting the invention entitle him to prevail.

To provide this weeding-out and perfecting process is a vital function performed by the so-called "grace period." This period of permissible prior use, publication, or placing on sale is a matter of practical necessity, not merely of "grace." It is a "proof-of-worth" period. To eliminate it would not bring more prompt disclosure of newly discovered technology, for in the cases needing its protection the inventions are already publicly disclosed. To eliminate it would, however, require that other remedies be provided for the practical needs concerned, as the Commission has recognized by Recommendations II and III.

The needs are not alleviated by the provision for preliminary applications: the careful inventor will again be penalized, in favor of the speculator and the wild-guesser, if he labors to obtain and give, in his preliminary document, the practical, working information ordinarily deemed requisite for asserting completion of an invention or disclosure of a completed invention.

The proposed system would inordinately add to the paper work, cost, and complexity of protecting inventions. The questions of support for claims would be of the greatest complexity since the system would invite the disclosures of bits and pieces rather than a unified invention.

The application papers filed by another, or any publication, use, or placing on sale effected by another anywhere in the world, would erect a bar to the rights of an inventor whose application had not been filed earlier. Thus, no longer could the inventor risk disclosing his ideas to others or securing the assistance of others unless under the strictest bonds of secrecy and trust.

A regime of strict secrecy in pre-patent dealings with inventions has not been the rule in the United States. It has been the rule in those countries where a first-to-file system prevails. We do not believe this custom should be emulated.

The secrecy necessary for preventing unauthorized disclosures while inventions are being tested and developed is usually available to the larger companies, which have their own testing facilities and have their employees bound to secrecy agreements. It is often not available to small companies, and hardly at all to independent inventors. They commonly have no alternative but to draw upon the aid and judgment of others, in arms-length relationships, for the process of perfecting and proving the worth of their ideas. We do not believe they should be deterred from doing this, or required to spend money for patent applications, before being able safely to pursue steps needed for determination of the worth of their ideas.

Confidential disclosures of inventive work in progress, or mere rumors of it, to persons having hostile interests sometimes lead to disclosure in a publication, a use or a patent application unknown to the inventor. The first-to-file system would create strong inducements to acts of this kind designed and intended to bar the inventor's rights if his application were deferred to the completion of his work. Yet Recommendation III offers no real remedy. If the unauthorized use or publication is not known to the inventor, he cannot be expected to file a complete application within six months after its occurrence as the recommendation would require. And even if he should learn of the earlier use soon enough, the burden of proof of derivation and unauthorized disclosure placed upon him by the recommendation would seem insurmountable if the person intending to bar him had taken care to obscure his connection with the restrictive acts.

The proposed system would destroy the rights of the inventor whose invention is made and tested in public view. Some inventions are actually conceived and tested "on the spot" under conditions imposing no bond of confidence or secrecy upon persons witnessing them. Recommendation II would be of no avail to the inventor working under such conditions. Recommendation III, part 2, would also be of no avail, for his own making of the invention would have consituted a "public divulgation."

We consider it harmful to extend the concepts of "prior art" to knowledge, use, or placing on sale anywhere in the world. This would abandon the reliance in our law upon publications and patents, which are ascertainable with reasonable certainty, as the principal measures of the information available to the American public. It would create vast new areas of potential invalidating matter having little relation to the funds of information upon which artisans and inventors must build to advance the useful arts. These new areas of prior art would not be accessible to the Patent Office, and invalidating information contained in them could arise even *after* an applicant's invention if available at any time before his filing date; so every application filed and every patent issued would be under a worldwide cloud of potential invalidity and subject to the vagaries of proof of foreign acts. The search necessary to dissipate this cloud would impose large and unreasonable expense upon the inventor. It would increase the cost of patent litigation by opening up the need to take depositions in other countries, a practice that there has heretofore been little occasion to use.

This does not even represent harmonization of international patent practice. The only major industrial countries that consider use or sale in foreign countries as "prior art" are France, Italy, Mexico, Netherlands, and Sweden. Countries not having this provision are Argentina, Australia, Austria, Belgium, Brazil, Canada, Denmark, Germany (West), Great Britain, Japan, New Zealand, Norway, and Switzerland.

John Kelton
Subcommittee Chairman
New York, N.Y.

I should like to take this opportunity to point out that the American Patent Law Association appointed a special committee to study the patent system and that in the final report of this committee, dated July 14, 1966, it was recommended "that the United States abolish interferences and award the patent on the basis of the first to file, users prior to the filing date to be given a personal right to continue such use."

This recommendation is not identical with that of the President's Committee; however, I think that it illustrates that there is now by no means unanimity within the patent law profession.

B. M. Oliver
Palo Alto, Calif.

Hybrid propulsion

The article "Electric Cars—Hope Springs Eternal" by Nilo Lindgren (SPECTRUM, pp. 48–60, Apr. 1967) easily qualifies as the most informative and comprehensive of the recent spate of such surveys. It helped stimulate me toward some thoughts that I'd like to submit for consideration and discussion by others.

Mr. Lindgren refers to some closely guarded concepts for general-purpose vehicles and indicates that these are "rather dimly envisioned in the dark future." He mentions that these may be "hybrid" vehicles using electric propulsion in the city and a combustion engine for expressway driving. It appears to me that a modification of this concept could result in substantial reduction of pollutants and permit implementation at a relatively early date.

An internal-combustion engine operated over a wide range of loads and shaft speeds gives rise to a much higher concentration of undesirable exhaust products than a similar engine designed for, and operated at, a specific load-speed point. With appropriate energy storage provisions to absorb excess engine output under low-load conditions and to supplement that output under peak loads, it is possible—at least conceptually—to allow the engine to operate at steady state. Further, it appears possible to reduce engine size substantially (for equivalent vehicle performance) and, in city driving, to operate with the engine shut down much of the time. Pollution thus may be reduced in three ways—by operating the engine optimally, by reduction in engine size, and by reduction in engine-on time.

A suitable propulsion system for such a vehicle might consist of electric traction motors, batteries, and a generator matched to an internal-combustion engine. (The engine might well be diesel rather than spark ignition, as the desirable fuel, economic, and exhaust characteristics of the diesel engine are not in this case countered by response problems.) The engine–generator combination would be sized to handle traction loads at cruise speed, plus auxiliary loads such as lights and air conditioning, and expected recharging demands, without battery assistance. Battery assistance would provide peak tractive effort of the order of three times cruise requirements for passing and long upgrades. In city driving, the batteries would carry the load until discharged to a predetermined level, whereupon the engine–generator would be employed to take over the load *and* recharge the batteries until full charge was restored. (After short city trips, external power could be employed for recharging to reduce engine-on time further.)

Providing both high performance and minimum pollution implies two operating modes with manual or speed-sensing mode selection. In the city mode, the engine would be shut down, except when needed. In the highway mode, the engine would be maintained in quick-response condition by keeping it in full-speed idle when not needed (e.g., intermittently during operation below cruise speeds).

Some rough preliminary calculations indicate that such a system is presently feasible with no extravagant development demands *except* in the battery area, where development comparable to that required for all-electric operation seems necessary. An 1820-kg vehicle capable of 110-km/h cruise requires perhaps 40 to 50 hp at the motor shaft(s). With motor and generator efficiency each at 90 percent, battery energy efficiency at 70 percent, and battery depth-of-discharge limited to 35 percent for longevity reasons (engine–generator cut in at 25 percent depth of discharge), and 10–12.5 kW in nontraction loads, the generator capacity should be 47–60 kW, the engine rating 70–90 hp, and the battery capacity 30–40 kWh. For reasonable gross weight, battery specific capacity should be 110 Wh/kg or better; high-rate capabilities (maximum discharge rate 2.1 amperes, maximum charge rate 1.6 amperes) also are needed. If such rates can be attained without other penalties, battery life expectancy at the stated depth-of-discharge criteria would correspond to vehicle life expectancy (based on nickel-cadmium and nickel-iron types). For city operation, the engine duty cycle is approximately 45 percent and the engine-off time per cycle 22 minutes.

Although the propulsion concept suggested herein does not match the pollution reduction potential of an all-electric system, it seems to offer very substantial relief. At the same time, it avoids performance penalties, avoids the penalties of city-car specialization, and reduces the impact on the automotive and petroleum industries.

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Error in Conversion

In "Wired Broadcasting in Great Britain" (pp. 97–105 of the April issue), an error appeared on page 105 under "Network Costs." The original figures of $2600 per mile for a multipair network and $2400 per mile for a CATV network were incorrectly converted. The correct figures are $1600 and $1500, respectively, per kilometer.

R. P. Gabriel
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Book reviews

Optimal Control, Rufus Oldenburger—*Holt, Rinehart and Winston, 383 Madison Ave., New York, N.Y., 1966; 242 pages, $9.50.* This is a book on optimal control without the calculus of variations. Whereas much of the optimal control research reported in the last decade is dedicated to the proposition that the generalized control problem is an extension of the classical calculus of variations, Prof. Oldenburger here presents optimal control as an extension of classical control. In the preface, he states the approach this way:

"The control engineer is primarily concerned with keeping the maximum error to a minimum, and then with such other aspects of the response as the number of oscillations in the transients due to step disturbances, the magnitude of overswings and underswings, and the durations. He is interested in the entire response and thus simultaneously in infinitely many indexes of performance."

The class of problems to which this philosophy is applied in the book is quite specialized, being generically represented by the servomechanism with bounded actuator velocity. In block diagram terms, the major problem studied is that shown in Fig. 1. (The reviewer regrets that neither this nor any other block diagram appears in the book. Evidently, Prof. Oldenburger does not value graphical presentations of this kind as highly as the writer of this review.) Those familiar with the past work of the author will recognize that the engine governor problem so extensively studied by him is included here. Ideal system performance is taken as that for which the system error, $r - c$, is identically zero. Load disturbances as steps, ramps, pulses, and combinations of these are considered, including cases where the coming disturbance is known to the controller beforehand.

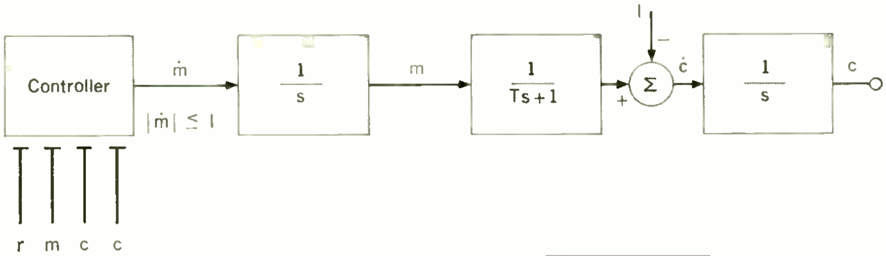
The first specific problem considered is that of the second-order case (with $T = 0$) and an unexpected initial error with $r = 0$. The solution is given as

$$\dot{m} = -\operatorname{sgn} \Sigma_2 \qquad \Sigma_2 \neq 0$$
$$= -\operatorname{sgn} \dot{c} \qquad \Sigma_2 = 0 \qquad (1)$$
$$\Sigma_2 = c + \tfrac{1}{2}\dot{c}|\dot{c}|$$

This solution, so well known to control engineers as a minimal time solution, is especially well liked by Prof. Oldenburger. He has defined $\dot{c}|\dot{c}|$ as the absquare for special reference and writes: "For a step load change where we start at the origin O, the curve Δ is optimal in the sense that the maximum system error is minimized, there is no overswing, and time is minimal; in fact, in the author's experience all reasonable criteria of optimality are satisfied simultaneously by the optimal curve Δ." The author's "optimal curve Δ" corresponds to (1).

In the more complicated third-order case it is similarly shown that the minimal response time control has desirable properties with respect to the number of underswings and the size of the maximum overswing as well as transient duration. In the progress of this demonstration, a switching surface for the system of Fig. 1 is derived by time domain arguments unrelated to the maximum principle but rather based on the assumption that the desired solution is bang-bang and has a minimum number of control reversals. Suboptimal controls of third- and higher-order systems are also presented based on control of the two dominant roots at $s = 0$ by a control law similar to (1). The approach is essentially the same as that proposed in 1955 by Kalman.[1]

FIGURE 1. Block diagram of basic problem, where r represents the reference input, c is the controlled output, l is the load disturbance, m is the manipulated variable, and $\dot{m}$ is the control variable (= dm/dt).



One of the stated purposes of the book is to supply proofs of the properties of "absquare" control, which were omitted in the early publications of Prof. Oldenburger. Readers familiar with these publications should find the book quite useful. It should be emphasized, however, that, as Prof. Oldenburger comments, hundreds of papers have been written on the subject of bang-bang control. It is unfortunate that all bibliographical material is omitted from this volume and only a sketchy review of the history of the problem with six references is given in the introduction.

The discussion of switching functions is central to the development of the book, and some of the analysis gets to be rather heavy going. Those interested in a derivation from the point of view of the "maximum principle" will find a complete derivation in the book of the same name by Athans and Falb.[2] Also, a very closely related study by Schmidt[3] should be consulted.

To summarize, this is not so much a book on optimal control but rather is a moderately complete defense of the nice properties of minimum time bang-bang control. The book is addressed to those practicing engineers who would wish to consider application of such control and includes several illustrations where successful application has been made in the past. Many derivations of switching functions are included. Several of these could be shortened by use of alternate techniques but the method presented is intended to be best suited to those who have read and used Prof. Oldenburger's previous publications. The unique feature of the book is the proof that the switching surface for minimum time also has other desirable properties from an application point of view. Within the somewhat limited scope of the book, its most serious defect is the virtually complete lack of reference made to other workers in a very popular field.

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1. Kalman, R. E., "Analysis and design principles of second and higher order saturating servomechanisms," *AIEE Trans.* (*Pt. II. Industry and General Applications*), vol. 74,

pp. 294–310, Nov. 1955; also in *Optimal and Self-Optimizing Control*, R. Oldenburger, ed. Cambridge: M.I.T. Press, 1966, chap. 6.

2. Athans, M., and Falb, P. L., *Optimal Control.* New York: McGraw-Hill, 1966.

3. Schmidt, S., "The analysis and design of continuous and sampled-data feedback control systems with a saturating type non-linearity," NASA TN-D-20, Washington, 1959. Summarized in Peschon, J., *Disciplines and Techniques of Systems Control.* New York: Blaisdell, 1964, pp. 231–242.

System Analysis by Digital Computer, Franklin F. Kuo and James F. Kaiser—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 432 pages, illus., $8.95.* The analysis and design of electric networks by digital computer is the subject of this book, the first to give treatment to the topic. The editors carefully compiled the volume from notes prepared for a summer conference in computer science, held at Princeton University in August 1966 and co-sponsored by Princeton University and the COSINE Committee of the Commission on Engineering Education. Although the book consists of a collection of papers, each is well written and carefully chosen to achieve a unified and inclusive approach.

The book opens with a survey of network analysis by digital computer and discusses both programs and techniques. Chapter 2 presents a computer method of frequency analysis of linear networks. The next two chapters first describe the formulation of the equations for the analysis of linear active networks using state-space techniques, and then discuss numerical methods for time- and frequency-domain computer analysis.

Two chapters are devoted to network design. One describes the development of a program for the synthesis of filters; the other presents a tutorial discussion of optimization techniques and their incorporation into a general program.

Chapter 7 is devoted to a comprehensive treatment of the design and realization of digital filters. The area of simulation is also the subject of chapter 8, which describes the sampled-data system simulation language, Blodi, and chapter 9, on hybrid computation. Discussions of the ALPAK system and Altran language for symbolic algebra on a computer, computer-produced movies, and man–computer graphical communication comprise the remainder of the book.

Although a few user-oriented languages are presented, the book is primarily devoted to the development of the theory and techniques of network analysis and design with the use of a digital computer. For full appreciation of much of the material, a prerequisite for the reader would be a background in network theory. However, each chapter offers a tutorial introduction to its subject and serves either as a survey or as an example of techniques presented. Theoretical results are generally summarized, but extensive bibliographies are provided for the reader wishing further detail. Practical considerations in implementing the various techniques described in many of the chapters forms a valuable portion of the book.

Although the book is comprehensive in its selection of chapters, some areas receive uneven treatment. Time-domain analysis is treated, but frequency-domain analysis is given much more emphasis. Areas such as the analysis of networks with nonlinear active elements, analysis of networks affected by component tolerances, and S-domain analysis and synthesis are only briefly mentioned in chapter I.

The book as a whole demonstrates the general considerations taken in the development of the techniques for the formulation and solution of network problems by the computer and, also, the computer's use as a tool to provide greater insight into engineering problems. Indications of further developments are given; for example, many of the chapters point to the potential of more direct man–computer interaction, such as the use of graphical displays in the analysis procedures.

This book is the first to bring many of the initial developments of this rapidly emerging field together and will serve as an introduction and source of references for the subject. In addition, the techniques and experiences presented will be useful to those with specific interest in the topics discussed.

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Basic Carrier Telephony (revised second edition), David Talley—*John F. Rider Publishers, Inc., 116 W. 14 St., New York N.Y., 1966; 189 pages, illus., $4.95 pprbk.* Mr. Talley's book, as his preface implies, is oriented toward beginners in the carrier telephone field or people who require only a general knowledge of the working principles of carrier transmission. It is profusely illustrated with simplified (sometimes oversimplified) diagrams that give substance to the nontechnical language of the text, and questions and problems are listed at the end of each chapter.

The range of subject matter covered in this way is tremendous. The first half of the book begins with an up-to-date summary of world telephone business and typical interoffice and toll network layouts. Then an assortment of basic concepts are developed, including characteristics of speech and hearing, frequency translation, wire transmission, decibels, modulation, and filtering, etc., in bewildering sequence. The last half, considerably more concentrated in technical content, describes many types of Western Electric, Kellogg, and Lenkurt carrier systems for open-wire, cable pair, coaxial cable, and radio use, giving operating features, block diagrams, frequency allocations, levels, and other pertinent information.

The material is up to date enough to contain allusions to L4, N3, and "hardened route" coaxial cable systems, and to include a new chapter describing the Western Electric TI Carrier system, a time-division-multiplex, pulse-code-modulation system that is making carrier operation profitable for the first time in metropolitan exchange trunk areas. Mr. Talley's treatment of PCM is good except for his casual, almost apologetic statement of the advantage of PCM transmission. It is this feature, of course, which makes possible complete signal regeneration at every repeater point and results in high-quality transmission independent of line length for even the poorest of transmission media in terms of noise, crosstalk, reflections, and loss stability. It should have more emphasis.

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Analysis and Synthesis of Tunnel Diode Circuits, J. O. Scanlan—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1966; 268 pages, illus., $9.75.* This is the fourth and certainly most rigorous textbook on tunnel diode circuits to be published since the discovery of the tunnel diode by Esaki in 1958. In contrast to the preceding texts, which broadly cover the entire spectrum of tunnel diode circuits, this book restricts itself to sinusoidal circuits. In particular, the emphasis is upon the network-theoretical approach to general tunnel diode circuit analysis and synthesis, with few examples of physical circuit realizations.

The five chapters of this book divide it into three parts. The first two introductory chapters treat in considerable detail the physics of the tunnel diode and its equivalent circuit, the latter including noise sources and simplified terminal stability criteria. The third and fourth chapters form the heart of the book, considering in great detail small-signal tunnel diode amplification and general network synthesis. The basic properties of the tunnel diode transmission and reflection amplifier, such as available gain, noise figure, and distortion, are included in the presentation. With the introduction of modern filter theory, the broad-banding of these amplifiers is treated rigorously, leading to familiar gain–bandwidth relationships and synthesis procedures. The final chapter considers nonlinear, large-signal sinusoidal tunnel diode circuits such as oscillators, mixers, and detectors.

This book represents the best unified treatment of sinusoidal tunnel diode circuit theory in existence. Its strong emphasis on network theory seems justified in that the tunnel diode is the first physical embodiment of the broadband negative resistor sought by network theorists. As such, the book is recommended both to the network theorist and to the student or generalist seeking an understanding of one important class of tunnel diode circuit applications.

It is felt, however, that several subjects touched upon in the text are of sufficient importance to be treated in greater detail without loss of generality and within the network-theoretical frame of reference. These include a quantitative treatment of nonideal circulator-coupled amplifiers, such as was presented for hybrid-coupled amplifiers, a more detailed treatment of the various tunnel diode stability criteria, a more thorough treatment of tunnel diode stabilization within the framework of the broad-banding theory, and a consideration of the effect of transmission-line and waveguide elements on the theory. With regard to format, the use of appendixes for some of the derivations and of tabular summaries of the more significant results would have further improved the presentation. On balance, however, this book makes an important contribution to the literature of tunnel diodes and is highly recommended to workers in the field.

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Printed Circuits Handbook, Clyde F. Coombs, Jr., ed.—*McGraw-Hill Book Co., Inc., 330 W. 42 St., New York, N.Y., 1967; 544 pages, illus., $15.00.* This new handbook is intended to "bridge the gap between the art and science of printed circuitry." The aim of the authors, to provide the information necessary to establish a production facility and to control the processes involved, has, I think, on the whole been met. In particular, the wealth of detail offered on image transfer, plating, etching, and soldering would appear sufficient for most purposes. Also, the chapters on the machining and multilayer assembly of laminates, although short, are concise and to the point.

The multiple authorship of the text, while lending authority, has resulted in some redundancy, errors, and awkward organization of the material in certain areas. For example, substrates are discussed in five of the chapters, some of which give identical information. In another instance, Teflon is referred to as a thermosetting resin and silicone oils as silicon oils. (The author on encapsulants and coatings, however, does not make this error.) These and other items are minor but, collectively, they indicate a certain haste and lack of editing. The section on soldering and fluxes espouses a viewpoint which is not universally accepted. This is the author's prerogative. One might question, however, his omitting any discussion on the sensitive and widely used copper mirror test for fluxes while including the more dubious degassing test for solders.

In spite of such shortcomings, this handbook is a valuable addition to the field. The engineer and production man alike will be rewarded by a careful reading of the material since it does cover many of the problems commonly encountered in producing printed circuitry.

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New Library Books

The books described below were recently acquired by the Engineering Societies Library. Members of the IEEE in Canada and the continental United States may borrow books from the library by mail. The books may be kept up to two weeks; a charge of fifty cents for a week or a fraction thereof is made for each volume, exclusive of transit time. Requests for books and for information on literature searches, translation services, and photocopying and microfilming of library materials should be addressed to the Engineering Societies Library, 345 East 47 Street, New York, N.Y. 10017.

Advances in Communication Systems Theory and Applications, vol. 2, A. V. Balakrishnan, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 328 pages, $13.50.* The objective of the series is to feature contributions in a broadly defined field embracing both theory and practice. Like the first, this second volume covers a spectrum of topics: laser transmission; stochastic approximation; optical techniques in communication systems; synchronous satellite communication systems; theory of adaptive data compression; manned-space-flight communications systems; and an orbiting geophysical observatory system. A major aim of each chapter is to place each new theory within the overall scheme.

Advances in Microwaves, vol. 1, 1966, Leo Young, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 400 pages, $17.50.* The aim of the present series will be to document significant progress in the area indicated by the title, with "microwaves" broadly defined as that aspect which is of interest to microwave engineers and physicists. The contents will provide a permanent record of the advances judged important in contemporary eyes, and in this sense will be a service to the scientific and engineering community. Each contribution will be written by an expert who has played a major role in the particular topic covered and can provide a critical review. It is hoped that the level will be such that scientists or engineers in different, though perhaps related, fields can get a good general view of the specific advance described. Among the topics discussed in this volume are optical waveguides, directional couplers, application of Lie algebraic theory to microwave networks, and two contributions relating to waveguides.

Communication Satellite Systems Technology (Progress in Astronautics and Aeronautics, vol. 19), Richard B. Marsten, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 1051 pages, $12.00.* Collected here are more than 50 technical papers, most of which were presented at the AIAA Communications Satellite Systems Conference of 1966, and were revised for publication here. The first three of the six chapters, each of which contains several papers, are state-of-the-art presentations and cover commercial point-to-point systems, military satellite communication systems, and satellite support subsystems and components. Chapters 4 and 5 are concerned with high-power systems and systems concepts and their applications, including contributions on multiple access, direct broadcasting, and television networking, the national information grid, and communications from deep space. The final chapter contains discussions of sociological aspects of communication satellite systems. The overall intent of the conference was to describe current solutions to a variety of problems and conditions, thus laying the groundwork for further development.

Control Systems Theory, Olle I. Elgerd—*McGraw-Hill Book Co., Inc., 330 West 42 St., New York, N.Y., 1967; 562 pages, $12.50.* This book undertakes the task of bridging the existing gap between the classical view of control and modern control theory. Its objectives are, specifically, (1) to give a basic presentation of the fundamental control problems, (2) to integrate modern concepts with conventional design techniques, (3) to strip some of the new theories of some of the mathematical clothing in which they are obscured in order to make them understandable to the senior undergraduate engineering student, and (4) to bring into focus the importance of the modern computer—analog, digital and hybrid—in design and on-line operation of control systems. The book is directed toward an audience consisting of the senior undergraduate and first-year graduate student and the practicing control engineer.

Frequency Independent Antennas, Victor H. Rumsey—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y., 1966; 150 pages, $7.50.* The author of this book attempts to provide comprehensive coverage of frequency-independent antennas from the first papers, published in 1957, through those published in 1965; he includes discussion of current theoretical and practical work. Most of the material has been gathered from scattered journal articles, with the addition of some original contributions. One chapter each is devoted to the basic principles and analysis of dipole, frequency-independent, plane-sheet, spiral, and log-periodic antennas. The remaining chapters deal with the periodic structure approach and solutions of Maxwell's equations for idealized spiral and sinusoidal structures.

Fundamentals of Silicon Integrated Device Technology, vol. 1: Oxidation, Diffusion and Epitaxy, R. M. Burger and R. P. Donovan, eds.—*Prentice-Hall, Inc., Englewood Cliffs, N.J., 1967; 495 pages, $15.00.* This is the first volume of a series covering most of the technology necessary for the design and fabrication of contemporary integrated devices. Also included in the series will be basic process technology, materials and their properties, device theory, and design information, as well as various aspects of integrated device applications. The present volume describes the practices and theories associated with three of the most basic technologies employed in the fabrication of silicon integrated devices. Much practical detail is provided to assist in implementing each process, and the theory underlying each process is summarized to provide better understanding of the process fundamentals. The authors have attempted to identify both the capabilities and the limitations of oxidation, diffusion, and epitaxy.

Germanium (including **Radioactive Isotopes of Germanium** by P. Rudenko and L. V. Kovtun), V. I. Davydov—*Gordon & Breach, 150 Fifth Ave., New York, N.Y., 1966; 417 pages, $18.00.* A translation of a Russian monograph which provides an extensive collection of data on the minerals and ores of germanium, raw material sources and methods of production, and the physicochemical properties of germanium and its compounds. An appendix describes the production and analysis of the radioactive isotopes, and an introductory chapter discusses the importance and uses of germanium in technology.

High-Power Semiconductor-Magnetic Pulse Generators (M.I.T. Research Monograph No. 39), Godfrey T. Coate and Laurence R. Swain, Jr.—*M.I.T. Press, 50 Ames St., Cambridge, Mass., 1966; 136 pages, $7.50.* This book stems from an M.I.T. program directed toward development of a solid-state replacement for hydrogen-thyratron and vacuum-tube radar modulators. A circuit configuration utilizing silicon controlled rectifiers and saturable magnetic devices was evolved that meets typical radar-modulator requirements, operates from unregulated low-voltage supplies, and appears to offer significant advantages. A description of this circuit, together with design and performance information, is presented. It is expected that the circuit, and the book, will be found useful by persons requiring such pulse generators. It is hoped that the book may lead to a wider appreciation of the principles applied in discussing the circuit and to the development of a variety of useful circuit configurations that take advantage of the special properties of semiconductor and magnetic power-switching elements.

Geometric Programming Theory and Application, Richard J. Duffin, Elinor L. Peterson, and Clarence Zener—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y., 1967; 278 pages, $12.50.* Geometric programming is a new mathematical discipline for use in developing engineering designs. This book presents the first comprehensive description of the method, based on journal articles by the authors. The theoretical development of this new method is discussed, as well as its application in actual engineering problems. The formulation is in terms of nonlinear functions, termed positive polynomials, which are especially suited to expressing physical and economic relationships. Extended examples are given for applications to the design of electrical transformers and the design of a thermal differential sea-power plant.

High-Temperature Nonmetallic Thermocouples and Sheaths, Grigorii Valentinovich Samsonov and Pavel Stepanovich Kislyi—*Consultants Bureau, 227 West 17 St., New York, N.Y., 1967; 133 pages, $22.50, pprbk.* This translated Russian publication discusses the results of researches into the possibility of using refractory materials for the purpose of automating the thermal control of metallurgical processes. In addition to giving general information on the theory of thermoelectric phenomena and the refractory properties of high-melting materials, the book discusses in detail the utilization of the high thermoelectric properties of these materials for the production of special high-temperature thermocouples and the utilization of the refractory properties to provide protection for ordinary metallic thermocouples.

7th International Electronic Circuit Packaging Symposium (formerly **Advances in Electronic Circuit Packaging),** *Western Electronic Show and Convention, 3600 Wilshire Avenue, Los Angeles, Calif.* This volume contains the papers presented at the Seventh International Electronic Circuit Packaging Symposium, held during the 1966 Western Electronic Show and Convention. The following are samples of the topics discussed: advanced microelectronic packaging techniques; a simulation approach for evaluating system packaging; electronic package design for rugged military field service; automated interconnection schemes; hybrid integrated circuit delay line; Wirecon—a wire-connected module system; and various papers on microminiaturization, integrated circuits, and the joining of metals by percussive/arc welding and by mechanical thermal pulse methods.

Standards and Practices for Instrumentation, James E. French, ed.—*Instrument Society of America, 530 William Penn Place, Pittsburgh, Pa., 1966; various pagings, $30.00, pprbk.* A compilation of complete ISA recommended practices and abstracted instrumentation and control standards of 24 other technical organizatons including the IEEE, ASME, ASHRAE, ASA, and ASTM, some 500 in all. There are also abstracts of 130 British, Canadian, and international standards, all of them indexed by subject, sponsor, and standard number; complete ordering information is given. Established definitions, symbols, design data, tests, specifications, and procedures are given in the ISA standards and practices to meet the needs of engineers, designers, researchers, manufacturers, and users. The index to the abstracts locates existing standards in a wide range of subject areas from atmospheric analysis to vacuum technology.

Recent Books

Advances in Control System. vol. 4: Theory and Application, C. T. Leondes, ed.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.*, $14.50

Advances in Nuclear Science and Technology, vol. 3, 1966, Paul Greebler and Ernest J. Henley, eds.—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.*, $17.50

Calculul Electric al Retelelor Interconectate, Hans Edelmann—*Editura Tehnica, Bucharest, Romania*

CATV Operator's Handbook (First Edition), Verne M. Ray, ed.—*TAB Books, Drawer D, 18 Frederick Rd., Thurmont, Md.*, $7.95 pprbk.

Circuits, Devices, and Systems (A First Course in Electrical Engineering), Ralph J. Smith—*John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y.*, $11.95

Digest of Literature on Dielectrics (vol. 29), prepared by the Committee on Digest of Literature—*National Academy of Sciences–National Research Council, Washington, D.C.*, $20.00

Electric and Magnetic Fields, Stephen S. Attwood—*Dover Publications, Inc., 180 Varick St., New York, N.Y.*, $3.00

Electricity and Magnetism, Bernhard Kurrelmeyer and Walter H. Mais—*D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N.J.*, $12.75

Elements of Feedback and Control, A. M. Hardie—*Oxford University Press, 417 Fifth Ave., New York, N.Y.*, $8.80

Equivalent Circuits of Electric Machinery, Gabriel Kron—*Dover Publications, Inc., 180 Varick St., New York, N.Y.*, $2.25

Exercises in Mathematics, J. Bass—*Academic Press, Inc., 111 Fifth Ave., New York, N.Y.*, $14.75

Manufacturing Organization and Management (Second Edition), Harold T. Amrine, John A. Ritchey, and Oliver S. Hulley—*Prentice-Hall, Inc., Englewood Cliffs, N.J.*, $13.25

New Applications of Modern Magnets, G. R. Polgreen—*Ginn Library Services, Statler Building, Boston, Mass.*, $12.50

Patents, William J. Navin—*Practising Law Institute, 20 Vesey St., New York N.Y.*

Silver (Economics, Metallurgy, and Use), Allison Butts and Charles D. Coxe, eds. —*D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N.J.*, $13.50

The Radio Amateur's Handbook, American Radio Relay League (Headquarters Staff)—*American Radio Relay League, Inc., Administrative Headquarters, Newington, Conn.*, $4.00 pprbk.

The Semiconductor Data Book (Second Edition), Motorola Semiconductor Products Division—*Motorola Semiconductor Products Inc., Box 955, Phoenix, Ariz.*

Wave Propagation and Turbulent Media, Roy N. Adams and Eugene D. Denman—*American Elsevier Publishing Co. Inc., 52 Vanderbilt Ave., New York N.Y.*, $7.50

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ROBERT E. MATKINS

VOLUME 4 □ NUMBER 7 JULY 1967

IEEE spectrum

features

Departments: *please turn to the next page*

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

On-line handprinting input transducers are paving the way for greater computer flexibility. The systems discussed in the article beginning on page 72 recognize handprinted alphanumeric characters with a high degree of accuracy. The character extremes shown on the cover were fed into the system to evaluate recognition capability of distorted figures; the tinted areas were not recognized.

Spectral lines

IEEE's educational role. In order to evaluate the effectiveness of the IEEE in fulfilling its constitutional objective of being an "educational organization," the Executive Committee recently appointed an *ad hoc* committee, under the chairmanship of Dr. Bernard M. Oliver, which is studying ways to strengthen our educational activities.

The present activities of the Institute include many that are related to educational institutions or are directed toward educational ends. Examples are:

1. Section sponsorship of lecture series to assist the practicing engineer to orient himself in new fields.
2. Group sponsorship of organized workshops directed toward teaching subjects of emerging importance.
3. Publication of articles of a tutorial nature in technical journals of the Institute.
4. Publication of the STUDENT JOURNAL six times a year for undergraduate Student Members in the United States and Canada. (Students in Regions 8, 9, and 10 and graduate students in Regions 1–7 receive SPECTRUM instead.)
5. Operation of Student Branches at 230 universities and colleges and 59 technical institutes for the approximately 20 000 Student Members of the IEEE.
6. Publication of career guidance pamphlets.
7. Active participation in ECPD, whose major activity is accrediting engineering curricula in U.S. colleges, universities, and technical institutes.

I have omitted from this list the regular publications and numerous conferences and meetings that are the IEEE's major means for disseminating technical information. The term "educational activities" is being used to designate those activities of an instructional rather than an informative nature, activities designed to develop for the participant the background material needed to understand and utilize the new information reported in the regular publications and at meetings and conferences. Thus, educational activities are close in organization and content to a university course, although the format may be different.

Although it would be difficult to draw a sharp line of distinction between IEEE's educational and informative activities—and little reason to do so—the committee's concern has been focused on the educational aspect.

The committee identified three areas in which the Institute might well offer improved services to its members: (1) in continuing education, i.e., programs for the engineer and scientist who wishes to further his education without interrupting his employment; (2) in the provision of greater assistance to both students and faculty of colleges, universities, and technical institutes; and (3) in a more effective program at the secondary school level for informing students of the challenges and excitement of careers in the electrical/electronics area and for providing teachers with material to enrich the curriculum. In each of these areas, the attempt was made to identify services that the Institute is uniquely qualified to provide. It is not the intent to compete with universities or private publishers but to supplement their activities in ways a professional society is specially equipped to do.

The Institute has some unique assets with which it can develop its educational program. In its 196 Sections, it has a geographically widely dispersed organizational structure; in its award structure it has a means of recognizing professional achievement; in its membership it has the leading professionals in their fields. But, most important, there is a tradition of voluntary service that enables the Institute to develop programs by calling on the best talent available regardless of whether the individuals are employed by industry, government, or universities. Thus the task is to determine the educational services that our present and future members need and then to develop useful programs that utilize these important assets.

The committee has discussed a number of possibilities that warrant further study. These include:

1. The publication of monographs and course material in new technological areas as soon as possible after the technical advances are made. There is now a serious time delay between developments in industrial and governmental laboratories and the appearance of this material in such a published form that the nonspecialist can absorb it quickly and efficiently. This possibility is also being studied by the Publications Board.
2. The sponsorship of lecture series recorded on video tape or in slide-tape format for circulation to Sections, Student Branches, or other appropriate units.
3. Development of guides to the literature to assist the neophyte in a specific field. These guides would list various textbooks, review and tutorial articles, films, etc., that are available, and include critical comments.
4. The organization of educational materials in important new technological fields into ordered sequences that would include problem sets and some sort of examination system. An individual would undertake a systematic program and upon its completion receive an appropriate certificate. An accrediting, agency such as ECPD in the United States, might certify the contents of the program so that a man completing it is given individual recognition that has meaning to employers and possibly universities.

In order to develop and support a program including ideas of this type, it may well be necessary to make some organizational rearrangements within the Institute. This question is also under study by the *ad hoc* committee.

An *ad hoc* committee study cannot hope to develop in detail a complete program for as complex an organization as the IEEE. However, it is clear that the Institute has significant assets for service in the educational area. I hope we are wise enough to exploit these potentialities effectively.

F. Karl Willenbrock

Authors

Commercial satellite communications experience (page 63)

E. J. Martin (M) is presently serving as manager of the Advanced Systems Analysis Department for Communications Satellite Corporation (Comsat), Washington, D.C., where he has responsibility for the generation, analysis, and evaluation of concepts for new applications of satellite communications.

He was graduated from Fordham University, Bronx, N.Y., with an A.B. degree in mathematics in 1954 and, three years later, he received the Exceptional Service Award of the U.S. Air Force. Mr. Martin received the M.S. degree in mathematics and physics from Northeastern University in 1959. He was with the Air Force Cambridge Research Laboratories and was a project officer in the Communications Satellite Project Office of the Defense Communications Agency prior to joining Comsat in 1964.

He has published many papers on radio propagation and communications.

W. S. McKee, who is a member of the technical staff of the Space Segment Implementation Division of Communications Satellite Corporation, received the B.S. degree in electrical engineering in 1958 from the University of Maryland and attended graduate school at George Washington University. Between 1959 and 1964 he was a technical representative for the Hughes Aircraft Company. In the following year, while serving as a senior project engineer with the Western Union Telegraph Company, he was responsible for the implementation of portions of the Autodin Overseas program, including contract monitoring and preparation of manning documents. He is presently engaged in monitoring the orbital position and condition of Early Bird, and in the coordination of satellite launch and positioning operations for the Intelsat II program.

The human side of engineering (page 70)

E. M. Turner (SM) presently serves as technical manager of the Antenna Radome Group in the Research and Technology Division at Wright-Patterson Air Force Base, Ohio. He received the E.E. and M.S.E.E. degrees in 1934 and 1948, respectively, from the University of Cincinnati. Between 1936 and 1941 he was a power plant engineer with the Appalachian Electric Power Company. For the next five years he served the U.S. Army as a radar officer and, subsequently, he joined the Erie Resistor Corporation as a development engineer in ceramics and plastics. In 1948 he joined the Wright-Patterson AFB as a project engineer in electronic systems, assuming his present post 11 years later.

Mr. Turner is the inventor of the spiral slot and the scimitar antennas, the antennaverter, the space-frequency filter circuit, and the radant supergain structure. In addition, he has made substantial contributions in the areas of pulse analyzers, panoramic receivers, low-frequency direction finding, unfurable, and electrically small antennas, and the polarization control of antenna systems.

Handprinting input device for computer systems (page 72)

J. G. Simek (M) is on the staff of the Systems Development Division of the International Business Machines Corporation, Endicott, N.Y. He received the bachelor of science degree in 1957 and the master of science degree in 1963, both in electrical engineering, and both from Cornell University, Ithaca, N.Y. While an undergraduate at Cornell, he was elected to Eta Kappa Nu.

Mr. Simek joined the International Business Machines Corporation in 1957 and, until he returned to Cornell under an IBM Graduate Study Grant, he was engaged in the design of various transistor and magnetic circuits for use in data collection and communications systems. Since 1963 he has been involved with studies in handprinting recognition; he is presently the manager of a group responsible for the design of special small-signal circuits.