15th anniversary

With this issue, the *RCA Engineer* starts into its sixteenth year of publication. Its editors, its authors and its readers are to be congratulated on the completion of fifteen years of successful publication.

Considering the propensity we have for putting extra emphasis on anniversaries that are multiples of five, it does not seem unnatural to take a quick glimpse backwards if only to put some perspective into where we are now and where we are going.

The first volume of the *RCA Engineer* covers many subjects that are still of interest: color television, VHF and UHF television transmitters, precision radar, computers, transistors, and Electrofax just to name a few. The present and recent issues contain some papers on extensions of these subjects. However, they also contain papers on subjects that could not be included in the early volumes. Holograms, lasers, masers, liquid crystals, integrated circuits, microwave microelectronics, space electronics, thermoelectrics and design automation show up in a most superficial look.

I am not surprised at anything on the list. I am impressed by its length—clear evidence of the technical dynamism that continues to characterize our industry—clear evidence of the continuing need for an RCA-oriented means of communication among our engineers. I believe the *RCA Engineer* fills that need well.

Dr. James Hillier
Executive Vice President
Research and Engineering
Princeton, New Jersey

RCA Engineer Staff

W. O. Hadlock	Editor
J. C. Phillips	Associate Editor
Mrs. J. Heritage	Editorial Secretary
V. Bartholomew	Art Director
A. Whiting	Design and Layout

Consulting Editors

C. A. Meyer	Technical Publications Adm., Electronic Components
C. W. Sall	Technical Publications Adm., Laboratories
F. J. Strobl	Technical Publications Adm. Corporate Engineering Services

Our cover

. . . illustrates the basic elements of RCA's holographic color-TV tape player system—one of the newest concepts in home entertainment (see W. Hannan's article, p. 14). The beam from a low-power gas laser passes through the holograms (images) on the clear plastic tape. The images are picked up by a color TV camera and deciphered to produce full-color pictures on a standard color-TV receiver. **Photo credit:** Tom Cook, RCA Laboratories.

l 16 No 1
n | Jul
970

RCA Engineer

echnical journal published by
A Corporate Engineering Services 2-8,
mden, N.J.

A *Engineer* articles are indexed
nually in the April-May Issue and
the "Index to RCA Technical Papers."

• To disseminate to RCA engineers technical information of professional value • To publish in an appropriate manner important technical developments at RCA, and the role of the engineer • To serve as a medium of interchange of technical information between various groups at RCA • To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions • To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field • To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management • To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

ontents

editorial input

for future growth

This issue is dedicated to the future—yours and mine, as fellow technical employees of RCA. The front cover shows some of the inner workings of the SelectaVision system which promises to be one of RCA's most significant developments in home entertainment since color television. The system, the first consumer product to use lasers and holography, is described in some detail in Mr. Hannan's article (p. 14). Beyond SelectaVision, holography seems to hold forth a great deal of future promise in the marketplace. It offers potential benefits in information storage, three-dimensional displays, image multiplication and recording, and interferometry; all these areas are surveyed in this issue by Dr. Ramberg (p. 10). Two other significant applications of holography—integrated circuit reproduction and secure personal identification systems—are being developed by the Zurich Laboratories, as described by Dr. Greenaway (p. 19).

Leading the issue are two papers that have strong significance in every engineer's look into RCA's future. Mr. Sarnoff's recent address to RCA shareholders (p. 3) describes important new attitudes of RCA—a corporation moving vigorously ahead with new programs and new philosophies towards its role as "a multinational industrial enterprise doing business in computer-based information systems and diversified consumer and commercial services." Dr. Nergaard (p. 6) looks to the future in a way that should be particularly stimulating to engineers who will have to define their goals within the framework of the "sociological seventies."* Looking back over his forty-three years in research and engineering, Dr. Nergaard brings fresh insight to the achievements and to the mistakes of the past—regarded in light of the promise and the pitfalls of the future.

Traditionally, Anniversary Issues of the *RCA Engineer* have had a rather cosmopolitan flavor—drawing papers from many different areas of RCA on many different technical subjects. This anniversary issue is no exception; the nineteen contributions represent fourteen different areas and at least as many different subjects. Each paper, in its own way, is providing for the future—by communicating new technical achievements to fellow members of the technical staff—by providing benchmarks to measure past accomplishments—and by defining problems and establishing challenges for the future.

As we all know, this is a time of national economic difficulty in which profits continue to decrease as costs of doing business increase. But, if the insight, the determination, and the competence displayed in these pages are good indicators, prospects for RCA's future are bright indeed.

Appropriately, the theme of the recent Corporate Engineering Conference was the "role of engineers and their management in improving the earnings posture of RCA in future years" (see the "News and Highlights" section, p. 78), and many of the topics discussed there are covered also in greater detail in this issue.

---

*See "Editorial input—science, society, and the seventies," *RCA Engineer*, Vol. 15, No. 5 (Feb-Mar 1970) p. 2.

Future issues

The next issue of the *RCA Engineer* featur linear integrated circuits (LICs). Some of th topics to be discussed are:

LIC arrays

LIC's for RF and IF service

IC stereo preamplifier

Metallization and interconnection materials

Threshold logic

Market impact of LIC's

Etch thinning of silicon wafers

Hybrid microcircuit packaging

Operational amplifiers

IC voltage regulator

Discussions of the following themes a planned for future issues:

RCA engineering in New York

Consumer electronics

Displays, optics, photochromics

Computers: next generation

Mathematics in engineering

Advanced Technology Laboratories

Address to RCA Shareholders—1970

R. W. Sarnoff

n his address at the Annual Meeting of RCA Shareholders recently, Mr. Sarnoff discussed the changing dimensions of our company as it enters the decade of the seventies. The full text of his remarks are reproduced below with the thought that you, as a member of RCA's Technical Staff, will want to be fully aware of the principal aspects of the new RCA to which you are making a vital contribution.

Robert W. Sarnoff
Chairman of the Board and President
RCA Corporation
New York, N.Y.
became head of RCA after a career of more than thirty years in the fields of information and communications. He was elected Chairman of RCA on January 7, 1970, after having served as President since January 1, 1966, and as Chief Executive Officer since January 1, 1968. Under his direction, the corporation has had a gross annual sales volume exceeding $3 billion, with 57 manufacturing plants in the United States and in 9 countries abroad, and with more than 130,000 employees. It turns out a vast range of products for consumer, commercial, and government markets, ranging from integrated circuits to large computers and from portable radios to spacecraft communications and control systems. In addition to its manufacturing activities, RCA is engaged in broadcasting through its subsidiary, the National Broadcasting Company, Inc.; in servicing electronic equipment through the RCA Service Company; in international communications through RCA Global Communications, Inc.; in publishing through Random House, Inc.; in education and training through RCA Industries, Inc.; and in the rental and leasing of automobiles, trucks, and other equipment through the Hertz Corporation. Its David Sarnoff Research Center at Princeton, N.J., is one of the world's foremost electronics laboratories. Prior to becoming President of RCA, Mr. Sarnoff served for more than seven years as Chairman of the Board of the National Broadcasting Company. For three preceding years, he was President of NBC. Throughout this ten-year period, he also served as NBC's Chief Executive Officer. During much of this time, he was active in the management of RCA as well as NBC, serving for more than eight years on the RCA Board of Directors; for more than ten years as a member of the corporation's Executive Council; and for more than two years as Chairman of the RCA Planning Committee, concerned with long-range business development. Mr. Sarnoff has been honored by numerous civic and professional organizations and by the Governments of France and Italy. He also has received eleven honorary degrees from colleges and universities in the United States.

I WELCOME this opportunity to report to you on how RCA is facing the economic and social challenges of today, and preparing for a new cycle of progress and profitability tomorrow.

Lower corporate earnings in the first quarter of 1970 has been the experience of many large corporations—and RCA has been no exception. A decline in consumer buying intent has hit color television and other home instruments sales very hard. Tight money has constricted the commercial electronics and component markets. Because of uncertainty about the profit outlook, advertisers have been cautious about making major broadcasting commitments. And curbs on travel expenses have adversely affected the car rental market.

Meanwhile, one curve on the nation's economic chart has maintained upward consistency, and this is cost. All the basic costs of doing business—employment, materials, transportation—have risen sharply, while profits have fallen.

RCA first experienced the adverse effects of these trends in late 1969. As a result, while sales reached a new high of $3.4 billion, earnings declined about $2 million below the record 1968 level. 1970 first quarter sales declined 5 per cent and profit 36 per cent.

The economic climate presently remains uncertain, but hopefully it will improve as social security payments rise, the surtax is removed, and interest rates decline. If so, we can anticipate a modest return of consumer confidence and increased spending,

---

Reprint RE-16-1-22
Address to Shareholders on May 5, 1970.

with most of the impact beginning to be felt late in the year.

We expect RCA to become less vulnerable to fluctuations in the economy as we develop a wider and more balanced range of activities. While greater economic security is not the sole objective of diversification, it is an important by-product.

RCA has already moved a long way toward becoming a fundamentally different company from the one we have known in the past.

Until recently, our business had been largely oriented toward the consumer products market. It derived the most substantial part of its volume and profit from the sale of electronic home entertainment instruments and from radio and television broadcasting. At the same time, we developed wide-ranging technical capabilities through our research and development programs, and in government contract work on advanced electronics for space and defense.

It has become apparent, however, that some of our principal established businesses are reaching maturity, and that a continuation of RCA's growth and profit momentum can best be assured by creating new business opportunities. Broadcasting and color television manufacturing should continue to generate substantial volume and profit for years to come, but the era of their most vigorous expansion has passed.

We believe that our brightest prospects for a significant growth rate in the future lie in fields broader than those we have cultivated so profitably during RCA's first half century. In the 1970's and beyond, information in all its forms will be put to increasingly sophisticated use by business, industry, and government—and eventually by individuals at home.

There will be increasing worldwide need for advanced systems to gather, communicate, and process information for every conceivable purpose—from business planning to the formulation of national economic and social policy. Simultaneously, there will be accelerating demand for new and diversified services for a society endowed with more leisure time.

It is our goal—and we are well on our way to its attainment—to make RCA a multinational industrial enterprise doing business principally in computer-based information systems and diversified consumer and commercial services. While we intend to maintain a leading position in the consumer electronic products market, we expect this activity ultimately to account for a lesser share of RCA's total volume and profit.

Much of the new structure is already visible. Its design reflects the greater emphasis given to enhancing RCA's capabilities and reputation as a systems-oriented company. The heart of this effort is our growing computer business.

RCA has already invested far more to develop a strong and profitable position in the computer industry than we have ever put into any previous business venture, including the development of color television. This effort has generated a momentum that is now carrying us forward at a substantially higher growth rate than the industry as a whole, and toward our goal of a solid profit position in the early 1970's.

In the first quarter this year, our domestic shipments nearly doubled compared to the same period last year.

During 1969, RCA's domestic computer shipments accounted for 3.7 per cent of the industry total, putting us in fifth place. Our scheduled shipments for 1970, account for slightly more than 7 per cent of the total projected for the industry.

During the past five years, no company other than IBM has attained a market share of as much as 7 per cent. If this pattern continues, RCA's schedule of domestic shipments in 1970 should place us in a firm Number Two position. An indication of our rapid growth is the number of new accounts obtained in the first quarter of 1970 versus 1969—a more than threefold increase.

Our computer strategy has been carefully planned and coordinated.

Our computer product line has been designed for the most dynamic growth segment of the market—the remote systems whose varied applications include time-sharing service for many users through individual terminals and communications networks.

We have developed pioneer marketing concepts designed to make RCA the easiest and best computer company to do business with.

Our personnel and facilities have continued to multiply in step with the planned growth of our computer business. For example, RCA's computer sales force has nearly doubled in the last fifteen months. This expansion has played an important role in the favorable results so far in 1970.

Much of our research and development effort is being concentrated on projects relating either entirely or substantially to computer activities.

Our developing strength in computer-based systems is the keystone to many of our future plans and programs. The advantages of a broad systems capability are already evident in our government work. For example, it requires a company with across-the-board competence in electronic systems to handle the highly complicated Aegis system for fleet defense, for which RCA was recently awarded a major prime Navy contract.

Many of the challenges facing business and government will call equally for a broad capability to conceive and develop complex non-military systems in the 1970's and beyond. An example is RCA's recently announced SECANT, a low-cost aircraft collision avoidance system designed for use by aircraft ranging from crop dusters to the largest commercial planes. It was created to solve a rapidly escalating major national problem—air collision. We believe that its unique abilities should ultimately establish it as the standard for national and international aviation.

Both examples illustrate the important need for a company with demonstrated competence in computers, communications, and systems development. RCA is rapidly becoming such a company.

As we shift RCA's main emphasis toward computer-based systems, we are seeking also to create a closer balance in our total business between product and service activities.

Ve have expanded and diversified our ervice operations during the past few ears in both traditional and new fields f business for RCA. Among them ave been new global satellite commuications services, publishing, and auto vehicle rental. We have since aken further steps in preparation for even more vigorous growth in the service sector in the 1970's:

We have entered the frozen prepared food industry through a new subsidiary, Banquet Foods Corporation. This provides RCA a profitable base in a new consumer service area which is one of the fastest growing segments of the domestic economy.

We are scheduled this summer to acquire and operate the Alaska Communications System as a subsidiary of RCA Global Communications. For the first time, RCA will become involved in domestic telephone and telecommunications service, in a region with unsurpassed growth potential for communications.

We have established a new company —ServiceAmerica—to provide nationwide servicing for all brands of television sets and other home entertainment products. This step was undertaken after extensive research which indicated an expanding need for service in the entire consumer electronic products market.

These basic changes in RCA's business orientation have been accompanied over the past several years by other moves to improve its marketing and operating effectiveness for greater profitability. For example, we have taken a vigorous approach to new global business opportunities. We have reorganized internally for this effort, and have launched a number of new manufacturing and service operations in other countries during the past four years. These include such activities as color tubes, semiconductors, records, television sets and components.

As RCA continues to change in character and scope, so do its organization and management. We recently realigned our information systems activities, and have just established a new Solid State Division to focus on our expanding operations in the dynamic technology of semiconductors and integrated circuits.

Our systems orientation and entry into new product and service areas have generated a need for fresh young managerial talent at many levels. Fortunately, we have been able to meet many of our requirements by promotion from within, but we have also been successful in attracting qualified talent to help fulfill our new needs.

The result is a vigorous and youthful pattern of management in depth. At the top operating level is a new generation of executives who have brought drive and imagination to our key activities. As a group, our top operating executives, divisional managers, and subsidiary company presidents average only 50 years of age. Many of those with the most critical responsibilities are considerably younger.

One of our most challenging tasks during this period of basic change in RCA is to evaluate our established activities with an eye to their present performance and future potential as profit contributors. Our policy is to discontinue or redirect those which fail to measure up to our requirements. At the same time, we are strengthening our corporate-wide program of strict cost control. While this will provide immediate benefits in the current economic climate, our aim is to improve the company's total cost structure in order to enhance the profitability of all our operations in the long run.

It is our management's objective at all times to make the best use of RCA's assets for the benefit of its shareholders, and its employees as well. At the same time, we recognize that profit alone should not be the sole aim of any business, because we also bear broad responsibilities to our customers, to the communities where we work, and to our country.

It has long been RCA policy that our customers, including business and government as well as individuals, are entitled to the assurance of high quality and reliability in everything they buy or lease from us. To assure full implementation of this policy in these more complex times, we have established an office of Consumer Affairs at the corporate staff level. It is responsible throughout the company for overseeing customer interests and requirements.

As a major industrial enterprise, RCA also has a responsibility to help preserve the health and beauty of the environment wherever it operates. Over the past five years, we have spent millions to reduce and eliminate sources of pollution from our manufacturing operations. We have also instituted a company-wide program to encourage voluntary activities by RCA employees to improve the environment in our various plant communities.

Some of the nation's most perplexing environmental problems have arisen from the deterioration of our cities. To aid in their solution, RCA has undertaken a number of programs on its own and in cooperation with others in the cities where it has plants or other facilities. For example, we continue to train young people, who now lack skills, to obtain rewarding jobs. We also support, in cooperation with local school boards, a unique program to enable drop-outs among our employees to earn high school diplomas. In Camden, New Jersey, we have joined three other companies in a $100 million urban renewal program in the industrial heart of the city.

Many other examples could be cited to illustrate the same point. The public has a claim upon the participation and help of American business in trying to improve the social and physical environment which we all share. RCA will continue to give priority attention to fulfilling its obligation.

This highlight review has sought to describe the extent to which RCA is rapidly becoming a different enterprise, attuned to a new technical, business and social environment at home and abroad. It has already undergone basic changes in its structure and its operations in preparation for a new cycle of growth. It will change even more over the next few years.

We do not minimize the problems of the present, but neither do we doubt RCA's ability to take them in stride on its way to more vigorous growth and greater profitability as a leader in systems and services. Given our corporate capabilities and management determination, and the continued support of our shareholders, we firmly believe that the 1970's will be our company's most successful decade.

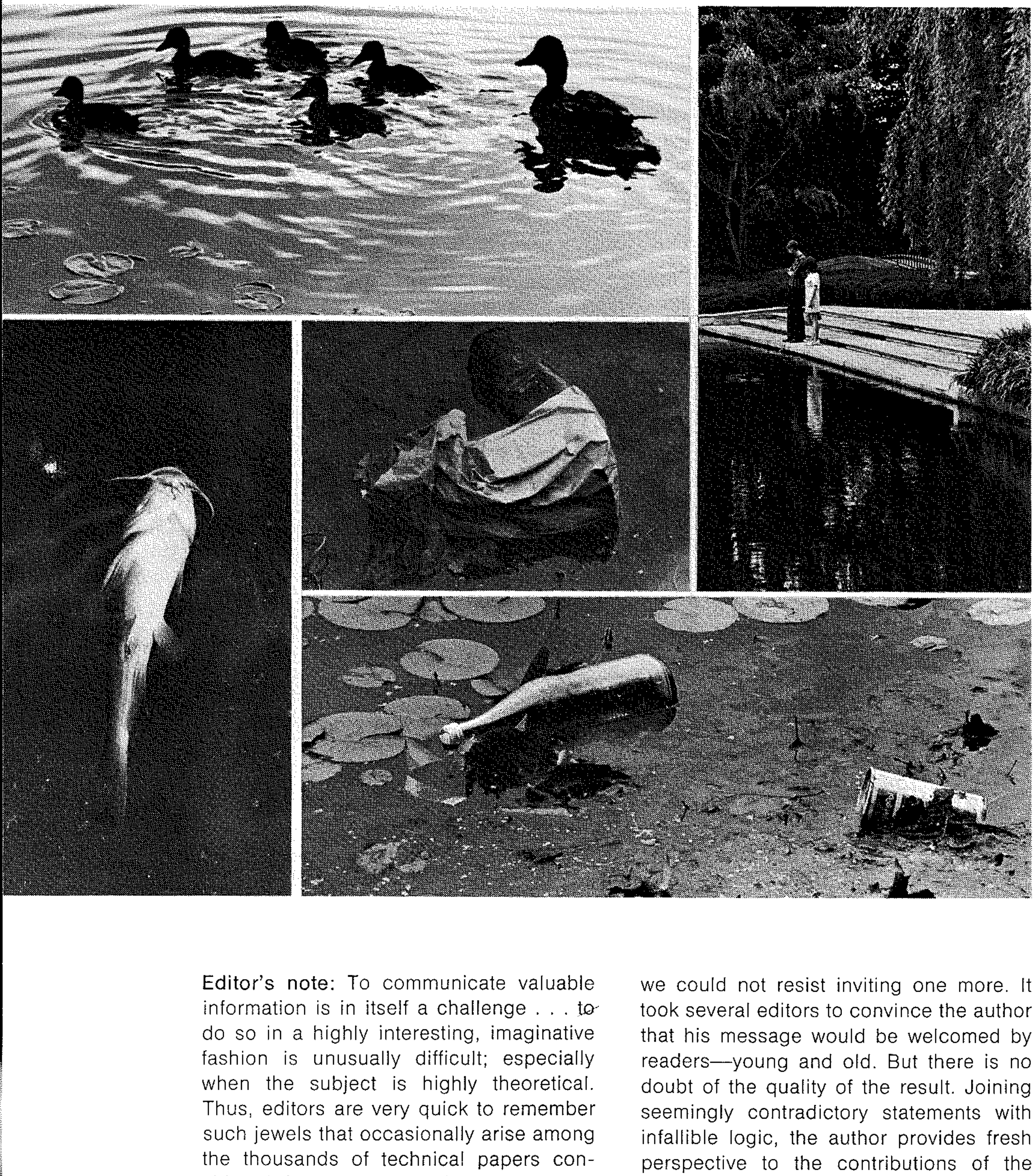
The Engineer and the Corporation

Reflections on muddied waters

Dr. L. S. Nergaard

And the Lord said, I will destroy man whom I have created from the face of the earth; both man, and the beast, and the creeping thing, and the fowls of the air; for it repenteth me that I have made them.

—Genesis 6:7



WHEN THE EDITOR of the ENGINEER asked me to write something on the future of engineering and the future engineer, my first impulse was to say *no.* I am not trained in history, economics, philosophy, psychology, sociology and ecology—all of which I deem necessary to a meaningful look at the future—and least of all am I a seer. Furthermore, my look at the technological world has been through slits (gun ports?) in the walls of research laboratories and my views are conditioned by the environment and traditions of the institutions in which I have lived and by the shibboleths of the profession I follow. When I finally did accede to the request, I did so with the understanding that the result might well be a "happening," in the sense of Henahan.[1]

By training, I am predisposed to look at where I am and how I got there before assaying the future, i.e., to extrapolate from past experience.[2] Because it is probably too late for me to gain knowledge, let alone wisdom, I will have to go with personal experience and cast it in ways that appeal to me and may be provocative to others. Then, should I fail to discern the future, perhaps someone more erudite

Editor's note: To communicate valuable information is in itself a challenge . . . to do so in a highly interesting, imaginative fashion is unusually difficult; especially when the subject is highly theoretical. Thus, editors are very quick to remember such jewels that occasionally arise among the thousands of technical papers considered for publication. (Envy has a lot to do with it also.) So, realizing that Dr. Nergaard contributed four such jewels in past issues and was nearing retirement, we could not resist inviting one more. It took several editors to convince the author that his message would be welcomed by readers—young and old. But there is no doubt of the quality of the result. Joining seemingly contradictory statements with infallible logic, the author provides fresh perspective to the contributions of the past and the promise of the future: "I hear discontent among the young people. And this is the best sign of all, for they, not we, 'shall inherit the earth' within a generation . . . it is too bad that the past is irrelevant; the young might get some ideas from a little prowling."

Reprint RE-16-1-6
Final manuscript received February 23, 1970.

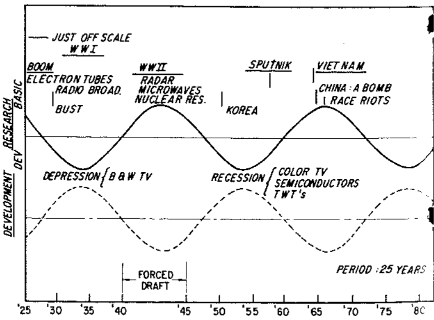


Fig. 1—An impression of research and development since World War I.

an I will get a glimpse.

bout five years ago, while thinking bout where I was, I got the strange eling that I had been there before, at ast once, perhaps twice. On reviewg my career, I was led to construct e upper curve in Fig. 1. It shows the researchiness of research" versus me. The curve is subjective, averages ut the growth of the industry, and in fact a sinusoid, arrived at by and-waving. Assume for the moment at the curve represents something. hen:

1) The periodicity is 25 years, i.e., about one generation.
2) There seems to be a correlation with wars.
3) There seems to be a correlation with the depressions, by whatever name, that follow or precede the wars.

On further reflection, I was led to onstruct the lower curve which is my mpression of how development in roduct divisions is phased with respect to research. When research becomes wholly impractical, product ivisions become justifiably concerned and undertake the work they had reviously expected of research. Then, n the course of time, product divisions and research draw close together and re bosom buddies for a while. Then hey drift apart again when it appears hat research is back on the beam.

Now the two generations encompassed y Fig. 1 may be singular and unrepresentative of the long haul, so I did ome digging into our past history and constructed Fig. 2. The chart shows:

1) Top strip: wars
2) Second strip: depressions,
3) Third strip: some notable inventions and discoveries that contribute to the next three strips,
4) Fourth strip: the rise of the power industry,
5) Fifth strip: the rise of mass transportation, and
6) Last strip: the rise of world-wide communications.

The periodicity of Fig. 1 reappears in the first two strips: we have engaged in a war every 25 years, on the average, and every war has been followed by at least one depression (again, by whatever name)—and this over a 300-year span. One is tempted to conclude that every generation repeats the blunders of the last. Perhaps the next will be the first exception . . . one can hope so.

As to Fig. 1, if the curve is representative of more than an individual experience, the periodicity requires an explanation. A possible explanation of the oscillatory behavior is that the human mind has the capacity to acquire and store knowledge and a reluctance (inductance?) to use it, so it acquires and stores basic knowledge up to a point where economics intervenes and then uses it until the supply is inadequate to cope with rising practical problems; then the search for new knowledge is imperative again. Is the need to start over again every 25 years a factor in "technological obsolescense?" Perhaps so, but then the conjectured explanation may be in error and the periodicity in research may be imposed by the more impelling periodicity of Fig. 2. Either alternative is likely too facile an explanation, and the two are probably interdependent.

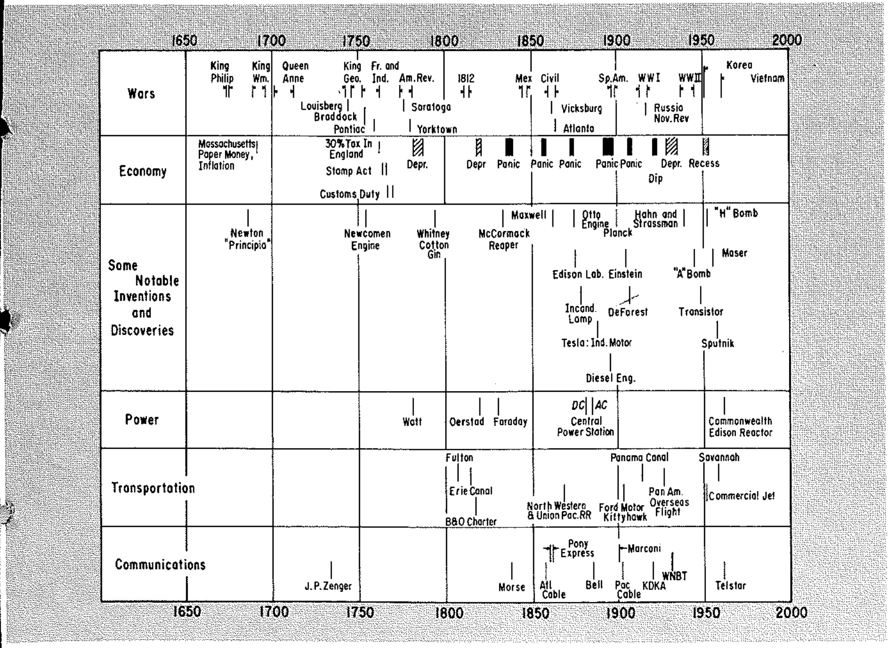


Fig. 2—Anglo-American Wars, depressions, and the growth of some industries.

Dr. Leon S. Nergaard, Director
Microwave Research Laboratory
RCA Laboratories, Princeton, N.J.
attended the University of Minnesota and received the BSEE in 1927. He received the MSEE from Union College, Schenectady, N.Y., in 1930 and the PhD in physics from the University of Minnesota in 1935. From 1927 to 1930 Dr. Nergaard was associated with the research laboratory and vacuum-tube engineering department of the General Electric Company. He held a teaching assistantship in the Department of Physics at the University of Minnesota from 1930 to 1933. Dr. Nergaard joined the RCA Manufacturing Company in 1933 and transferred to RCA Laboratories as a research physicist in 1942 where he worked on pulse-radar tubes until the end of the war. Since then he has worked on transmitting tubes and television transmitters, then switched to solid-state physics, particularly the semiconducting properties of oxide cathodes. He assumed responsibility for the microwave work at RCA Laboratories in 1957. In 1959 he was appointed associate laboratory director, Electronics Research Laboratory. He assumed his present responsibility in 1961. He is responsible for 24 issued patents and 28 papers, has received two RCA Achievement Awards and the David Sarnoff Award for Outstanding Achievement in Science. Dr. Nergaard is a Fellow of the American Physical Society and the IEEE, a member of the American Association for the Advancement of Science. He has been active in numerous committees of the IEEE, URSI, and a member of Theta Kappa Nu, Gamma Alpha and Sigma Xi.

To explore the possible interdependence, I chose easily-accessible data, namely, U.S. Patents issued by year; one would expect that research has some part in the making of inventions.[3] From these data I constructed Fig. 3, which shows patents per year per million of population since 1836. (Earlier records were destroyed in a

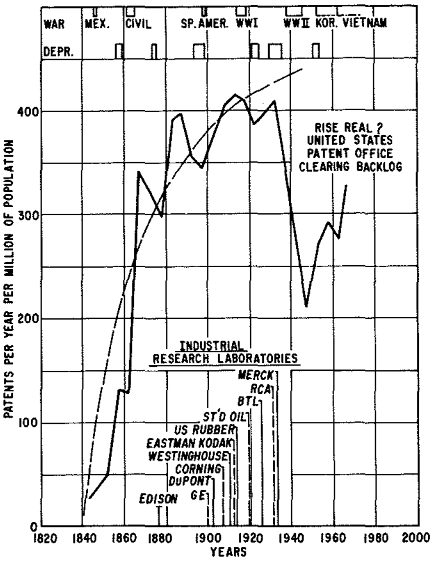


Fig. 3—Patents issued by the U.S. Patent Office per million of population.

fire in the Patent Department, so little is known of earlier patents except that 9957 were issued).[4] The general tenor of the curve (shown by the dotted line) is described by

$$y=y_\infty\ (1-e^{-t/\tau}) \tag{1}$$

where y_∞ is an asymptotic value (455 patents/yr/million population); t is time in years; and τ is a time constant ~30 years).

I construe the broken curve to represent the industrial revolution in this country. Superimposed on the smoothed curve are fluctuations which show a correlation with the benchmarks (wars and depressions) noted at the top of the Fig. 3. It appears that there is a correlation between wars and depressions on the one hand and research on the other, insofar as it may be characterized in terms of patents issued; that is, until 1930, when something catastrophic happened. One might have expected a "low" in patents imposed by security during World War II, but the spate of patents issued immediately after the war did not make up the loss nor has the rate of invention, or at least the issuance of patents, recovered during the generation following. I have discussed the post-1930 behavior of the curve with many people from a variety of backgrounds and have found almost as many opinions as to the cause as people queried. A recurring opinion is that we are trying to substitute instrumentation for brains. For my own part, I will go with those who hold no opinion and regard the whole thing as a vast, if fascinating, mystery.

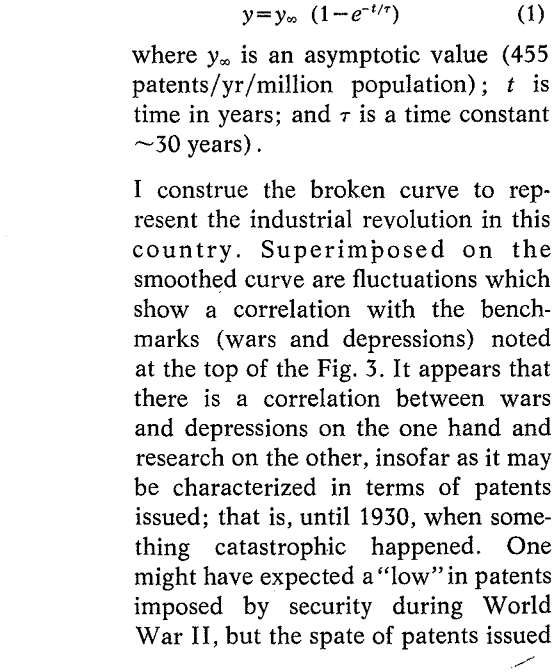


Fig. 4—The growth of an industry; dollar-sales in electronics as a function of time.

To return to Fig. 2, the bottom three strips show significant events in the rise of modern power generation, transportation, and communications. However, they give no impression of the rate of growth and where we are now. One might expect a growth such as shown by the dotted line in Fig. 3 if the variables are properly couched. But what of the saturation and asymptotic value? Is there indeed a limit to growth in a given industry? Fig. 4 is an attempt to look at this question in a field that is close to home. It shows the dollar sales of the electronics industry versus time since 1950.[5] The shape of the curve reminded me of the solution of a simple equation in reaction-rate theory. The equation is

$$\partial y/\partial t=(y/T)\,[1-(y/y_\infty)] \tag{2}$$

where y is the dependent variable; t is the independent variable (time); y_∞ is the asymptotic value; and T is the time constant.

It will be noted that the equation is bi-stable; i.e., the rate of change of the dependent variable is zero when $y=0$ or $y=y_\infty$. Hence, if y is zero it takes a perturbation of some kind to give y an initial value, then the increase follows. The solution to the differential equation is

$$y=\frac{y_\infty}{1+exp[-(t-t_o)/T]} \tag{3}$$

where y, t, y_∞, and T have their previous definitions and t_o is the time at which $y=y_\infty/2$, the only easily-identifiable fiducial point on the curve. This curve has been drawn through the data (circled points) of Fig. 4. To arrive at something like a fit, the constants were adjusted to

$t_o=1962$
$y=\$28$ billions
$T=5.45$ years

The fit is remarkably good until 196
when a marked upward deviation o
curs. An examination of the details c
the data revealed no obvious explana
tion of the departure from the curve—
except inflation. A "correction" c
5%/year yields the points shown a
triangles. The corrected curve doe
appear to have a saturation value.[6]

The fit of the theoretical curve to th
"experimental" data prompts a digre
sion; let us look at the possible impl
cations of the theoretical model. A
noted earlier, the model is bistable an
it takes a perturbation to set thing
moving. If the perturbation is an in
vention that makes a one percen
ripple, then with $T=5.45$ years, it wil
take 23 years (one generation) t
reach the fiducial point in time. I
industry takes note of the invention a
the 10% point, it will take another 1
years to reach the fiducial point and i
development starts at the 25% point
it will take 5.5 years to reach th
fiducial point. All of this reminiscen
of another set of curves (reproduce
as Fig. 5) which shows a 25-year ga
between research and commercial use
During the growth period, the be
havior can be represented by an ap
proximation to Eq. 2

$$\partial y/\partial t=y/t \qquad (4$$

which says that dollar sales at an
time t are proportional the sum total
past dollar sales. Hence $1/T$ is appr
priately called the *Joneses* coefficien
Beyond the fiducial point, Eq. 2 ma
be approximated by

$$\partial y/\partial t=(y-y_\infty)/T \qquad ($$

and dollar sales diminish in acco
with Malthus' law of diminishing r
turns. That dollar sales should satura
in the face of an increasing populatio
may seem strange. But an examinatio
of black-and-white television sal
shows saturation; price erosion ju
about offsets the increase in unit sale
so dollar sales remain about constan
So much for the digression.

Throughout this squint at the pa
there runs a periodicity of about
years and a time constant of about
years. Perhaps, it takes a new gener
tion to see out of the ruts of the c
and proceed with fresh perspecti

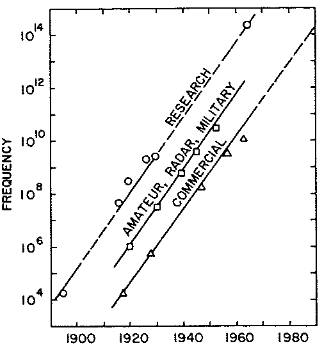


Fig. 5—Utilization of the communications spectrum from World War I on.

But why the coherence? One expects coherence in the generations of a family or clan. But between families or clans one might expect randomness —noise, in the engineer's language. The answer may be—again in the engineer's language—phase-locking, so that all tend to act in concert on matters of dominant concern to the group. By some strange coincidence, Eq. 2 is just the equation used by van der Pol to study the phase-locking of oscillators.[10] Whether this observation has any relevance to group behavior (coherence) is speculative; but if anyone questions coherence among segments of our youth he need only recall the Woodstock Festival.[11]

So here we are, wondering about the "break-through" that will provide the next big sales market in our industry and coming up with "add-ons" for the most part. Perhaps we are too close to the scene and should back off and view the whole landscape with a cold, calculating eye.

When I try to do this, I see a Technological Era that has provided us with a host of marvelous tools and toys. I see the tools that have provided us with the "mechanical" means (and the toys . . . some of the financing) to build the power, transportation, and communications facilities we now have—and new tools and new toys. I see fields tilled by mechanical means to provide an abundance of food, and I see displaced tillers of the soil moving to the city where they no longer share in the abundance. I see the landscape buried in concrete so we can build new tools and toys on weekdays and can get to mountains scarred by ski-slopes, lakes polluted by DDT and beer cans, and rivers swimming in garbage on week-ends.[12, 13] I am tempted to stay home and admire the redwood forests in the form of lawn furniture and the pine forests in the form of third-class mail. Then I wonder if technology has not become an end in itself, not a means. And when I hear "Standard of Living," I wonder if it isn't a self-serving term.

But when I look and listen more carefully I think I see glimpses of light on the horizon and hear rumblings. I hear strange words such as *pollution* and *ecology*. I hear discontent among our young people. And this is the best sign of all, for they, not we, "shall inherit the earth" within a generation; and they are concerned about what we propose to leave them. I think I hear them challenging our Technological Culture and its set of values.[2, 14] Some of them are disruptive and violent. This ruffles my complacency but then I recall that revolutionists have historically behaved this way and the militants do claim to be provoking a revolution.[15] However, the "silent minority" of the revolution who in times past built the new society when the violence subsided seem in the present instance to be groping, sometimes aimlessly, toward undefined goals. And they seem to be too naive or too alienated from our culture to seek advice from those who might help.[16] After all, there have been and are other cultures with different sets of values, most of which we self-righteously write off as heathen, primitive, or otherwise inferior to ours.[17, 18] It is too bad that the past is irrelevant; the young might get some ideas from a little prowling.

But the young have time on their side, and we will stall and create diversions while they define their goals and lay their plans to achieve them. I am reminded of Eda Le Shan's angry statement that you rub a baby's stomach while the bottle warms and put men on the moon while cities rot—both are diversions.[19]

It may be that what I think I see is all a vast illusion, a mirage, and that the horizon is bare and dreary; I hope not. I hope that somewhere among the young there is an inconspicuous Noah quietly building an ark from which will issue a new era, perhaps the Sociological Era, with new goals and a new set of values. I hope it is an Ecological Era in the broadest sense: an era in which man comes to peace with himself and nature and makes restitution for past neglect and desecration. It would be a task worthy of the tools we acquired in the Technological Era and of the new generation of engineers and scientists. But I have few dragons left to fight, so to the young I say

Morituri te salutamus.[20]

References

1. Henahan, Donal, "Like, Y'Know, A guide to the Avant Garde," *N.Y. Times*, Jan. 4, 1970. Definition: Happening—as in "It's what's happening"—a familiar riposte by artists meaning "don't blame me if I turn out junk."
2. It may be that this approach is no longer valid; what counts is knowledge, not experience: "How to manage Brainpower," excerpt from a speech by C. A. Anderson of SRI; *Science*, vol. 165, (Sept. 12, 1969) p. 1106.
3. I am indebted to Mr. E. J. Norton of the RCA Patent Department at Princeton for the data.
4. Data were averaged by five year periods to eliminate minor fluctuations yet preserve expected major variations.
5. See also, Fink, D., *Spectrum* Vol. 6, No. 12 (Dec. 1969) pp. 57-60.
6. For a provocative view of the "S-curve" in a larger context, see John Platt, *Science*, Vol. 166 (Nov. 28, 1969) pp. 1115-1121.
7. Nergaard, L. S., "Microwave Research, Devices for the Future," RCA ENGINEER, Vol. 10, No. 4 (Dec. '64-Jan. '65) p. 7.
8. "Keeping up with, etc."
9. Statistical Abstract of the U.S., Bureau of the Census, U.S. Department of Commerce, 88th Edition.
10. Balth. van der Pol, *Proc. IRE*, Vol. 22, No. 9 (Sept. 1934) p. 1051.
11. August 15-17, 1969, Bethel, New York.
12. For those who can't get to the mountains for traffic, see the photograph in the "Travel Section," *N.Y. Times*, Sunday, Feb. 1, 1970.
13. I have trouble with my eyes; corrective lenses help the myopia and astigmatism to a certain extent, but they don't seem to do anything for occasional spells of cynicism.
14. Bernhard, Robert, "Student rebels: behind ivy-covered barricades," *Scientific Research* (Sept. 29, 1969).
15. For example, Patrick Henry in the Virginia House of Burgesses, 1765.
16. This works both ways, "The Generation Gap —Is Anyone Listening?," Eda Le Shan, *Image*, Vol. 7, No. 4, (Feb. 1970) p. 19.
17. "Patterns of Culture," Ruth Benedict, Houghton-Mifflin Co., N.Y., 1934, is a standard reference on this subject.
18. There seem to be certain semantic problems between men of Judaeo-Christian and Taoist cultures in Paris, even now.
19. WNDT-TV Channel 13, *Newsfront*, 10:30, Aug. 27, 1969.
20. We who are about to die salute thee.

Postscript

Three passions, simple but overwhelmingly strong, have governed my life; the longing for love, the search for knowledge, and unbearable pity for the suffering of mankind.

—Bertrand Russell
(May 18, 1872; Feb. 2, 1970)

Holographic applications—a review and a forecast

Dr. E. G. Ramberg

A review of work in holography during the past six years causes some of its earlier promises to recede into the background. This applies, in particular, to its widespread use for three-dimensional visual display and to its potential for overcoming the present limits of the electron and x-ray microscope. Instead, the future of holography appears to lie largely in its role as a link in information-processing systems, where relative immunity to damage, insensitivity to positioning, ease of coding, and simplicity of the required optical systems give the hologram an advantage over the conventional optical image. In addition, holography can be expected to become an increasingly useful tool in interferometry, ultrasonic diagnostics, and integrated-circuit production.

Dr. Edward G. Ramberg
Materials and Device Research
RCA Laboratories
Princeton, New Jersey

received the AB from Cornell University in 1928 and the PhD in theoretical physics from the University of Munich in 1932. After working on the theory of x-ray spectra as research assistant at Cornell, he joined the Electronic Research Laboratory of RCA in Camden in 1935. He has been associated with the RCA Laboratories in Princeton since their establishment in 1942. He has worked primarily on electron optics as applied to electron microscopy and television, various phases of physical electronics, thermoelectricity, and optics. In 1949, he was visiting professor in physics at the University of Munich and, in 1960 and 1961, Fulbright Lecturer at the Technische Hochschule, Darmstadt. Dr. Ramberg is a Fellow of the IEEE and the APS and a member of Sigma Xi and the Electron Microscope Society of America.

The elapsing of about six years since the application of laser technology to holography warrants a review of its accomplishments and a new estimate of its potentialities. In attempting this task, we may classify the applications of holography as follows, fully aware of the inevitable overlap between categories:

1) Three-dimensional image display;
2) Information storage;
3) Image multiplication and recording;
4) Interferometry;
5) Coding, lens correction, and pattern recognition; and
6) Wavelength translation.

Three-dimensional image display

To the layman, the most striking property of a hologram is its ability to construct a fully three-dimensional image of any object. The utility of this property for advertising purposes and artistic effects is obvious and has been exploited, as in a 7-foot holographic image display at the new headquarters of the General Motors Corporation in New York.[1] It has at least equal potential as a visual aid in education, conveying to the student an accurate idea of space relations in an object or device. Even objects in motion can be recorded satisfactorily in the hologram by the use of Q-switched ruby lasers, with pulse times of the order of 10 ns.[2] Illumination by large-area diffuse scatterers, in conjunction with new high-sensitivity, high-resolution photographic materials,[3] permits even large-scale front-lighted hologram images of human subjects.[4] The necessity of laser illumination of the subject can also be circumvented by preparing an "integral photograph" of the subject with a fly's eye lens and recording a hologram from the latter.[5]

Good-quality three-dimensional images in natural color have been recovered from holograms prepared with three superposed laser beams of different wavelengths on "thick" recording media by illumination with a white light reconstructing beam, utilizing the wavelength selectivity of the thick hologram.[6] The polarization conditions in the original light wave can also be reproduced if two pairs of differently oriented reference and reconstructing beams with mutually perpendicular polarization are employed.[7] Both color and polarization can be preserved, even with a thin hologram, at the expense of a certain superposed noise background, provided that the triple recording and reconstructing beams are coded by identical diffusers before incidence on the hologram plate.[8,9]

One of the important properties of the hologram is that it makes possible—e.g., by Q-switched laser exposure—the recording of an instantaneous situation in depth, permitting detailed examination at a later time. Thus Thompson and Parrent[10] study the particle distribution in aerosols with their "disdrometer," examining the hologram image with a mechanically displaced television camera. A similar advantage is realized by recording microscope images as holograms, the hologram plate being located near the intermediate image.[11] Since a real image of the microscope interior may be formed in reconstruction, this technique permits image modification after recording by the insertion of phase plates or stops in the real focal plane of the objective.[12]

Considerable effort has been directed toward reducing the information content of holograms, while yet preserving the essential feature of enabling the viewer to see the object from a wide range of directions. If only horizontal parallax is to be preserved, the hologram can be reduced to a narrow horizontal strip, approximately a pupillar diameter in height; a sequence of such (Fourier-transform) strip holograms can be formed into a continuous-motion motion-picture strip.[13] If the correct aspect is required only for a finite number of angular positions the complete hologram may be replaced (for visual observation) by an assembly of elementary holograms, with an area comparable to that of the pupil of the human eye, located at the desired positions, the intervening space being filled up with holograms identical with their neighbors.[14] This technique has been found advantageous for preparing holograms, e.g., for computed models of organic molecules.[15] It obviously also has applications for the three-dimensional visual examination of subjects for which

---

Reprint RE-16-1-7
Final manuscript received February 23, 1970.

-ray patterns have been recorded with wide range of x-ray source orientaions.

t the same time, bandwidth requirements for television and film-dimension requirements for motion pictures preclude the use of holograms for three-dimensional entertainment.

Information storage

We must here distinguish between thin (or surface) and thick (or volume) holograms. Roughly, the dividing line is a hologram of thickness $t=(\lambda/2)\sin^2(\alpha/2)$ where α is the angle between the object beam and the reference beam and λ is the wavelength of the radiation used in recording the hologram. Surface holograms generally reproduce two images (a true and a conjugate image) and are neither wavelength- nor direction-selective. Thick holograms produce only one (true) image and this only when the reconstructing beam approximates the reference beam in direction as well as in wavelength.

Thin holograms have found application in numerous read-only memory systems.[16,17,18] The memory plate generally consists of a high-resolution plate on which an array of small holograms is recorded. A digitally controlled deflection system (which may be mechanical or, preferably, electro-optic or ultrasonic) or a light-emitting diode array directs the reconstructing beam to the selected hologram, whereupon the hologram projects a prerecorded mask pattern on a fixed diode sensor array. Any element of the array may be interrogated, determining the polarity of the corresponding bit in the recorded pattern. The system lends itself to high storage densities and short access times. As compared with direct photographic recording, the holographic technique has the advantage of greater immunity to damage, aberration-free image transfer without lenses, and reduced sensitivity to errors in scanning beam positioning. Curie-point writing on magnetic *MnBi* holograms, introduced by Mezrich,[19] promises to remove the "read-only" limitation.

Thick holograms have the advantage that a large number of patterns can be recorded in superposition by shifting the orientation of the reference beam relative to the hologram medium; these patterns can then be read out by corresponding angular displacements of the reconstructing beam. They may be irreversible, like photographic emulsions and undeveloped dichromated gelatine, or reversible like the photochromics[20,21,22] and lithium niobate;[23] the last material has the advantage of recording phase holograms, which have inherently higher efficiency than absorption holograms.

It may be noted that the theoretical limit of information density in volume holograms is 1 picture element for a volume of the hologram medium equal to λ^3.[24] Empirically, the storage of a hundred line drawings in a $2\times2\times0.5$ in^3 crystal of *KBr* has been reported.[25] For a further discussion of holographic memories we refer to the article "Research in Optical Memories" by J. A. Rajchman to be published in a future issue.

Image multiplication and recording

In integrated-circuit manufacture there are two essential steps which can benefit by, and eventually be combined through, the application of holography. The basic problem is to image an array of identical patterns with very high resolution on a wafer coated with photoresist. In the conventional procedure, a mask is prepared by the "step-and-repeat" imaging of a single master pattern, and the mask with the developed array is illuminated in contact with the photoresist-coated wafer surface. This procedure leads to rapid deterioration and limited life of the mask. If, instead, a hologram is prepared of the pattern array, equal resolution may be obtained in the wafer plane without wear or deterioration.[26] As a further step, the hologram of the pattern array may be replaced by a hologram of point sources (formed e.g., by pinholes or, more efficiently, by a lens plate) coinciding with the centers of the individual patterns. If, during the process of wafer printing, the point reference source is replaced by a master pattern centered on the reference source location, an array of pattern images is reconstructed in the plane of the wafer.[27] It is true that only the center of every pattern is reproduced without aberration, which increases from the center outward. However, promising results have been obtained by this process, with the possibility of further improvement. In this process, speckle noise in the image can be eliminated by the use of a rotating diffuser in the beam illuminating the master pattern. [See also D. L. Greenaway, "Holographic research at the Zurich Laboratories," in this issue.]

Interferometry

Interferometry is the measurement of small differences in thickness—or, more generally, small differences in optical path length—by the interference of light waves. Holography has greatly simplified and extended this procedure. In ordinary interferometry, two carefully matched comparison paths must be provided, one containing the subject and the other the standard with which it is to be compared. In holography, two optical paths which differ in the time at which they were recorded can be compared —e.g., the optical path through the same subject in a disturbed and an undisturbed condition. If holograms for these two conditions are recorded in superposition and then developed, reconstruction will provide two superposed images traversed by dark fringes where the image-forming light has suffered a change in path of an integer multiple of half wavelengths. Similar "real-time" differential interferometry is observed if only a single hologram (of the undisturbed subject) is recorded and the subject is viewed through the developed hologram in the position in which it was originally recorded.[28] Holographic differential interferometry has been successfully applied to the study of strains in machine parts, defects in automobile tires,[1] vibration analysis,[29] and the study of turbulence in aerodynamics.[30] In real-time differential interferometry the difficulty of repositioning of the hologram after development has been avoided by replacing the photographic emulsion with a photochromic film.[31]

Apart from differential interferometry, which also finds a valuable application in microscopy,[32] numerous other types of interferometry can be effected with holograms. For example, contour maps of objects can be prepared either by using coherent light with two slightly different wavelengths for recording the holograms[33] or recording holograms of the subject immersed in fluids of slightly different index.[34] The difference in wavelength or refractive index controls the step in depth corresponding to a fringe separation.

Coding, lens correction, and pattern recognition

It has been shown that images can be coded by placing a diffuser either between the hologram and object[35] or in the reference beam.[8] Reconstruction requires the placement of an identical diffuser in the position relative to the hologram which the diffuser occupied during recording. In place of the diffuser in the reconstructing beam, a hologram of the diffused source formed with a point reference source and registered with the original hologram can also serve as "decoder."[36]

Optical-system defects can be corrected by a hologram by interchanging the roles of the object beam, passing through the imperfect system, and the reference beam during recording and reconstruction. The value of this technique for correcting—e.g., spherical aberration—is limited by the relatively low optical efficiency of the hologram.[37]

The usefulness of holography for pattern recognition, as described by VanderLugt,[38] relies on the recording of intensity distributions corresponding to the cross-correlation integral of the complex amplitudes of the signal pattern and the field which is to be searched. This cross correlation integral is a sensitive measure of pattern identity or similarity. The technique also has the important advantage of being insensitive to pattern displacement. Its most interesting application so far appears to be the identification of fingerprints.[39] The discrimination between patterns has been found excellent; an as-yet unsolved problem is the classification of the fingerprints into subgroups, which would facilitate the comparison of a given fingerprint with those in a large master file.

Wavelength translation

The hologram technique makes it possible, in principle, to reconstruct three-dimensional optical images of any object which transmits or scatters invisible coherent radiation of any kind, provided that the intensity distribution in a plane of the radiation in question can be recorded with adequate resolution. To reconstruct the image, scaled by the ratio of the (visible-light) wavelength used in reconstruction to the wavelength of the radiation used in recording, the original hologram must simply be enlarged or reduced to the same scale and illuminated by a reconstructing beam similar to the reference beam in orientation and convergence. Within limits, the scale of reproduction can be varied by altering the convergence of the reconstructing beam, at the expense of introducing aberrations and errors in perspective. Efforts to apply this technique or holographic wavelength translation have been made in electron and x-ray microscopy, scaling the wavelength up by factors ranging from 100,000 to 1000, and in the field of ultrasonics and microwaves, comparably scaled down.

While holography owes its origin to Gabor's efforts to improve the performance of the electron microscope[40] and its application to x-rays followed after a short interval, more recent work in holographic wavelength translation has been concentrated in ultrasonics and microwaves. In ultrasonics the frequency range employed is from 10 kHz to 15 MHz, corresponding to wavelengths (in water) from 15 cm to 0.1 mm. The longer (kilohertz) waves are used for exploring larger structures under water, the shorter ones, for finding flaws within opaque, but otherwise uniform, bodies and for medical applications, ultrasonic examination of soft tissues supplementing x-ray examinations. In the long-wavelength range, mechanical scanning of the sound field with the microphone is employed and the reference wave may be added synthetically in recording the amplitude variation in the field.[41] For the shorter waves, camera tubes with longitudinally resonant piezoelectric plates as targets may be employed as sensors.[42] A basic advantage of holography for ultrasonic exploration is the fact that it permits exploration of the image in depth after recording. At the same time, this image is necessarily greatly distorted in depth, since reducing its dimensions by a factor equal to the ratio of the ultrasonic and optical wavelengths would lead to an image much too small for direct observation.

In the microwave field, the most striking application of holographic techniques has been the construction of terrain maps by optical translation techniques from amplitude and phase information received, in response to emitted wave trains, by a small radar antenna mounted on a plane.[43] The return signals are recorded on a plate, with flight direction as one rectangular coordinate and range (corresponding to the terrain coordinate at right angle to the flight direction) as the other. The record consists of a sequence of linear holograms generated by lines of constant range on the terrain from which, by suitable optical processing, a terrain map can be reconstructed.

Forecast

Apart from such highly specialized applications, what are the most promising prospective uses of holography? In some areas, such as strain measurement and interferometry in general, it has already established itself beyond a doubt, in view of its greater simplicity and broader range of application (to objects of arbitrary shape, with or without intervening refracting elements) as compared with conventional interferometry. The storage of transient three-dimensional phenomena for future study, exemplified by the holographic photography of aerosols and turbulent flow, is another field in which the role of holography is assured. This property may also prove of great value in the light microscopy of organic specimens. Two-dimensional holographic information stores for computers possess the advantages of high storage density and rapid access; they are superior to optical image stores in their immunity to damage and reduced requirements in optical equipment and scanning precision. The very high storage density possible in volume holograms assures a continued search for suitable materials, preferably combining the high efficiency characteristic of refractive index storage (as in lithium niobate) with reversibility, long life, and high sensitivity. Holograms also provide an excellent means for coding information which is to be unintelligible to the unauthorized viewer—a property which could be used to advantage for credit cards. Conversely, they can be expected to play a role in pattern recognition (as in checking fingerprints) automatic keyword selection, etc.

The likelihood that holography can contribute materially to improving resolution in electron and x-ray microscopy remains remote there is no evidence that current limitations in the coherence and intensity of electron and x-ray sources will undergo great changes. Ultrasonic holography for flaw detection and physiological examination appears more promising, giving greater depth of focus than direct ultrasonic imaging and a simpler, more rapid method of recording than ultrasonic ranging.

The application of holography to true three-dimensional imaging for entertainment purposes—in particular motion pictures and television—is also likely to be limited. While such holographic films and television would require a very great increase in film area (and bring corresponding difficulties in film transport) in the first instance and an excessive increase in transmission bandwidth in the second, they do not provide the viewer with more, at any instant, than stereo film and television, which can be had for the relatively small cost of doubling the film area and transmission bandwidth, respectively. This is not true for scientific applications, since here the holographic record may be used for the repeated examination of phenomena from different viewing directions. Furthermore, there may be limited demand for stationary holographic portraits (in particular, thick holograms illuminated from the front by a white-light point source), just as holograms have, to some extent, been used in advertising displays. Holographic illustrations for instructional purposes can be expected to play a more significant role; they would require the use of a hologram viewer, since image reconstruction is not possible with diffuse white-light illumination. Composite holograms, prepared for three-dimensional viewing from a sequence of different aspects of molecular models or a sequence of radiograms recorded with different directions of x-ray irradiation, represent a specific example.

It is becoming increasingly evident that the important services which holography can provide in the entertainment field lie in another direction—namely, in the sophisticated utilization of the peculiarities of the hologram to improve the economy and performance of visual entertainment systems. Relative immunity to dust and damage, insensitivity to positioning errors (of Fourier-transform holograms), and the possibility of rapid duplication on inexpensive stock are some of the pertinent favorable properties of the hologram. W. Hannan's article in this issue "Holographic Movies for TV Viewing" describes the application of these and other properties in the development of a practical low-cost television tape player. The eventual use of holography to effect economies in integrated-circuit production represents a further, more indirect, contribution to the field of information processing in general.

In summary, while some of the early anticipations for holography are likely to be disappointed, its patent advantages for optical information processing systems and its uses as an effective research tool assure it a firm and expanding role in the future.

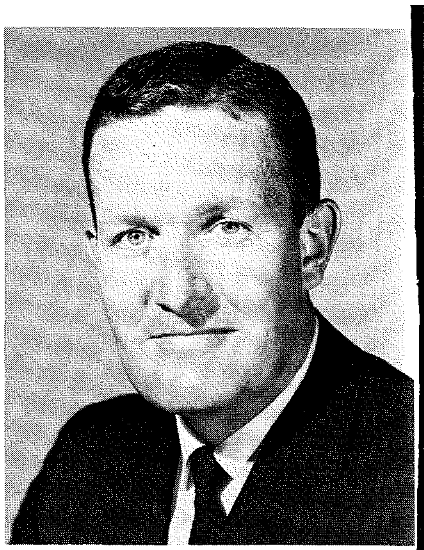
References

1. "Many Holographic Roads Lead to Ann Arbor," *Laser Focus* Vol. 5 (Feb. 1969) pp. 16-17.
2. Brooks, R. E., Heflinger, L. O., Wuerker, R. F., and Briones, R. A., "Holographic Photography of High-Speed Phenomena with Conventional and Q-Switched Lasers," *App. Phys. Lett.* Vol. 7 (1965) pp. 92-94.
3. Frecska, S. A., "Characteristics of the Agfa-Gevaert Type 10E70 Holographic Film," *Appl. Opt.*, Vol. 7 (1968) pp. 2312-2314.
4. Siebert, L. D., "Large-Scale Front-Lighted Hologram of a Human Subject," *IEEE Proc.* Vol. 56 (1968) pp. 1242-1243.
5. Pole, R. V., "3-D Imagery and Holograms of Objects Illuminated in White Light," *Appl. Phys. Lett.* Vol. 10 (1967) pp. 20-22.
6. Pennington, K. S., and Lin, L. H., "Multicolor Wavefront Reconstruction," *Appl. Phys. Lett.* Vol. 7 (1965) pp. 56-57.
7. Fourney, M. E., Waggoner, A. P., and Mate, K. V., "Recording Polarization Effects via Holography," *J.O.S.A.* Vol. 58 (1968) pp. 701-702.
8. Collier, R. J., and Pennington, K. S., "Multicolor Imaging from Holograms Formed on Two-Dimensional Media," *Appl. Opt.* Vol. 6 (1967) pp. 1091-1095.
9. Kurtz, C. N., "Holographic Polarization Recording with an Encoded Reference Beam," *Appl. Phys. Lett.* Vol. 14 (1969) pp. 59-60.
10. Parrent, Jr., G. P., and Thompson, B. J., "On The Fraunhofer (Far-Field) Diffraction Patterns of Opaque and Transparent Objects with Coherent Background," *Opt. Acta* Vol. 11 (1964) pp. 183-193.
11. van Ligten, R. F., and Osterberg, H., "Holographic Microscopy," *Nature* Vol. 211 (1966) pp. 282-283.
12. Ellis, G. W., "Holomicrography: Transformation of Image During Reconstruction a posteriori," *Science* Vol. 154 (1966) pp. 1195-1197.
13. DeBitetto, D. J., "A Holographic Motion Picture Film with Constant Velocity Transport," *Appl. Phys. Lett.* Vol. 12 (1968) pp. 295-297.
14. Lin, L. H., "A Method of Hologram Information Reduction by Spatial Frequency Sampling." *Appl. Opt.* Vol. 7 (1968) pp. 549-554.
15. "Inexpensive Holograms by Computers," "*Scientific Research* Vol. 4 (May 26, 1969) p. 53.
16. Reynolds, J. L., Tao, T. Y., and Schools, R. S., "An Experimental Optical Memory System," *NEREM Record* (Nov. 1968) p. 78.
17. LaMacchia, J. T., Lin, L. H., and Burckhardt, C. B., "Formation and Evaluation of a Hologram Array for an Optical Memory," *J.O.S.A.* Vol. 59 (1969) p. 490.
18. Vilkomerson, D. H. R., Mezrich, R. S., and Bostwick, D. I., "Holographic Read-Only Memories Accessed by Light-Emitting Diodes," *AFIPS Conference Proceedings* Vol. 33 (1968) p. 1197.
19. Mezrich, R. S., "Curie-Point Writing of Magnetic Holograms on MnBi," *Appl. Phys. Lett.* Vol. 14 (1969) pp. 132-134.
20. Baldwin, W. J., "Determination of the Information Storage Capacity of Photochromic Glass with Holography," *Appl. Opt.* Vol. 6 (1967) p. 1428.
21. Bosomworth, D. R., and Gerritsen, H. J., "Thick Holograms In Photochromic Materials," *Appl. Opt.* Vol. 7 (1968) pp. 95-98.
22. Kiss, Z. J., "Photochromic Materials for Quantum Electronics," *IEEE J. Quantum El.* Vol. *QE-5* (1969) pp. 12-17.
23. Chen, F. S., LaMacchia, J. T., and Fraser, D. B., "Holographic Storage in Lithium Niobate," *Appl. Phys. Lett.* Vol. 13 (1968) pp. 223-225.
24. van Heerden, P. J., "Theory of Optical Information Storage in Solids," *Appl. Opt.* Vol. 2 (1963) pp. 393-400.
25. Kalman, G. U., "Holographic Graphical Storage in Thick Alkali Halide Crystals," *1968 IEEE International Convention Record,* p. 35.
26. "Major Advance in Wafer-Making Forecast," *Electronic Design* (June 21, 1966) p. 17.
27. Groh, G., "Multiple Imaging by Means of Point Holograms," *Appl. Opt.* Vol. 7 (1968) pp. 1643-1644.
28. Hildebrand, B. P., and Haines, K. A., "Interferometric Measurements Using the Wavefront Reconstruction Technique," *Appl. Opt.* Vol. 5 (1966) pp. 172-173.
29. Powell, R. L., and Stetson, K. A., "Interferometric Vibration Analysis by Wavefront Reconstruction," *J.O.S.A.* Vol. 55 (1965) pp. 1593-1598 and 1694-1695.
30. Tanner, L. H., "Some Applications of Holography in Fluid Mechanics," *J. Sci. Instr.* Vol. 43 (1966) pp. 81-83.
31. Chau, H. H. M., "Holographic Interferometer for Isopachic Stress Analysis," *Rev. Sci. Instr.* Vol. 39 (1968) pp. 1789-1792.
32. Snow, K., and Vandewarker, R., "An Application of Holography to Interference Microscopy," *Appl. Opt.* Vol. 7 (1968) pp. 549-554.
33. Zelenka, J. S., and Varner, J. R., "A New Method for Generating Contours Holographically," *Appl. Opt.* Vol. 7 (1967) pp. 2107-2110.
34. Shiotake, N., Tsuruta, T., Itoh, Y., Tsujiuchi, Takeya, N., and Matsuda, K., "Holographic Generation of Contour Map of Diffusely Reflecting Surface by Using Immersion Method," *Jap. J. Appl. Phys.* Vol. 7 (1968) pp. 904-909.
35. Leith, E. N., and Upatnieks, J., "Holographic Imagery Through Diffusing Media," *J.O.S.A.* Vol. 56 (1966) p. 523.
36. Haina, D., Lanzl, F., Mager, H. J., and Waidelich, W., "On the Compensation of Extended-Source Holograms," *Z. f. angew. Phys.* Vol. 25 (1968) pp. 205-208.
37. Upatnieks, J., VanderLugt, A., and Leith, E., "Correcting of Lens Aberrations by Means of Hologram," *Appl. Opt.* Vol. 5 (1966) pp. 589-593.
38. VanderLugt, A., "Signal Detection by Complex Spatial Filtering," *IEEE Trans. Inform. Theory* Vol. IT-10 (1964) pp. 139-145.
39. Horvath, V. V., Holeman, J. M., and Lemmond, C. Q., "Holographic Technique Recognizes Fingerprints," *Laser Focus* Vol. 3 (June 1967) pp. 18-23.
40. Gabor, D., "Microscopy by Reconstructed Wavefronts," *Proc. Roy. Soc. (London)* Vol. A197 (1949) pp. 454-487.
41. Metherell, A. F., El-Sum, H. M. A., Dreher, J. J., and Larmore, L., "Introduction to Acoustic Holography," *J. Ac. Soc. Am.* Vol. 42 (1967) pp. 733-742.
42. Jacobs, J. E., "Ultrasound Image Converter Systems Utilizing Electron-Scanning Techniques," *IEEE Trans. Sonics & Ultrasonics* Vol. SU-15 (1968) pp. 146-152.
43. Leith, E. N., and Ingalls, A. L., "Synthetic Antenna Data Processing by Wavefront Reconstruction," *Appl. Opt.* Vol. 7 (1968) pp. 539-544.

Holographic movies for TV viewing

W. J. Hannan

RCA has developed a low-cost color-TV tape player using lasers and holography. In commercial form, the tape player is expected to be the first consumer product to employ lasers, and will be designed to attach to the antenna connections of any standard color television set. It will play full-color programs recorded on low-cost clear-plastic tapes. This paper discusses the reasons for using lasers and holography, the fundamentals of the recording and playback processes, and the method of tape manufacture. Market impact and cost considerations are also covered in some detail.



William J. Hannan
Consumer Research Laboratory
RCA Laboratories
Princeton, N.J.
graduated from the RCA Institute in 1951 and was hired by RCA as an engineer in the Industrial Products Division. He received the BSEE from Drexel Institute in 1954 and was awarded a Sarnoff Fellowship which he used to obtain the MSEE from the Polytechnic Institute of Brooklyn in 1955. From 1956 to 1966, Mr. Hannan worked in the Applied Research Section of Defense Electronic Products. By 1958 he had become a Senior Engineer and in 1959 was promoted to Group Leader. Since 1966 he has been a Group Head at RCA Laboratories working mainly in the field of holography.

The concept of color movies through a home TV receiver is not new, but RCA has devised a new method for implementing it. Using two relatively new technologies—lasers and holography—holograms of color movies are embossed on tapes made of clear, inexpensive plastic material. The tapes can then be played back through a conventional TV receiver, where the tape is passed through a laser beam and the reconstructed hologram images are picked up with a TV camera and displayed on the TV set (see Fig. 1).

Why holograms?

Holograms are usually thought of as devices that reproduce three-dimensional images. For the holographic video tape application, however, the holograms produce only two-dimensional images. (It is possible to make holographic tapes that produce three-dimensional images, but it seems unlikely that a practical TV system could be developed to display them.)

The main reason for using holograms is the low-cost replication potential of the holographic tapes—the cost advantage being due to a unique manufacturing process developed at RCA Laboratories whereby holographic movies are embossed on vinyl tape. Two other important advantages afforded by holography—scratch resistance and image immobilization—are discussed later.

Phase holograms

It is well known that images can be embossed in plastic. In fact, many magazine covers are produced by this method because relief images tend to stand out more than conventional images. However, replication of holograms by an embossing process is entirely new.

Obviously, the embossing process calls for the storage of information in the form of a relief pattern. For this reason, phase holograms were selected for the holographic tape. A phase hologram is essentially a relief map of a diffraction pattern. The magnitude of the surface corrugation in a typical phase hologram can be seen in a photomicrograph of the surface of the tape, shown in Fig. 2. The surface has the appearance of a series of mountain ranges—the separation between mountain peaks being about 1 micrometer and the average peak-to-valley distance on the order of 0.05 micrometer.

Scratch and dirt resistance

Most home-movie enthusiasts who use 16-mm or smaller film are familiar with the scratch and dirt problems that plague small-frame movies. The problem gets worse, of course, as frame size is reduced. Ultimately, one has to compromise between cost per hour of playing time and the noise he will tolerate in the image.

The redundant nature of holograms offers a potential solution to this problem. Highly redundant holograms can be produced by illuminating an object such that the same information is recorded on many different areas of the hologram. Thus, if one part of a hologram is scratched, spotted with dirt, or otherwise mutilated, other parts of the hologram still reconstruct the entire image. Scratches and dirt do cause a loss of information, but the loss shows up as only a slight decrease in contrast and resolution.

Holograms made of diffusely reflecting or diffusely illuminated objects have a tremendous amount of redundancy. This fact is apparent when one realizes that diffused light spreads over a very wide angle. Therefore, when a transparency is illuminated with diffused light, light from every point on the transparency is spread all over the hologram. Conversely, every point on the hologram contains information about the entire object, indicating a very high degree (in fact, the maximum degree) of redundancy.

Unfortunately, diffuse holograms are not suitable for applications such as holographic video tape, where it is necessary to record "microholograms." It turns out that an unwanted by-product of diffuse laser illumination is speckle noise that gets worse as holograms are made smaller. In fact, signal-to-noise ratio approaches a value of unity (zero dB) as image resolution becomes limited by hologram size. Obtaining a signal-to-noise ratio of 30 dB calls for increasing the hologram area by a factor of 1000 (over the area needed to satisfy resolution requirements)—a very high price to pay for redundancy. Holographic research at RCA Laboratories has led to a unique method—multiple beam illumination—for making holograms that produce speckle-free images.

Perhaps the easiest way to visualize how this comes about is to consider

Reprint RE-16-1-11
Final manuscript received February 23, 1970.

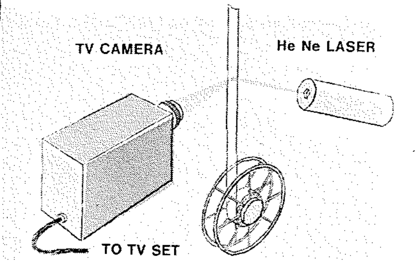


Fig. 1—Beam from a *HeNe* laser passes through clear vinyl tape that has holograms embossed on its surface and projects a motion picture image on a vidicon TV camera.

the use of a diffraction grating in place of a diffuser, as illustrated in Fig. 3. If the grating period (i.e., the spacing between grating lines) is just beyond the resolution limit of the display system (e.g., a TV receiver), the grating lines will not appear in the image.

A diffraction grating produces multiple beams, and the number of beams and their relative intensities depend upon fixed parameters of the grating. Since each beam diverges from the grating at a different angle, light from each point on the object is directed to a number of different areas on the hologram recording medium. Thus each object point is recorded with n-fold redundancy, where n is the number of equally intense beams produced by the grating. If the beams are not equally intense, less than n-fold redundancy will be realized. In this regard, a two-dimensional phase grating is a good choice because this type grating can produce nine equally-intense beams with about 80% efficiency. Fig. 4 shows a laser beam passing through an experimental two-dimensional phase grating.

In effect, multiple-beam recording creates a number of subholograms, each of which is capable of reconstructing the entire image. [Even though the individual subholograms are physically separated (see Fig. 5), their reconstructed images superimpose to form a high-resolution, composite image.] Therefore, if one or more of the subholograms is mutilated, the other holograms will still reconstruct the entire image.

Image immobilization

During playback, the tape moves continuously through the laser beam (see Fig. 1) and a motion picture image is projected onto the TV camera. There is no apparent image smear, even though the laser beam is continuously illuminating the tape. Actually, the motion picture images gradually fade from one frame to the next, the individual frames remaining immobilized while the holograms from which they originate move through the beam. This remarkable property is due to a unique image-immobilization characteristic of Fraunhofer holograms.

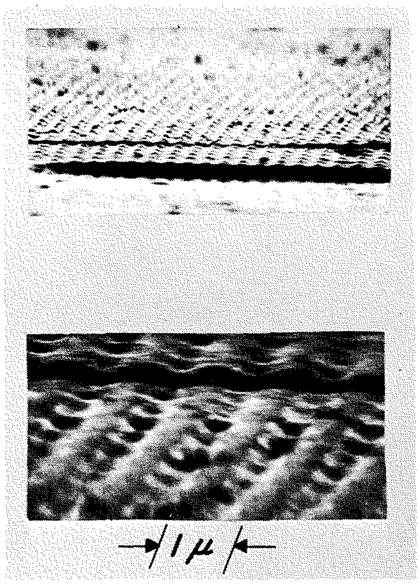


Fig. 2—Photomicrograph of the surface of a holographic tape.

How a Fraunhofer hologram immobilizes images is best illustrated by first considering how a diffraction grating works (Fig. 6). The angular diffraction of the first order beam is $\sin^{-1}(\lambda/d)$, where λ is the wavelength of the laser, and d is the grating period. (As shown later, a Fraunhofer hologram of a point object is a grating; during playback, the first-order beam reconstructs a point image.) The important fact to note is that angular diffraction is independent of translation of the grating; i.e., moving the grating back and forth or up and down, or combinations of these movements, will not change the angular diffraction of the first-order beam. With this in mind, let us now consider a Fraunhofer hologram.

As shown in Fig. 7, a Fraunhofer hologram is recorded by placing the object (in this case, a motion-picture transparency) at the focal plane of a lens. This causes light emanating from a point on the object to be collimated (i.e., converted from a spherical wave to a plane wave). If the reference beam is collimated, then the resultant hologram of the point object is a grating. Since angular diffraction of a beam passing through a grating is independent of grating translation, a Fraunhofer hologram of a point object can be translated without changing the position of the reconstructed point image. This argument can be extended to include all points in an image, thus showing that image position is practically independent of hologram translation.

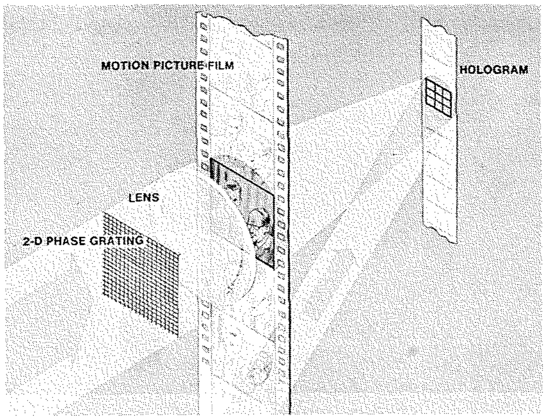


Fig. 3—Diffraction grating creates multiple beams, each of which records a subhologram. Holograms made this way have n-fold redundancy, where n is the number of equally intense beams which pass through the transparency.

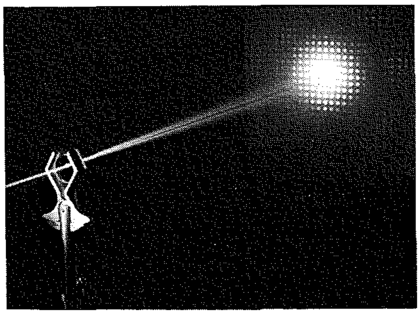


Fig. 4—Laser beam diffracted by a 2-D phase grating. Grating has sinusoidal surface corrugations running in orthogonal directions.

It has been found that the image immobilization of Fraunhofer holograms is so good that, even when the readout beam is between two holograms, the images reconstructed from the holograms almost perfectly superimpose; consequently, a motion picture is projected as frame-to-frame fades. Because an image is always projected onto the TV camera, regardless of the position of the tape, there is no need for shuttering or electronic synchronization between tape drive and camera scanning. It follows that fast, slow, stop, and reverse motion can be achieved—without flicker—simply by appropriate change of tape speed. In

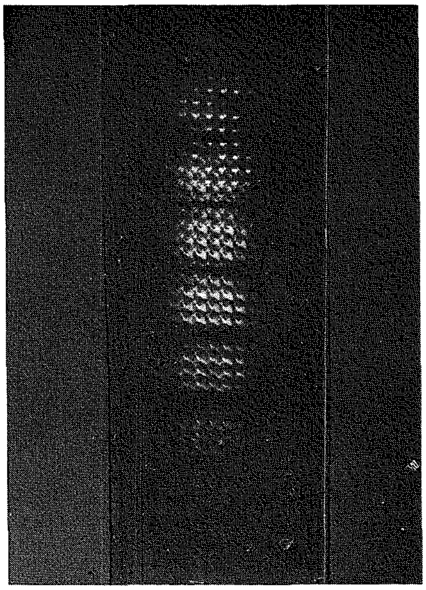


Fig. 5—Holographic tape was illuminated so as to make the subholograms stand out. In this case, there are about 20 subholograms per composite hologram.

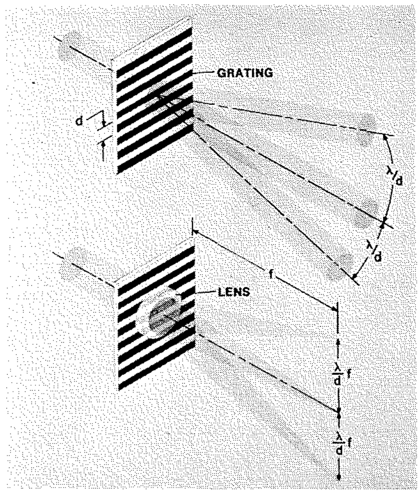


Fig. 6—Diffraction of a laser beam by a grating.

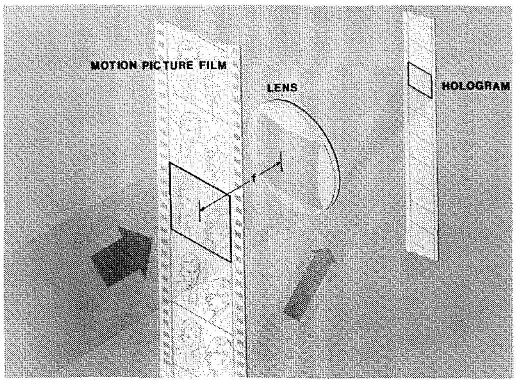


Fig. 7—Setup for recording Fraunhofer holograms. Object transparency is placed at focal plane of lens.

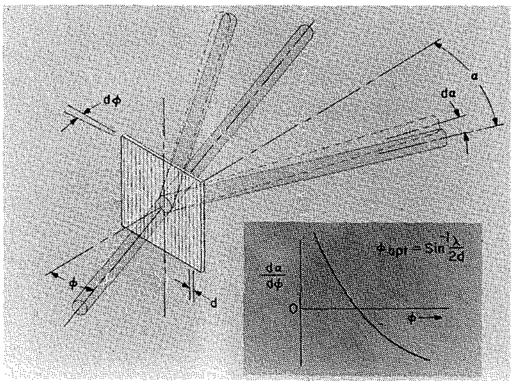


Fig. 8—Optimum readout angle.

the normal operating mode, tape speed need be controlled only to the accuracy demanded by the sound system. Hence the tape-drive mechanism commonly used for magnetic-tape recorders is adequate.

From an economic point of view, continuous motion transport is attractive because it exerts less strain on the tape and, therefore, allows the use of thinner, less-expensive tape. Perhaps an even more significant aspect of the thin-tape advantage is the smaller size cartridge required for a given playing time. Holograms have been successfully replicated on 1-mil vinyl tapes. Running at 3 in/s, a 3-inch reel will play for about 30 minutes.

Another important property of Fraunhofer holograms is that the reconstructed image remains in focus even when the camera is moved toward or away from the tape. In fact, the camera can be moved as much as one or two inches without seriously affecting image quality. This allows the tape transport to have rather loose tolerances—hence, low cost.

Transmission readout

Phase holograms can be read out either by reflecting the readout beam from the surface of the tape or by transmitting the laser beam through the tape. Transmission readout is preferred because it yields higher resolution images. The lower resolution associated with reflective readout can be traced to unavoidable imperfections in the tape and transport mechanism. To achieve high resolution in the reconstructed image, all the images from the subholograms must superimpose very accurately. But, with reflective readout the tape acts as a mirror, so that angular deflections of the tape (due to defects on the tape or its transport mechanism) cause corresponding angular deflections of the individual images from the subholograms. Superposition of displaced images leads, of course, to loss of resolution.

Images reconstructed by transmission readout are not significantly degraded by these defects, however, because the angular diffraction of a beam transmitted through a hologram is relatively insensitive to angle of incidence. Hence, defects such as twists and dimples that change the angle of incidence cause much less image displacement. To illustrate this characteristic and to show how the readout geometry can be optimized to minimize image displacements, let us again consider the diffraction of a laser beam by a grating. As mentioned previously, a Fraunhofer hologram of a point object is a grating; therefore, determining the sensitivity of first-order diffraction-angle of a grating to changes in angle of incidence of the laser beam gives a reasonably good estimate of the improvement afforded by transmission readout.

Fig. 8 shows a laser beam being diffracted by a grating. This Figure is similar to Fig. 6, but the angle of incidence ϕ is not 0°. According to a well-known law of optics: $\sin\phi + \sin\alpha = \lambda/d$. The relation of the ratio of change in grating angle $d\phi$ to change in first-order diffraction-angle $d\alpha$ and angle of incidence ϕ is shown in Fig. 8. This curve shows that an optimum angle of incidence exists for which the variation of diffraction angle (or image position) due to change in grating angle (or tape twist) is minimized. This optimum angle of incidence is given by $\phi_{opt} = \sin^{-1}(\lambda/2d)$.

Optimization amounts to ensuring that the tape is oriented such that an axis perpendicular to the surface of the tape bisects the angle between the object and reference beam axes. Transmission readout of replicated vinyl tapes, at the optimum readout angle, has yielded motion picture images with more than 30 cycle/mm resolution.

Spatial filtering

Noise caused by scratches is a more serious problem with transmission readout because the readout beam passes through both sides of the tape, the back side being particularly susceptible to scratches by the tape transport. Burrs and hard dirt particles in the transport mechanism cause most of the scratches, the scratches being in the direction of tape motion (see Fig. 9a). In conventional movies these scratches are quite noticeable, especially when they extend over a number of frames. In hologram movies, however, these scratches produce a radically different type of noise—they diffract the readout beam in a direction perpendicular to the scratches, causing a streak to appear across the image, as illustrated in Fig. 9b. As shown, the scratches do not cause a significant loss of information, but the noise streak is quite prominent because all scratches within the readout beam contribute to the same streak.

Fortunately, there is a simple, yet very effective, way to eliminate almost all noise due to scratches caused by the transport. It is called off-axis recording. What this amounts to is recording the holograms such that the reconstructed images do not fall within the same spatial region as the scratch noise. In other words, off-axis recording is a form of spatial filtering that prevents noise due to scratches along the tape from contaminating the mage. The effectiveness of this method is illustrated in Fig. 9c.

Color

Color encoding amounts to recording uminance information as a 0-to-3-MHz baseband signal, and blue and red information as amplitude-modulated 3.5- and 5.0-MHz subcarriers, as shown in Fig. 10. (Actually, the subcarrier frequencies differ slightly from these values, the true values being multiples of the horizontal scan frequency). In the encoded image the color information appears as amplitude-modulated grating patterns, the grating lines appearing as thin vertical stripes (Fig. 11).

During playback, the holotape produces a faithful reproduction of the encoded image exactly as it appeared on the original motion picture film. Accordingly, the output of the vidicon camera consists of a 3-MHz luminance signal and 3.5- and 5.0-MHz subcarriers that are amplitude modulated by the blue and red signals, respectively. Appropriate filtering and envelope detection separate the blue and red signals; the green signal is obtained by subtracting the red and blue signals from the luminance signal. The color signals are passed through a color matrix circuit that combines them in the proper proportions to reproduce the hues and saturations of the original color image.

Thus "stripe" encoding is used to record a color image on black-and-white film and subsequently reconstruct the original color picture by means of a single-vidicon camera. Further research is expected to yield optimized encoding methods.

Readout of color-encoded images with a vidicon camera calls for extremely good frame-to-frame registration. The reason for this stems from the lag characteristic of a vidicon; i.e., the incomplete readout of the image stored on the vidicon target during a single frame period. As a result of lag, vidicon output corresponds to the superposition of a number of frames. If successive frames are misregistered, the signal contributed from the earlier frames is usually high enough to cause significant phase shift of the color subcarriers that leads to spurious amplitude modulation. Fortunately, the need for costly, precision tape transports is avoided through the use of Fraunhofer holograms—their image immobilization property allowing considerable tolerances.

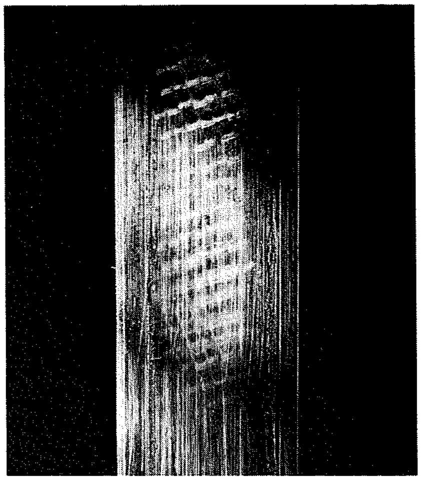


Fig. 9a—Scratches caused by burrs and hard dirt particles run in the direction of tape motion.

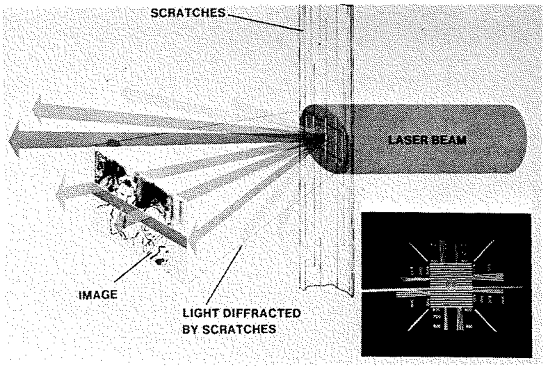


Fig. 9b—Spatial filtering of scratch noise for on-axis recording.

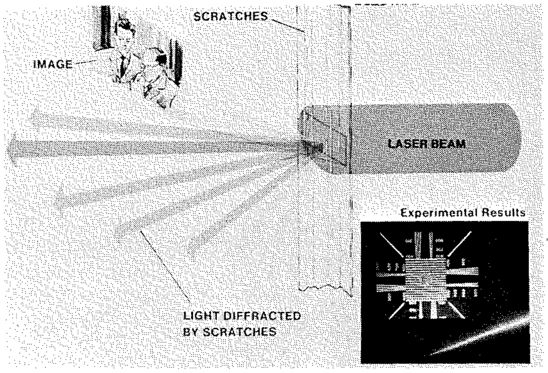


Fig. 9c—Spatial filtering of scratch noise for off-axis recording.

Tape manufacture

The basic manufacturing steps are illustrated in Fig. 12. The holographic recording material is a positive photoresist that is deposited on Cronar, a high-quality substrate material produced by DuPont. A special coating machine (Fig. 12a) had to be developed for coating photoresist on tape. Although the coating machine used for proving the feasibility of holographic recording is rather crude compared to sophisticated film-coating machines, the results are surprisingly good. This is another indication of the effectiveness of redundancy.

As previously described, the output of the encoding system is black-and-white 16-mm motion-picture film containing color-encoded images. An electron-beam recorder (Fig. 12b) which receives its input signal from color encoding circuits, is used to expose the film. The input to the encoding circuits can come from a live TV camera, a video tape recorder, or a flying-spot scanner.

The holographic recording setup (Fig. 12c) includes a *He-Cd* laser, photoresist tape and motion-picture transports, and a variety of lenses, mirrors, and beam splitters. In operation, the recorder operates automatically to produce a sequence of holograms corresponding to the film frames.

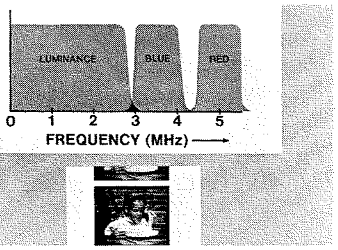


Fig. 10—Spectrum of color encoded signal.

After the photoresist-coated tape is exposed, it is sent through a developing machine (Fig. 12d) where the soft areas of the photoresist (i.e., the areas exposed to more intense light) are washed away. At this point, the holograms appear as corrugations in the surface of the tape.

A plating process (Fig. 12e) similar to that used to make *Ni* masters for phonograph records is used to produce a *Ni* master tape from the original photoresist tape. Additional master tapes can be made from the original tape, again using processes similar to those used for phonograph master making. In this regard, holograms have an interesting and important characteristic; that is, both positive and negative holograms produce positive images. Therefore, submasters can

Fig. 11—Color encoded image; thin vertical stripes convey the color information.

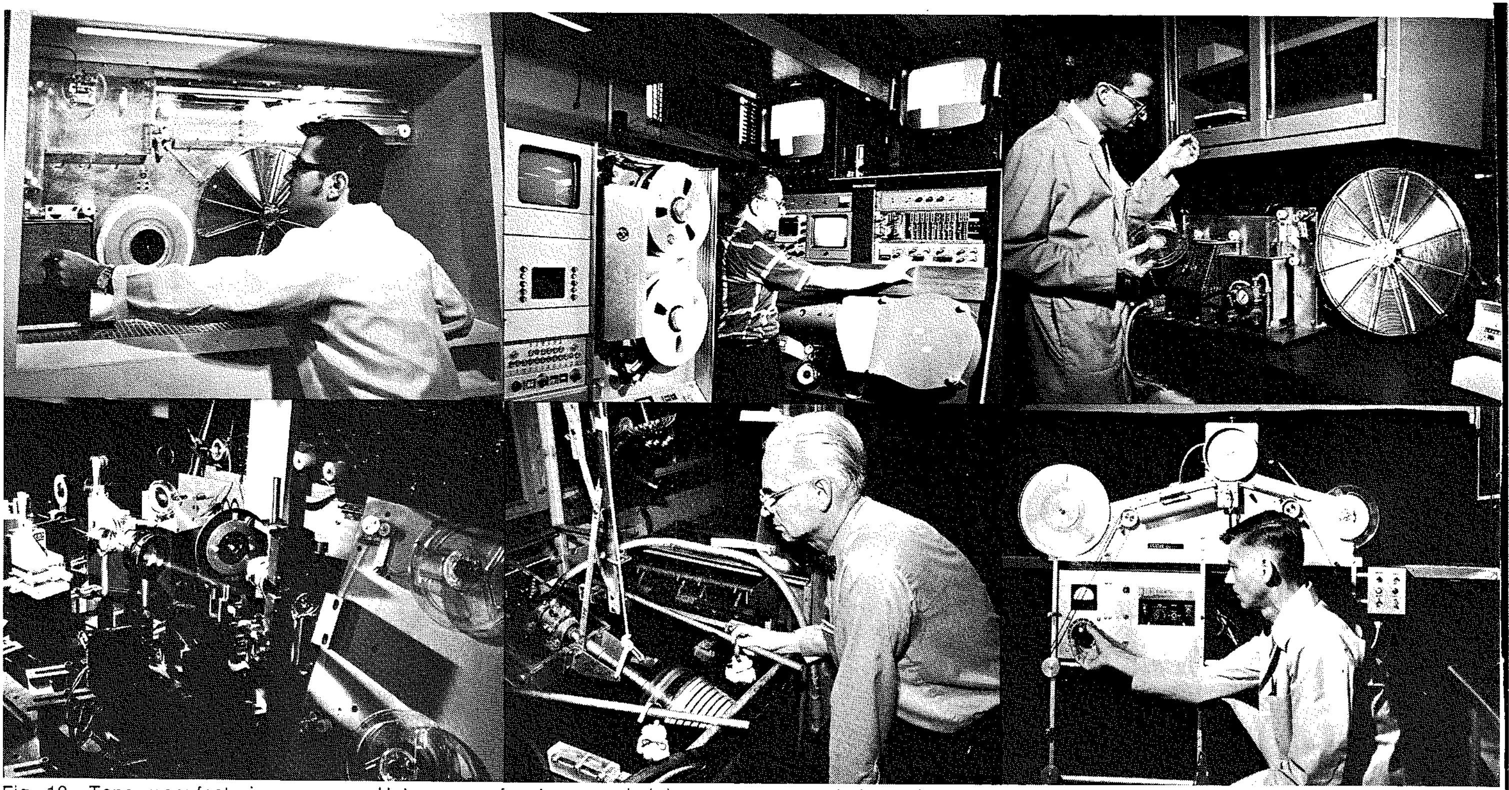


Fig. 12—Tape manufacturing process. Holograms of color encoded images are recorded on photoresist coated tape; *Ni* master tape is fabricated from the original holographic tape and used to emboss vinyl replicas. Clockwise from top left: Fig. 12a—coating; Fig. 12b—encoding; Fig. 12c—recording; Fig. 12d—developing; Fig. 12e—plating; and Fig. 12f—replicating.

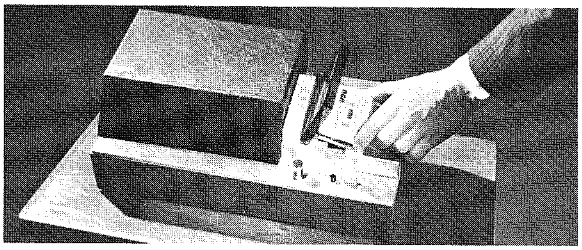


Fig. 13—Experimental cartridge player.

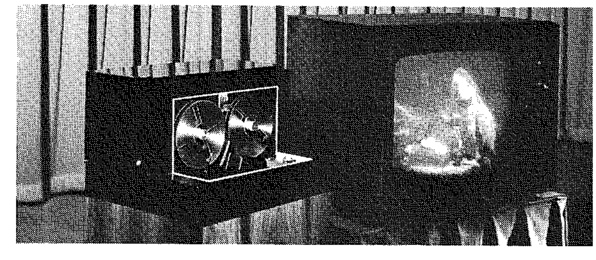


Fig. 14—Color player.

be made directly from the original master without phase inversion.

Vinyl replicas are manufactured by an embossing process (Fig. 12f), wherein the *Ni* master tape and a vinyl tape are sandwiched between two rollers.

Is there a market?

After evaluation of the market opportunities for prerecorded video systems, RCA's market research team concluded that many people will be willing to pay a little extra to "see what they want to see when they want to see it." One important conclusion that can be drawn from the initial market research done on prerecorded video programs is that the market size is very sensitive to the cost of the TV cartridge. The general consensus, at present, is that the cartridge must have a price tag under $10/half-hour playing time if it is to reach a reasonable segment of the consumer market. Subtracting royalty fees, distribution costs, and profit leaves about $1 for manufacturing cost. Neither magnetic tape nor photographic film currently show much promise for reaching the manufacturing cost goal. In contrast, RCA's holographic video tape offers a relatively low manufacturing cost.

Cost of vinyl tape based on small-volume purchase is about 30 cents per half-hour playing time. Large-volume purchase is expected to reduce this cost by a factor of 2, making the cost of the cartridge more than the cost of the tape itself. Home entertainment (musicals, sports, games, etc.), education, and a wide range of information-storage-and-retrieval applications are envisioned as the primary markets.

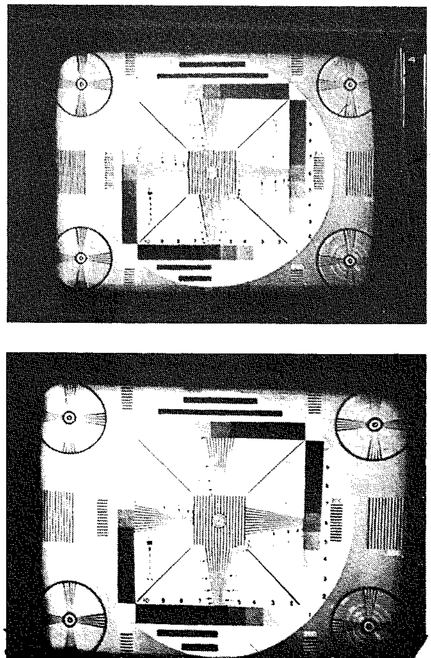


Fig. 15—Resolution capability of holographic tape.

Experimental results

Figs. 13 and 14 show experimental players that have been developed to demonstrate the feasibility of the holographic tape system; the major characteristics of both players are given in Table I. The cartridge player (Fig. 13) contains the basic components shown in Fig. 1, with a modified cassette package used to house the tape. Good black-and-white movies were demonstrated with this player.

The color player (Fig. 14) employs a single vidicon color camera. For experimental convenience, this player employed a reel-to-reel transport.

Table I—Characteristics of the experimental tape players.

Tape speed	7½ in/s
Tape width	½ in.
Tape thickness	1-mil
Laser wavelength	632.8 nm
Laser power	2 mW
Vidicon: black-and-white player	8134
color player	8507
Video bandwidth: luminance	3 MHz
chrominance	500 kHz
Output	VHF carrier

Shown in Fig. 15 are photos of images obtained from replicated holograms displayed on a wideband video monitor and a home TV receiver. Note that the resolution of the holographic tape exceeds that of a standard TV receiver.

Holographic research at the Zurich Laboratories

Dr. D. L. Greenaway

For several years, the RCA Laboratories in Zurich have been studying holographic applications. Particularly significant are the results of work that has been done in three areas: 1) Holographic integrated-circuit-mask storage with unit magnification, using the annular hologram technique; 2) holographic multiplication of images; and 3) the holocard personal identification system. This paper describes the results of this work, and provides some insight into possible future applications.

HOLOGRAPHIC RESEARCH has, over the past few years, expanded rapidly in laboratories throughout the world. The initial demonstrations showing that holography could provide truly three-dimensional reconstructions of objects without the uses of lenses, have now blossomed into a whole host of useful applications. As only three examples of these, we may mention holographic interferometry for materials and component testing; holographic optical processing for such purposes as character recognition and fingerprint identification; and holographic storage for computers. The holographic research being carried out at RCA Zurich is concerned in a large part with application of holography to the high resolution artwork processing steps involved in the manufacture of integrated circuits. This application has yet received rather less attention in the literature but is nonetheless being studied at laboratories other than RCA.

Present-day integrated-circuit manufacture involves the generation (increasingly under computer control) of large-scale artwork, and the subsequent photo-reduction of this artwork using highly corrected lenses and extremely precise mechanical equipment. The final set of master masks for a particular circuit is produced using a step-and-repeat camera, and process masks are produced from the masters by contact printing. The production process of transferring the mask information to the device wafers is also one of contact printing onto the photoresist-coated wafer. These contact printing steps are, at present, essential to preserve the extremely fine detail present in the device structures. It is necessary that line widths and spacings of the order of 2 microns (less than 0.1 mil) be faithfully reproduced, over the entire wafer area, and such resolutions are beyond the capabilities of present lens-projection systems. Quite clearly, because of the high cost of repetitive artwork generation, and the damage introduced to both the process masks and the photoresist layers on the wafer, one would like to eliminate completely the contact printing steps. Considerations such as these have prompted the investigation of a holographic approach to mask storage and projection imaging.

In general, the work in Zurich has shown that, under appropriate conditions, a holographic system of imaging can behave as a diffraction-limited optical system—capable of yielding images which have resolutions of the same order as the wavelength of the radiation being used. A holographic system can also have the significant advantage of built-in redundancy, thus eliminating the effect of environmental damage on stored information, but in addition optical functions may be performed that are beyond the capabilities of currently available conventional optical systems. Such functions include the possibility of obtaining micron resolutions over image fields many centimeters in extent in a single holographic imaging step. These advantages suggest that holographic techniques can find an important application in the field of integrated-circuit fabrication.

Integrated circuit mask storage

To store an integrated-circuit mask, the finished artwork (which is produced on the step-and-repeat camera) is recorded holographically to be subsequently retrieved as a projected real image. This image can be used to produce process masks, which are then contact-printed onto the wafers in the conventional way, or it may be projected directly onto the device wafer, thereby eliminating the need to touch the surface of either the master mask, or the delicate photoresist-coated water. This process takes place with no magnification or reduction in mask size, and, under this restriction, a holographic storage and imaging sys-

Dr. David L. Greenaway
Laboratories
RCA Limited
Zurich, Switzerland
received the BSc in Physics and Chemistry in 1956 and the PhD in Physics in 1959, both from the University of Reading, England. He worked at Standard Telecommunications Laboratories, Harlow, England from 1959-1961, on optical and electrical properties of silicon. He joined the RCA Laboratories at Zurich in 1961, where he worked for 4 years on the determination of band structure of semiconductors using optical techniques, particularly measurement of reflectivity. As a three-months assignment in 1965 (leave of absence from RCA) he was visiting Professor at the University of Buenos Aires, Argentina, initiating a program of optical measurements on semiconductors. For one year (1965-6) he was with the RCA Princeton Laboratories, initiating the first holographic work at RCA, in cooperation with H.J. Gerritsen. From 1966 to the present, he has been establishing a holographic group at RCA, Zurich, concerned largely with possible applications of holography to integrated-circuit manufacturing technology. This group works in close cooperation with the Princeton laboratories, and also with the divisions at Somerville and Lancaster. He recently became interested in the applications of holography to the fields of security and identification. He has received three RCA Achievements Awards (1962, 1966, and 1968). He was coauthor of a book *Optical Properties and Band Structure of Semiconductors*, with Gunther Harbeke (Pergamon Press, 1968), and has published over a dozen scientific papers. He is an associate of the Institute of Physics and the Physical Society, a member of the Optical Society of America, and a member of the Swiss Physical Society.

Reprint RE-16-1-2
Final manuscript received February 10, 1970

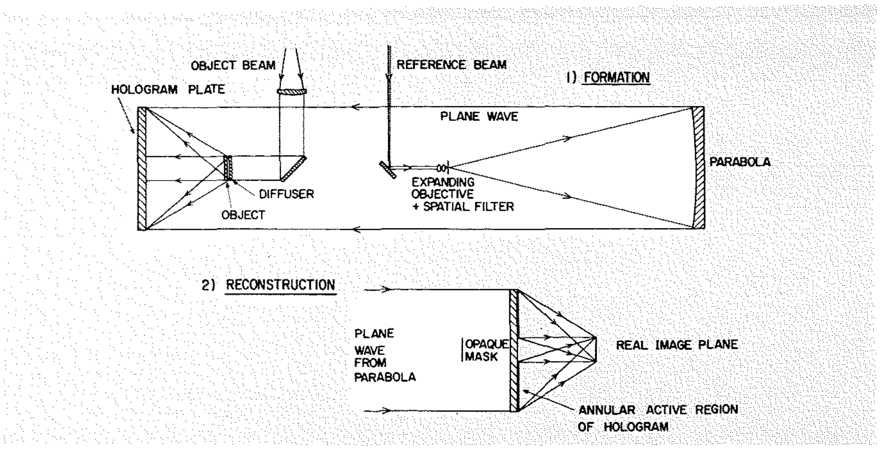


Fig. 1—Recording and reconstruction geometry for annular holograms.

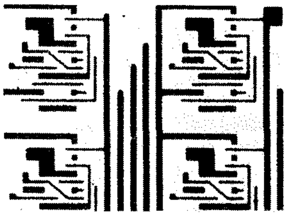


Fig. 2—Enlarged section of an integrated-circuit mask printed using the annular hologram technique under conditions of completely diffuse object illumination. The narrowest lines appearing on the mask are 6 microns (0.25 mils) wide.

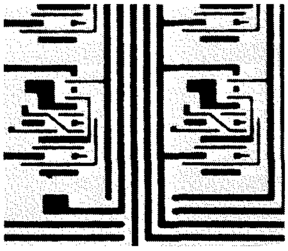


Fig. 3—Enlarged section of a mask printed using the annular hologram technique. Object illuminated by means of holographically generated beam splitter.

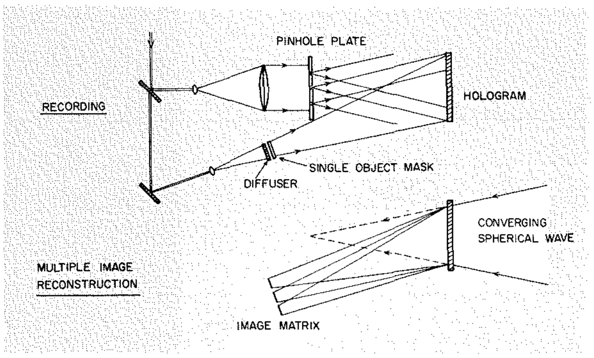


Fig. 4—Recording and reconstruction geometry for multi-image hologram using pinhole plate and diffuse object illumination.

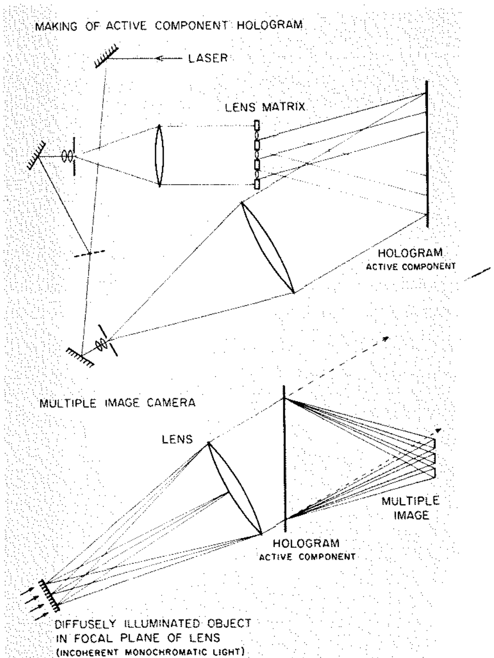


Fig. 5—Recording and information-coded playback geometry for the multi-image holographic filter.

tem can be free of aberrations: the projected real image retrieved from the hologram is distortion free, and aberrations associated with normal lens systems (spherical aberration and coma, for example) are completely eliminated.

The method described below for the holographic mask storage is referred to as the *annular hologram technique.* The basic optical systems for both storage and reconstruction are illustrated in Fig. 1. The accurate plane wavefront used for both recording and reconstruction is produced by means of a telescope parabolic mirror, which collimates the spatially filtered light from the laser (a 1-watt RCA argon-ion laser is used for these experiments). A parabolic mirror represents an economical way of obtaining a large-diameter beam of well-collimated radiation. The mirror (obtained from a local supplier at a cost of $300) has a 30-cm diameter, a 120-cm focal length, and produces a wavefront plane to better than 0.2 wavelengths. The axial geometry of the system greatly facilitates the alignment of the optical components, in particular focussing the parabola and adjusting the hologram plane perpendicular to the plane reference and reconstruction beams.

The diffuser, located close to the object mask, is perhaps the most critical element of the optical system. It is well known that the use of diffuse object illumination leads to holograms which have complete redundancy; i.e., information from one part of the object is stored over the entire active area of the hologram. A direct result of this redundancy is the appearance of granularity or "speckle" on the reconstructed images. The size of this granular structure is determined by the effective aperture of the hologram (given by the half angle θ subtended by an object point at the edges of the hologram plate), and is approximately equal to the diffraction limit of the system ($\lambda/2 \sin \theta$).

The early experiments using the annular hologram method were all performed using a diffuser (usually finely-ground 1-mm-thick opaque white Plexiglass). Fig. 2 shows the enlargement of the reconstruction from such a "diffuse" hologram (recorded on a 5x4-inch Kodak HR plate on microflat glass, using an object-to-hologram distance of approximately 8 cm). The granularity appears as a high-contrast fine structure and causes a marked deterioration to the edge definition. Clearly some method of avoiding the granularity is highly desirable, and our subsequent efforts were directed to this goal. The results using diffuse illumination did, however, demonstrate that the imaging is—as far as can be detected—aberration-free. The image field was flat, and all parts of the image could be sharply focussed to yield results comparable to Fig. 2. No distortion could be detected when the print of the reconstructed image was placed in contact with the original object mask. The limiting factor determining the resolution (apart from the granularity) was almost certainly the hologram substrate which had a flatness error of approximately ± 5 microns over the surface, and was of unknown homogeneity. In the reconstruction process, the plane wave must first pass through the hologram substrate; consequently, the optical quality of this substrate must be compatible with the resolutions that are required. Subsequent trials were made using optically polished substrates (flat to better than 1 wavelength) of slow-cooled optical glass which had refractive-index variations of less than 10^{-5}.

The use of optically polished substrates led to a further phase of this work: the recording of the annular

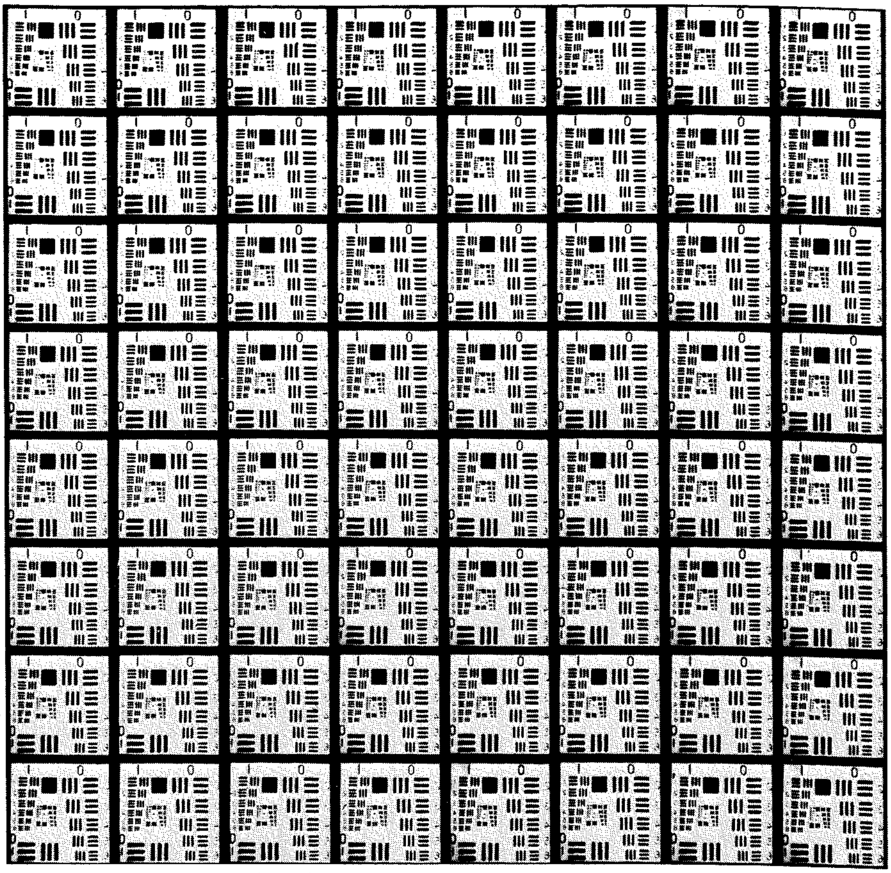


Fig. 6a—Part of 10x10 replicated matrix, low magnification.

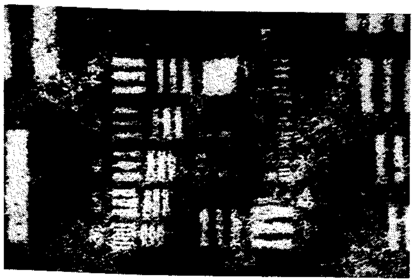


Fig. 6b—Central region of single unit of replicated matrix with no diffuser in object illuminating beam.

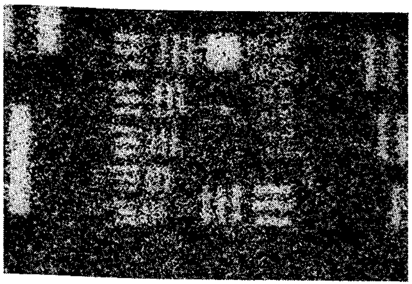


Fig. 6c—As in Fig. 6b, but with stationary diffuser.

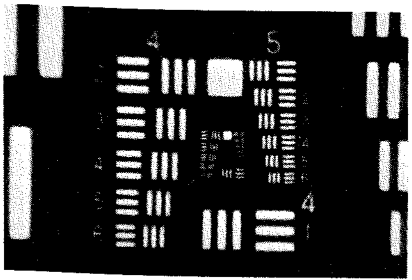


Fig. 6d—As in Fig. 6b, but with rotating diffuser. The broadest lines in block 5 of the bar pattern are just under 4 microns (0.16 mils) wide.

Fig. 6—Reconstructed images from a multi-image holographic filter. The active area was a 10-cm-diameter circle, and the hologram was recorded in Shipley AZ 1350 photo-resist using 4579 Å radiation. The reconstructed 10x10 matrix was 40x40 mm, and the object cell size 16x16 mm.

holograms in photo-resist instead of high-resolution photographic emulsions. Apart from the difficulty of having small quantities of special plates custom-coated with photographic emulsion, the use of photoresist brings two significant advantages:

1) The holograms can be truly two-dimensional, thus removing the angular dependance of reconstructed intensity encountered with normal photographic emulsions which will change thickness on processing; and

2) The available efficiency of a phase hologram is an order of magnitude greater than that obtainable from an amplitude hologram.

We have successfuly used Kodak Ortho Resist (KOR) as a recording medium for annular holograms, and the results given below were obtained using this resist.

To remove the granularity, yet still preserve sufficient redundancy to protect the image information from the effect of dust, scratches, and small hologram imperfections, the diffuser of Fig. 1 was replaced with a holographically-made beam splitter. This beam splitter, in effect a complex diffraction grating, creates a ring of diffraction images of the object mask on the available annular active area of the hologram plate. The beam splitters are made by interfering a series of coherent plane waves together in the appropriate geometry, and are also phase holograms in KOR. We have obtained efficiencies of greater than 50% in the ring of diffracted beams, and this method thus represents an efficient way of transferring the object information to the hologram medium. It is important, when recording partially redundant holograms of this type, that the modulation ratio (intensity of object beams to reference beam) be kept very low so that intermodulation terms giving rise to high-frequency noise in the reconstructed images are reduced. A reconstructed image from a partially redundant hologram, using a ring of 8 diffraction images recorded on a 6x5 inch hologram plate, is shown in Fig. 3. The KOR layer was produced by conventional spinning techniques, and had a thickness of about 5000 Å. The exposure time for the hologram was 5 minutes using about 400 mW of 4800-Å- argon-laser radiation. It can be seen that the granularity is reduced by this method, and edge definition is increased.

The resolution obtained over the whole mask area of the reconstructed image (shown in Fig. 3) is of the order of 1 micron, which corresponds with the theoretical diffraction limit of the recorded hologram. One drawback to printing these high-resolution reconstructed images onto 2x2-inch high-resolution plates is that the emulsion itself has a thickness of some 5 microns after processing, and this makes it difficult to assess the true resolution limit. Current efforts are being directed to the more realistic test of exposing the reconstructed images directly onto photoresist-coated chrome-clad plates, to assess the resolution and edge qual-

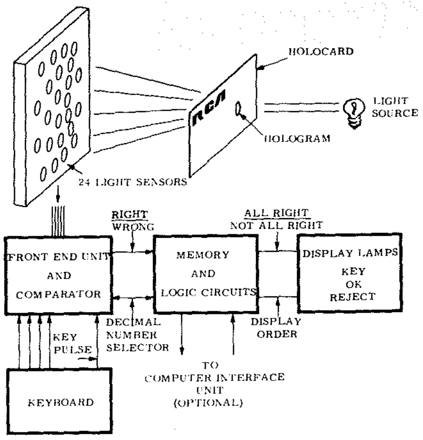


Fig. 7—Block diagram of holocard verification operation.

ity obtained after an etching step. To keep the final printing exposure to reasonable values, and at the same time, employ photoresists that are compatible with the device manufacturing processes(for example Kodak Thin Film Resist, or Shipley AZ 1350 positive resist) it then becomes necessary to expose the hologram using shorter-wavelength radiation. Both the 4579-Å argon-laser line, and the 4416-Å cadmium-laser line represent usable possibilities.

Holographic image multiplication

This particular aspect of the work in Zurich (being carried out by Dr. J. P. Russell) is concerned with the possibility of replacing the currently used step-and-repeat process with a holographic filter which will perform the function of multiplying an object transparency (the unit cell of the circuit mask) the required number of times with the correct geometry in a single optical imaging step. A number of non-holographic methods have been proposed for doing this; for example, lenticular screens, fly's-eye lenses, or matrixes of plane mirrors used with a high quality photo-reduction lens. All these methods suffer from excessive aberrations when the resolution required in the final image is of the order of microns.

Two distinct holographic methods can be envisaged to perform image multiplication. Both of these involve the use of a matrix of coherent light sources having the format of the required final set of images (for example, a 10x10 square matrix). In this paper, only the case where the source matrix takes the form of an array of diverging spherical waves is considered. In the first method, a hologram is formed between a diffuse object wave produced by suitably illuminating a transparency of a single element of the mask pattern and the matrix of spherical waves. A matrix of images is reconstructed by illuminating the hologram with a single conjugate spherical wave (converging) corresponding to the central element of the source array. Here, both the object information and the image multiplication instruction are stored in the hologram. Fig. 4 shows a schematic diagram of an optical system that was set up to test the method. The source matrix was simply a thin metal plate drilled with an 11x11 square array of 100-micron-diameter pinholes; the plate was illuminated at normal incidence with a plane wave coherent with the object beam. Reconstruction of the hologram with a converging spherical wave indeed gave the expected matrix of images, and the resoultion was seen to be somewhat better than the expected value of 100 microns over the whole matrix. Using a lens matrix instead of the pinhole plate to give a much smaller effective point-source size does, in fact, yield much higher resolution over the central area of the matrix of images; however, we have now shown that the off-axis aberrations which are inherent in this method preclude any change of obtaining micron-resolutions for the outside elements of the matrix.

The second holograph image-multiplication method overcomes the problem of off-axis aberrations inherent in the above technique. We now form a holographic filter which itself contains no object information. This filter is formed by interfering a set of spherical waves (generated by a lens matrix) with a plane wave. The hologram so formed is, in effect, a complex zone plate and, if illuminated by the conjugate plane wave, will reconstruct the matrix of converging spherical waves; these waves will come to a focus in the focal-plane of the original lens matrix. Each focal point is derived from an effectively diffraction-limited holographic-imaging system, in a manner analogous to the mask-storage method described above, ind is free of aberration. Image multiplication can now be obtained by coding object information from a single object transparency onto the conjugate plane wave used to illuminate the hologram. Fig. 5 shows the optical system used for recording the holographic filter and for obtainin the multiplied image matrix. The po sibility of reduction now exists b varying the ratio between the foca length of the hologram (the distanc between the lens matrix focus and th hologram being recorded) and th focal length of the collimating len (which codes the object information onto the conjugate reconstructing wave).

Results we have obtained using this method are illustrated in Fig. 6; Fig. 6a shows part of a 10x10 replicated image matrix at low magnification. The way in which the object mask is illuminated is of critical importance. The remaining prints of Fig. 6, taken using much higher magnification, show the effect of three modes of illumination: Fig. 6b was obtained using an undiffused beam of laser radiation, and leads to a transfer of all imperfections in the optical system, and stray interference effects onto the image matrix; Fig. 6c was obtained using a stationary diffuser, and shows the well-known, and in this case quite unacceptable, granularity characteristic of such illumination; Fig. 6d was made using a rotating diffuser, and shows that the granularity of Fig. 6c can be removed completely by destruction of the spatial coherence of the laser radiation. This series of prints had a built-in reduction factor of four, and, under high magnification, shows resolutions in excess of 500 line pairs/mm over the whole matrix of 100 images. Clearly any other object information can be replicated using this type of holographic filter by inserting a transparency of the appropriate unit cell into the coding beam.

For an integrated-circuit-mask production process this technique has considerable potential; also, it should be pointed out that the registraton properties are determined by the geometry of the original lens matrix used to produce the holographic filter. If angular fidelity is maintained, then for a given reduction ratio, all masks printed from filters made using the same lens matrix will have image arrays of identical geometry.

Work is continuing both from an experimental and from a theoretical standpoint, to assess the ultimate resolutions and field coverages which may be obtained using this process.

Holocard system

The present-day trend—foremost in the United States, but certainly increasing in Europe and other parts of the world—towards a computerized and cashless society, brings with it an increasing need for secure means of personal identification. Examples of this vary from the wide range of credit and bank identification cards together with the newly introduced money vending machines, to personal identification for recorded entry into restricted locations, and to the need for simpler forms of passport and international border control. To take the example of a credit or identification card, mis-use of such cards leads to considerable financial loss on the operators part. This loss consists to a smaller extent of purely fraudulent use of illegally obtained cards, and to the greater extent from the costs attempting to collect bad debts. Computerized on-line systems would obviously minimise this second loss area but, at present, virtually no truly online systems are in operation. Also, as such systems become more general, the need for really secure identification of the card holder becomes extremely important.

We have taken the basic idea of including a small hologram as in integral part of a credit or identification card, and developed from this a prototype of a secure personal identification system. The hologram contains coded digital information about the account of the card holder. Part or all of this account number, depending on the length of the number and the security required, is held by the card owner, but does not appear on the card in any printed form. In use, the card must be inserted into a verifier and the verification code punched sequentially into a keyboard by the user. This number is compared electronically with the number coded in the hologram, and an appropriate OK or REJECT signal is displayed to the vendor. If the system is operated in line with a computer, then the verification signal can be used to automatically address the particular account record so that the computer can respond with any necessary transaction guidance.

In the prototype system, small phase holograms, recorded using an argon laser are processed on Plexiglass blanks of standard credit card size. The hologram contains 24 bits of information corresponding to any 6-digit number. The recording process, which on these holograms involves spatial frequencies of over 500 lines/mm, requires the conventional holographic precautions to be taken, in addition to the technology of producing efficient phase holograms. Read-out of the holograms in the verifier is accomplished not using a laser, but a tungsten filament lamp, and the bit information is detected on a small matrix of low-cost cadmium sulphide photoresistors. Thus, the expense of a laser in the verifier is avoided, and the main expense is taken up by the keyboard and the comparator electronics which are all solid state and completely compatible with the use of integrated circuits. Fig. 7 shows a block diagram of the experimental 6-digit verifier which has been designed with the possibility of in-line operation in mind. A transmitter section has been incorporated into the verifier which on receipt of the OK signal, sends the Holocard information as a low-frequency pulse train into a two-wire link (for example, a telephone line) to the computer. As a computer simulator, a display device has been constructed which decodes the pulse train into a decimal display of the number transmitted. Such a display unit would, in fact, also be required in any off-line operation in order to decipher cards repeatedly rejected by the verifier. The display unit of course would not be available at the point-of-use of the cards.

A reconstruction using tungsten light of a test hologram, containing all 24 bits of information, is shown in Fig. 8, and this print illustrates the good signal-to-noise ratio that can be obtained using a polychromatic incoherent light source. One of the prototype 6-digit verifiers and the associated display unit is shown in Fig. 9.

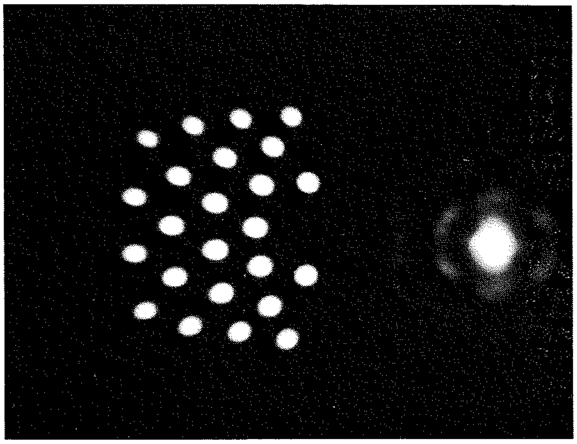


Fig. 8—24-bit holocard data storage reconstructed using polychromatic incoherent (tungsten lamp) source.

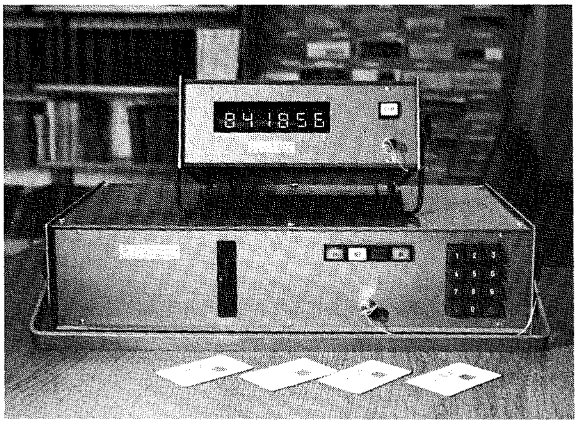


Fig. 9—Holocard verifier and display unit.

Advantages of the holocard system

In the holocard system, the information is stored holographically and, besides being difficult to forge or duplicate without highly specialized technical knowledge, is redundant and immune to both mutilation and alteration—and also to the effect of dust and scratches. This system of information storage can provide as much protection against fraudulent use as required, by varying the complexity and nature of the coded information and of the decoding equipment. The demand made upon the user is that he record separately (or remember) what in effect amounts to an additional telephone number, but this would appear to be a small price to pay for the high degree of security that the system can give. The system does not require lasers in the verification equipment, and the decoding operations are eminently suited to the use of integrated-circuit techniques. In the verifier described here no great precision is required when the Holocard is inserted; a positional accuracy of a few millimeters is sufficient. Finally, the whole system is compatible with computer controlled on-line operations.

Acknowledgment

The design and the development of the electronics for the verifying and associated equipment for the holocard system prototype was carried out by Mr. T. Bart of the RCA Technical Service Laboratory Zurich, and the invaluable assistance of this group is gratefully acknowledged.

The 4101C computer—converting to third generation through design automation

C. N. Batsel, Jr. | J. G. Mackinney

The 4101C computer is the latest development in the 4100-series of processors designed and manufactured by Electromagnetic and Aviation Systems Division (EASD). This development is particularly significant because the integrated-circuit technology and associated design-automation techniques and programs developed for the Spectra 70 have been applied to a computer designed specifically for real-time, military-oriented applications. The development is also significant because of the features included in the design that are aimed at broadening the range of application (beyond the military application). The 4101C represents also a high level of inter-divisional cooperation within RCA, with six organizations contributing significantly to its design and development.

J. G. Mackinney, Ldr.
System Programming
Electromagnetic and Aviation Systems Division
Van Nuys, California
received the AB in Physics from the University of California in 1953, and is continuing graduate work toward a degree in Mathematics. He received his initial programming training at the Livermore branch of the University of California Radiation Laboratory (now the Lawrence Radiation Laboratory). Beginning in 1954 he worked with the IBM 701 computer on a series of neutron diffusion models. During 1957, Mr. Mackinney was the programmer for TALOS flight simulation, using the NORC computer at Dahlgren, Virginia, for the Applied Physics Laboratory of Johns Hopkins University. From 1957 to 1962, he was employed by General Kinetics, Inc., of Arlington, Virginia, working on a wide variety of programming tasks, and designing, coding, and programming, for the IBM 750, 704, and 7090 as well as the UNIVAC 1103, SS-80, and 1107. Mr. Mackinney joined RCA in 1962, participating in the design and development of executive programs for an advanced system for military intelligence. His responsibility is the computer programming task direction for the Science Operational Support Equipment now under construction by EASD for the 1971 NASA Mars Mariner project. His recent experience includes system program responsibility for the United Air Lines and AIRCON Automated Communications Systems. Mr. Mackinney is a member of the Association for Computing Machinery and Alpha Chi Sigma Fraternity.

THE 4101C computer handles information in 32-bit words and fixed subfields of these words. Instructions are in conventional single-address format and require one word each. Internal processor operations are in parallel, organized about a single bus. Despite the drastic difference in internal machine organization between the 4101C and the Spectra 70 computers, only two new logic-module types had to be designed; standard Spectra 70 logic modules were used to the maximum extent possible. Extensive use was made of automation programs in the design of the six Spectra-70-type backplanes which comprise the computer's main frame.

The 4100 series

Since early in 1962, EASD has supplied computers for radar control and data analysis. The first computer, designed for the Missile Precision Instrumentation Radars (MIPIR), was designated the RCA 4101. This computer and all subsequent computers in the 4100 series, including the 4101C, are particularly characterized by a unique priority-interrupt system which allows multi-level programming and the handling of external interrupts. In the second version of the 4100 series, the 4102, the capability was added to accommodate peripheral equipment such as multiple magnetic tape units, a line printer, and a card reader. A special version of the 4102, designated the 4102S, was designed to provide increased memory capacity to a maximum of 32,768 words. The 4101B is an enhancement of the 4101 providing a faster clock, increased memory speed, and an increase in memory capacity from the 8,192 words of the 4101 computer to 16,384 words.

The high reliability and unique real-time characteristics of the 4100 computer were important factors in the award to EASD by United Air Lines for the world's largest teletype message switching system. This system processes more than 250,000 throughput messages per day with an average message length of 250 characters, through a central switching point located in Elk Grove, Illinois. The computer designed for the contract, the 4104, contains changes to the instruction format and repertory to enhance its performance in message switching applications. Directly addressable memory is 32,768 words. Subsequent to the United Air Lines contract, EASD was awarded a contract by RCA Global Communications for a message-switching system designated AIRCON. The 4104A computer delivered with this system included further instruction changes for communications applications. The memory capacity of these computers was increased to 65,536 words.

In 1964, a study of real-time techniques was performed to determine enhancements of the 4100-series computers that would result in a state-of-the-art processor to meet the requirements of radar systems, communications, and command and control. In addition to changes in processor organization and command structure, the use of integrated circuits for increased performance and high reliability was investigated. In particular, Computer Systems Division's (CSD's) Spectra 70 and Missile and Surface Radar's (M&SR's) Memopak techniques were studied and compared. Logic speeds considerably faster than the 50-ns pair-delay achievable with the standard 4100 circuits were necessary for the desired performance. This ruled out the use of diode tran-

---

Reprint RE-16-1-10
Final manuscript received August 1, 1969.

C. N. Batsel, Jr.
Electromagnetic and Aviation Systems Division
Van Nuys, California
received the BS in Engineering from the University of California at Los Angeles in 1952. In 1954 he received a MS from the same university. Mr. Batsel joined the Computer Systems Division of RCA in 1955. While with this division he participated in the proposal and system design of the AUTODIN message switching system for the U.S. Air Force, and in the design of high-density magnetic-tape recording and point-to-point communications systems. Since 1961, Mr. Batsel has been with the Electromagnetic and Aviation Systems Division. Currently, as Staff Engineering Scientist, his major assignments have been directed toward system design and proposal management for mass memory and display systems. Previously, he was Program Director for the 4100-series of data processors and was responsible for the development and hardware delivery of the equipment for the United Air Lines message switching system. Mr. Batsel was involved in studies leading to the conversion of the 4100 Series computer to integrated circuit hardware and directed the initial phases of the 4101C development program.

sistor logic (DTL) circuits widely available at the time. Schedule requirements did not permit the development of hybrid circuits or a major program directed at rigid codification of rules of usage. The CSD series-8 technology was selected since considerable investments had already been made in design rules, backplane wiring, and design automation. The plug-in circuit modules of the CSD Spectra 70 computers could be used directly in the 4101C design.

Definition of the 4101C

Table I summarizes the historical development of the 4100 computer series. The 4101C combines features of the previous machines to approach an optimal design within the imposed constraints. As delivered, it used only limited peripheral equipment required for the radar application. However, its input-output capability can readily be extended using the same principles which were developed for the more elaborate systems of the 4104 and 4104A.

The following factors were of primary consideration in the definition of the 4101C:

Considerable programming investment in 4101 programs for radar control.

Significantly decreased instruction execution times.

Implementation in integrated circuits.

Limited space and front access.

A tight schedule for a processor design in a new hardware technology.

Project costs.

With respect to programming considerations, all instructions existing in the original 4101 had to be present in the 4101C. The instruction set includes all 4101 instructions plus additional instructions recommended for the communication application. Indirect addressing was also added to further enhance the power of the computer. The required execution times necessitated the use of the fastest integrated circuits that could be implemented within the schedule and cost constraints. The Spectra 70 series-8 and the CSD design-automation programs were selected as the technology to be utilized in the new computer design. In addition to performance, the selection was based on the large investments in design rules and aids by CSD. The selection was also based on the prospect of lower costs if standard Spectra 70 series-8 plug-in cards (already in quantity production) were utilized in the design.

Since the logic was to be implemented in CSD Spectra-70 series-8 hardware, an additional task of significant magnitude was to coordinate design and manufacturing in several divisions of the Corporation.

Logic design

This portion of the work was performed by a team of three logic designers with prior experience in design of the 4100 computers and one logic designer experienced with series-8 circuits. Since rules for implementation with the series-8 integrated-circuit logic differ markedly from those for the 4100 discrete logic, the entire computer was redesigned to make optimum use of the new circuits. Standard Spectra 70 logic modules were used to the maximum extent possible; it was necessary to design only two new logic module types. A very important and time-consuming phase of the logic design effort was devoted to geographical partitioning of the logic to conform to wiring rules and allowable densities of the printed-wire backplanes. Logic and interface circuits were implemented with six backplanes and 414 modules consisting of 30 module types. The CSD design automation programs provided checks on logic design and partitioning for conformance to wiring rules; prepared net and pin lists (wire lists); and prepared routing and coordinate information for the physical layout of the printed-wire backplanes. Individual logic designers worked in Camden while design automation checks were run on their design so that corrections could be made quickly. A surprisingly small number of errors were detected. Wiring paths which could not be accommodated by printed wiring on the backplanes necessitated the addition of discrete wires which were installed by wire-wrap techniques. Discrete wiring averaged approximately 300 wires per backplane.

The Advanced Technology Laboratories of DEP assisted in the preconstruction validation of the 4101C by analyzing the timing chart and logic equations to determine that the sequences of micro-operations (resulting during the execution of given instructions under given conditions) were, in fact, valid. A program for the RCA 301 computer was developed to assist in this work.

New circuit design

Two new circuit designs were required in the design of the 4101C. To interface with the purchased memory system and tape transport, a line driver and a line receiver were designed which would match the requirements of these interfaces and the series-8 circuits. It was possible to match both the memory and tape unit interface with a single circuit design. These designs used discrete components.

Manufacture and assembly

The manufacture of components for the 4101C was necessarily dispersed

Table I—Characteristics of the 4100-series computers.

Characteristics	*4101*	*4101B*	*4102*	*4102S*	*4104 & 4104A*	*4101C*
Word length (bits)	30	30	30	30	30	32
Max. core size (words)	8k	16k	8k	32k	32k, 65k	32k
Memory cycle time (µs)	4.7	2.0	4.7	4.7	2.0	1.8
Clock rate (Hz)	$1x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$4x10^6$
Add time (µs)	19.2	9.9	16.5	16.5	9.9	4.6
Indirect addressing	No	No	No	No	Yes	Yes
No. of index registers	96	96	96	96	224	96
No. of instructions	39	39	40	40	52, 53	61
Secondary instruction fields	C&D	C&D	C&D	C&D	C	C&D
No. of priority levels	16	16	16	16	16	16
Circuit type	Discrete	Discrete	Discrete	Discrete	Discrete	Integrated
Peripheral equipment	Flexowriter, Magnetic tape	Flexowriter, Magnetic tape	Flexowriter, Magnetic tape, Card reader, Line printer	Same as 4102	Magnetic tape, Card reader, Line printer, Drum, TDX, CDX, MUX, Intercom, Peripheral sw.	Flexowriter, Magnetic tape

among several divisions of the Corporation. The standard Spectra 70 logic modules were manufactured at the Defense Communications Systems Division facility in Camden. In addition to the standard Spectra 70 modules, two new logic module types and two interface module types were designed and manufactured by EASD. The manufacture of printed wire backplanes was under the control of DEP Central Engineering. The standard MIPIR racks required by the Missile and Surface Radar (M&SR) Division were manufactured in Moorestown. EASD manufactured a special rack to house the logic and backplanes, the control console, interconnecting cables, and special mounting hardware. Power supplies were purchased from commercial sources. The equipment was assembled in the EASD engineering facility.

Interdivision coordination

The 4101C project required the cooperative efforts of a number of divisions within RCA. Advanced Technology Laboratories provided technical assistance to the designers by performing a design review of the control equations. The specific role of the contributing organizations of RCA are summarized below:

Electromagnetic and Aviation Systems Division (EASD)
System responsibility; logic, circuit, and packaging design; Vendor selection and follow; Assembly, test, and evaluation.

Missile and Surface Radar Division (M&SR)
Preparation of specification; Supply of racks;
Witness of acceptance tests.

Computer Systems Division (CSD)
Logic design rules;
Design automation;
Backplane drafting.

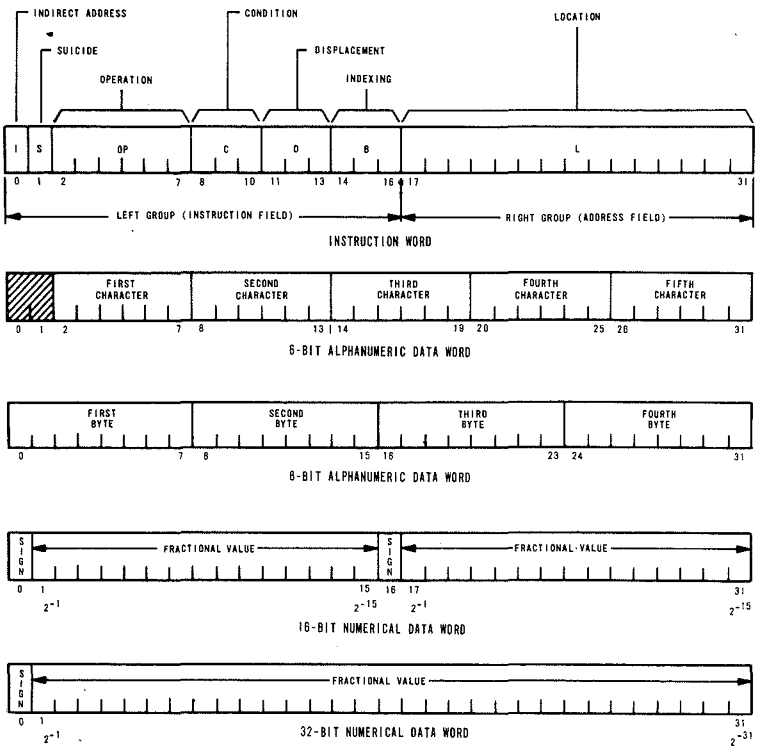


Fig. 1—Basic instruction and data forms.

Defense Communication Systems Division (DCSD)
Module manufacture

DEP Central Engineering
Backplane manufacture

DEP Advanced Technology Laboratories
Technical consultation;
Coordination of East Coast activities.

The wide dispersion of project functions throughout RCA provided an unusual challenge to the EASD project management. In addition to managing the cooperative effort of the various Corporate activities, it was necessary that CSD and EASD work closely together to transfer to EASD the working knowledge of Spectra 70 designs and design automation.

Description of the 4101C computer

The 4101C handles information in 32-bit words, and in fixed subfields of these words. Instructions are in conventional single-address format and require one word each. Internal processor operations are in parallel, organized about a single bus. Fig. 1 shows the basic forms of instruction and data.

Instruction format

Each instruction specifies, as a minimum, an operation (generally, the functions to be performed on the data) and a location (generally, a core memory address). The remaining

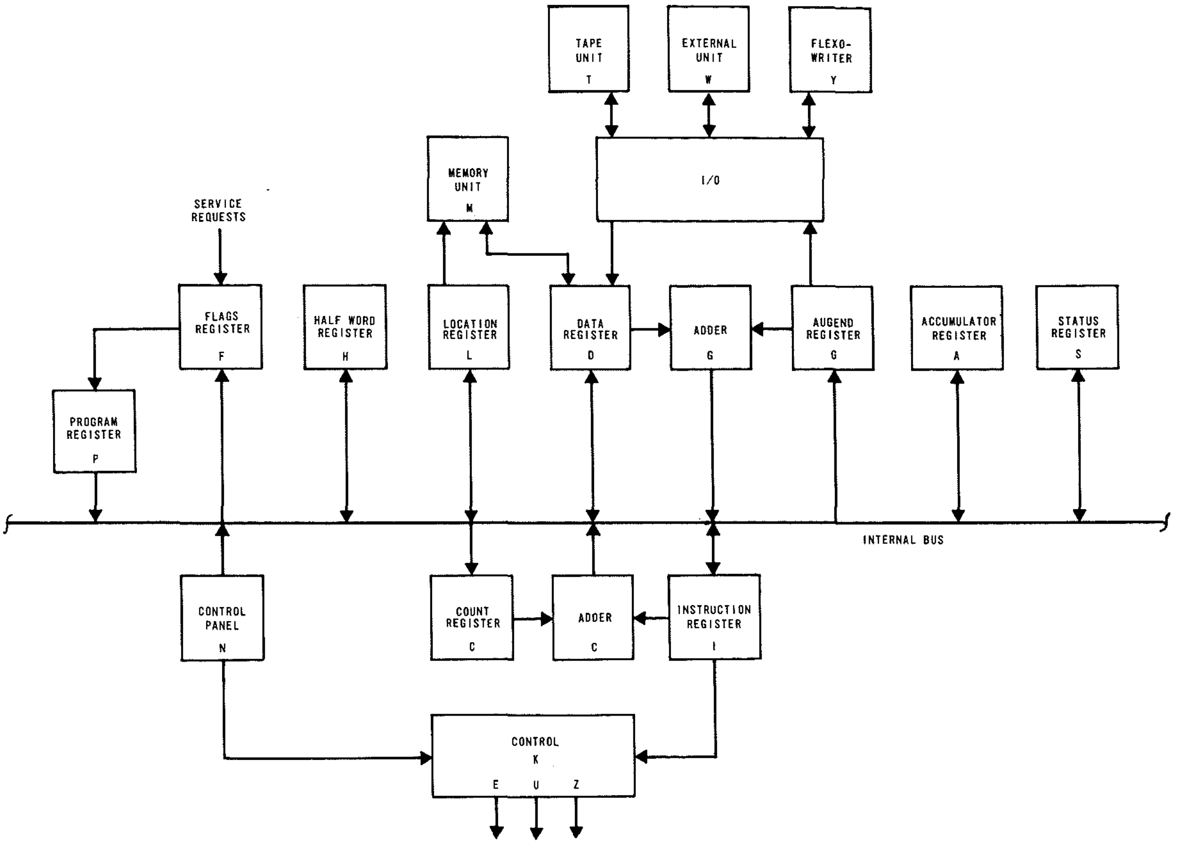


Fig. 2—RCA 4101C data processor, domain chart.

five fields of the instruction word provide the following options:

I—indirect addressing;
S—suicide (release of current program priority);
C—condition for execution of the operation, or a condition for branching, or a secondary operation such as decrementing an index;
D—displacement to be added to the program counter is branching condition-s satisfied;
B—B-box (index register) specification.

The operation field specifies one of the 58 primary operation codes. Depending on the primary code, the secondary operation (C) may be interpreted in a variety of ways. With normal arithmetic instructions, C gives a conditional branch (backward skip) of D instructions according to the final value in the accumulator, or it decrements the index.

Multiply and divide operations are provided for both full and half words, as shown in the 32-bit and 16-bit numerical dataforms in Fig. 1. Load and store operations are also provided for both forms.

Comparison instructions are provided for both 6-bit characters and 8-bit bytes, enabling the use of two alternate formats for packed alphanumeric data: five 6-bit characters or four 8-bit bytes, per word. Shift and masking instructions may also be used to pack six Baudot (5-bit) characters in one word. The logical instructions permit setting, resetting, or testing single bits (or groups of bits) as desired within the data word.

Executive space

Two hundred and fifty-six cells of core memory are allocated for executive space. While these cells may be treated as normal storage, they are primarily used as storage for index-register and program-counter values.

Each priority is assigned 6 cells for index register words, 1 cell for a program word (PW) and 1 cell for working storage. Thus, 8 cells are reserved for each of the 16 priorities, for a total of 128 executive space addresses.

Program priorities

The processor operates in 16 priorities to permit demand-based automatic execution of independent programs without the need for complex executive routines. Any priority except the lowest may be initiated by either pro-

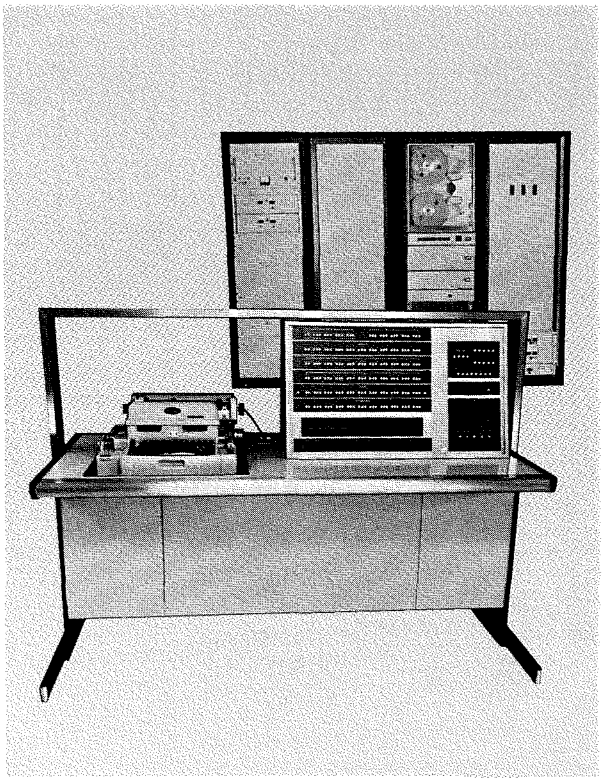


Fig. 3—4101C data processor.

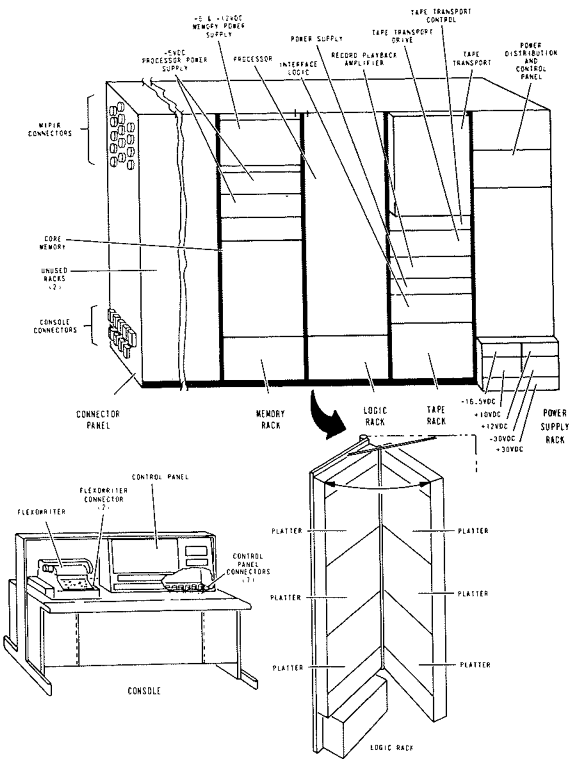


Fig. 4—4101C data processor, assembly locations.

without the need of complex executive routines. Any priority except the lowest may be initiated by either program or external demand. Once initiated, the priority remains active until a higher priority interruption, or until its own program suicides. A separate program word (PW) is stored in core memory executive space for each of the 16 priorities. Status indicator values are automatically transferred from the STATUS register into the PW of an interrupted or suiciding priority, and are restored in the STATUS register when that priority again becomes active. Similarly, the PROGRAM COUNTER value is transferred into the PW of an interrupted or suiciding priority and restored when the priority becomes active.

Input/output data transfer

Data transfers of a given type are associated with a particular priority level. Generally, only a single input or output instruction is needed to respond to an external data demand. A single instruction can

1) Specify the external device;
2) Execute the transfer of a word to or from core memory;
3) Decrement and test an index register to modify the core address; and
4) Suicide, to repeat when the demand signal comes on again.

Processor operating modes

The 4101C processor can be operated in any of three modes for normal use, and in several restricted modes for maintenance testing or program debugging. Choice of mode depends on the settings of the OVERRIDE and HALT ENABLE controls, on the selection of START-STOP switches, and on the setting of status bits in the program words for each priority. The operating mode determines the automatic response to each of the following alarm conditions:

Core memory parity error;
Parity error on rollback tape;
Instruction code 00 (halt or rollback);
Arithmetic overflow.

Logical organization

The organization of the processor around the 34-bit parallel central bus is shown in Fig. 2 which shows all ten active registers and the connecting data paths. The letters at the bottom of each box are used in designating signals and elements of that logical domain.

Interaction execution control

Ninety-five different micro-operations are used to perform all standard functions and the sixty-one programmable instructions of the 4101C. The three major classes of micro-operations are register resets, transfers from a register to the bus, and transfers from the bus to a register. Each class is enabled by a phase of the three-phase timing control. A set of three phases forms a "time slot" of approximately 200 ns. The basic logic equations which described the machine are written as functions of decoded instructions and of instruction "execution levels." A level normally corresponds to a memory-access cycle and may be composed of four, six, or eight time slots. Twenty-eight different levels are used, although the majority of instructions require only three.

Many of the registers in the processor are time-shared: they are used for different purposes at different times during a particular program sequence. The primary function of each register is reflected by its name and associated mnemonic:

Accumulator register (A)—The A-register stores the results of logical, shifting, and arithmetic operations; it acts as a carry-over for data between instructions.

Count register (C)—The C-register stores the current program count, that is, the address of current or next instruction.

Data register (D)—The D-register receives the data word during input operations; holds data transferred to or from the core memory; acts as a source for regenerating into memory words destroyed in the readout process; provides one input to the adder during arithmetic operations; and acts as a slave to the A-register during shift operations.

Flag register (F)—The F-register indicates the priority channels which require servicing; a bit is provided for each of priorities zero through fourteen.

Program register (P)—The P-register indicates the priority channel which is currently being serviced: 0 (highest priority) through 15 (lowest priority).

Augend register (G)—The G-register holds the data word during output instructions; provides one input to the adder during arithmetic operations; and holds the multiplicand and divisor during multiplication and division operations.

Half-word register (H)—The H-register provides temporary storage for the base address (the address field of the instruction word) or the effective address (the result of an indexing operation) and holds the most significant half of the multiplier or quotient during multiplication or division operations.

Instruction register (I)—The I-register holds the instruction field (left 17 bits) of the instruction word and controls its execution.

Location register (L)—The L-register provides the address for any core memory reference, and holds the least significant half of the multiplier and quotient during multiplication and division operations.

Status register (S)—The term S-register is a convenient label for a group of independent control flip-flops, which hold the results of executed control functions during and between instructions. The left six control values are set from the program word when a priority becomes active and are stored in the program word on suicide or interrupt.

Level A and B register (KL)—These registers display, respectively, the next and current instruction execution levels at any instant; value of zero to thirty-one are used.

Slot register (KS)—This string of eight indicators shows the next and current execution steps at any instant. The sequence is from S0 through S3, S5 or S7 according to the current levels and instruction.

Processor performance

Processor performance in a given application is a function of a number of characteristics of the processor, its integration into the overall operating system, and the sophistication and efficiency of the programming. Machine characteristics of the 4101C which can be highlighted as significant in affecting performance are the execution times of the instructions, the priority interrupt system, word length of 32 bits, and 32k words of directly addressable core memory. Other important features are the number of index registers, the secondary instruction field and indirect addressing Table II presents the speed of the processor as defined by the instruction execution times.

4101C hardware

The 4101C equipment is shown in Fig. 3. The equipment consists of four racks comprising the computer main frame and a control console. The four computer racks are: logic, memory, tape unit, and power supply. The control console consists of an operator/maintenance panel and an input/output typewriter. The logic rack contains the integrated circuit plug-in cards. The plug-ins conform to the dimensional standards of the Spectra 70 computers. The backplanes are mounted in a special hinged enclosure. The memory rack consists of the memory system and associated power supplies. The memory rack also contains two supplies in parallel to provide voltage to the logic rack. The tape unit rack consists of the tape unit and associated control electronics, power supplies, and interface electronics for the radar system and console typewriter (Flexowriter). The power supply rack consists of five commercially available supplies to provide voltage levels required in the computer, the power supply indicator panel, and a power distribution panel. An interface connector panel provides the terminal point for the physical connection of the fourteen 4101C interface cables to the radar data subsystem and nine cables to the console. The location of computer assemblies is illustrated in Fig. 4.

Table II—4101C computer instruction time.

Mnemonic	*Name*	*Execution Time (μs)*
HLT	Halt	4.6
RLB	Rollback	4.6
SAL	Shift accumulator, logical (A=shift count)	2.8+.5(A)
OPR	Operate	2.3
SAC	Shift accumulator, circular (A=shift count)	2.8+.5(A)
SAA	Shift accumulator, algebraic (A=shift count)	2.8+.5(A)
SKX	Skip on index	4.6
MAX	Mask accumulator to index	5.1
ADD	Add to accumulator	4.6
ADR	Add and replace	5.4
ADM	Add magnitude	4.6
AMR	Add magnitude and replace	5.4
SBT	Subtract accumulator from memory	4.6
SBR	Subtract and replace	5.4
SBM	Subtract magnitude	4.6
SMR	Subtract magnitude and replace	5.4
AUR	Add unity and replace	5.4
SUR	Subtract unity and replace	5.4
MPY	Multiply	37.1
PZM	Place zero in memory	4.9
PBM	Place B-box in memory	7.4
UHA	Upper halfword to memory	4.6
LHA	Lower halfword to memory	4.6
STL	Set location	4.9
LIM	Logical inclusive OR to memory	5.1
PBA	Place B-box in accumulator	4.6
PAB	Place accumulator in B-box	4.9
IMA	Interchange memory & accumulator	5.4
PZA	Place zero in accumulator	2.3
PMA	Place memory in accumulator	4.6
MAZ	Memory to accumulator & zero	5.1
PMO	Place memory on output	15.1
MPO	Memory to output	15.1
ALB	Add L to B-box	5.4
MPH	Multiply by half accumulator	21.1
DVD	Divide accumulator by memory	36.6
DVH	Divide by halfword	21.6
CAN	Complement and AND	4.6
CAR	Complement, AND, & replace	5.1
LIO	Logical inclusive OR	4.6
LIR	Logical inclusive OR & replace	5.1
LAN	Logical AND	4.6
LAR	Logical AND and replace	5.1
LEO	Logical exclusive OR	4.6
LER	Logical exclusive OR & replace	5.1
HUM	Halfword to upper memory	5.1
PAM	Place accumulator in memory	4.9
HLM	Halfword to lower memory	5.1
PIM	Place input in memory	9.0
IOC	Input-output command	15.1
PMB	Place memory in B-box	7.4
JLK	Jump and link	4.9
FLS	Flag set	2.3
JMP	Jump	2.3
JIX	Pump with index decrement	5.4
JSX	Jump and set index	4.9
LGC	Logical compare	4.6
CCH	Compare character	4.6
CBY	Compare byte	4.6
SKP	Skip	4.6
TST	Test memory	4.6

The computer main-frame logic is implemented on six backplanes and includes a total of 414 plug-in modules. The modules include twenty-six standard series-8 types and four specially designed types (two logic modules and two interface circuit modules). The backplanes are mounted on a swinging, fold-out frame with three backplanes located on each side of the frame.

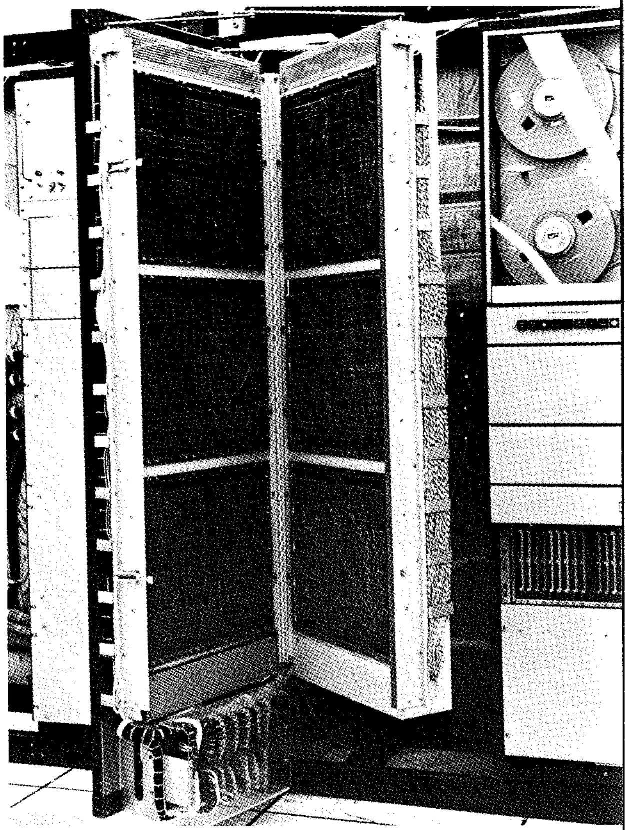


Fig. 5—Logic rack.

Fig. 5 illustrates the logic rack opened to expose the wiring of the backplane. A varying number of circuit connections on each backplane must be accommodated by discrete wires, however. Discrete wires are clearly visible in Fig. 5. The six backplanes of logic are identified as follows: (locations are referenced in this position in the view of Fig. 5).

Upper left—interface electronics and logic.

Middle left—control logic and memory interface.

Lower left—timing and control logic.

Upper right—register and adder logic.

Middle right—register and adder logic.

Lower right—control logic.

The backplanes are interconnected by cables which are connected to the backplanes by connectors inserted at the backplane edges. Power connections are made by attachment of individual power leads to the edge of the backplane.

The universal op-amp—a new concept in recording studio equipment

R. N. Andrews

The development of a universal operational amplifier board has led to a new concept in the design of recording-studio equipment: now a single type of plug-in board can be used for all the amplifier applications — except for the power amplifier. This paper briefly introduces the characteristics of the universal board and describes several typical applications.

THE OPERATIONAL AMPLIFIER has been applied to studio console design throughout the recording industry, and the advantages of this type of design in studio equipment have been well documented elsewhere. RCA Records has taken the operational amplifier one step further in the form of the universal operational amplifier board (UOAB).

The concept of the UOAB was developed by Mr. Robert Breed of the RCA Records Engineering Laboratories at Indianapolis in 1968. At that time, the recording studios at New York were about to launch a large expansion program and needed several new consoles with the capability of handling 16-track recordings. However, the UOAB offered such great potential that a break was made from more conventional design methods, experience has shown this to be a very wise decision.

A universal board for all stages in a piece of equipment yields the following advantages:

1) *Duplicate design work is eliminated.* For a particular application, only the gain and response of the feedback network need be calculated.
2) *Maintenance is simplified.* Only one type of board need be kept on hand.
3) *Costs are reduced.* It is cheaper to purchase one item in large quantities than to purchase several different items in small quantities.

A list of amplifier properties that are critical in recording studio equipment design, along with typical UOAB performance data, is given in Table I.

Circuit description

The circuit of the UOAB is shown in Fig. 1. Transistors *Q1* and *Q2* and associated components are emitter followers for power supply decoupling. *R7, R8,* and *C6* provide an offset voltage which can be used to polarize the output coupling capacitor, *C1.* The remainder of the components on the board allow connection of the UOAB to perform three or four common functions without requiring any external components.

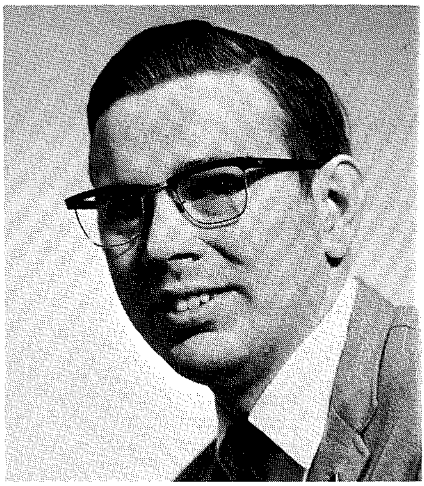
A large proportion of the development of the UOAB was involved in the selection of the operational amplifier module to be used. All of the available operational amplifiers were screened for noise floor and output capability as well as for the typical operational amplifier characteristics of open-loop gain, bandwidth, frequency response, and phase shift.

With current technology, integrated-circuit operational amplifiers could not meet the noise and output-power requirements. Therefore, attention was directed to discrete-component units. Presently, only two operational amplifiers have been found which meet all of the requirements. These are the Melcor, Model 1731, and the Automated Processes, Model 2520 (Fig. 2). The Automated Processes unit has a 2- or 3-dB lower noise floor, but both units provide excellent performance.

Typical applications

Currently, the UOAB is being used in several new 16-channel recording consoles and tape-mastering consoles (Fig. 3)—in every stage except the monitor power amplifiers. The UOAB is also being used in a master-tape-duplicating rack and four eight-track tape-playback machines.

The 16-channel studio recording consoles contain microphone pream-



Raymond N. Andrews, Mgr.
Recording Facilities Engineering
RCA Records
New York, N.Y.

joined the RCA Record Engineering Labs at Indianapolis as a technician. After receiving the BSEE from Purdue University in 1968, he returned to Record Engineering as a member of the Engineering staff. In April of 1969, he was appointed to his present position, responsible for new equipment for the RCA Recording Studios at New York, Chicago, Nashville, and Hollywood. He is a Member of the IEEE groups on Audio and Magnetics and the AES.

Table 1 - Typical performance characteristics of the universal operational amplifier board.

Desired quality	*Typical UOAB performance*
Low equivalent noise input	−129 dBm
Low distortion	less than 0.03%
Selectable input impedance	from less than 0.1 ohm to greater than 10 megohm
Low output impedance	less than 5 ohms
High output capability	7 volts RMS (Load > 100 ohms.)
Low input power	1 watt
High isolation between inputs when used as an active combiner	greater than 80 dB
Overload and short-circuit protected	Not damaged by indefinite overload or short circuit
Insensitive to noise on power supply	Heavy power supply filtering and decoupling is used

---

Reprint RE-16-1-1
Final manuscript received January 26, 1970.

plifiers, booster amplifiers, program combiners, and program amplifiers—all using the UOAB. Fig. 4 shows the circuit of the microphone preamplifier. The potentiometer provides up to 30 dB of attenuation to allow adjustment for microphone sensitivity, and the switch provides a low-frequency roll-off which can be used to minimize rumble and leakage from the rhythm section during a recording session. The cutoff frequencies available are 15 Hz (flat), 50 Hz, 100 Hz, and 200 Hz. This stage provides about 50 dB of gain with a signal-to-noise ratio greater than 70 dB.

Shown in Fig. 5 is an active program combiner. The output transformer is used to cancel the phase inversion introduced by the combiner. As opposed to the classic passive combiner network, this circuit has no loss and yet has greater than 80-dB isolation between inputs.

The two examples discussed thus far were both unequalized stages. Fig. 6 illustrates the use of the UOAB as a tape-playback amplifier, with NAB-standard equalization. A signal-to-noise ratio of greater than 65 dB has been realized with this circuit.

Conclusion

The above examples demonstrate the design flexibility of the UOAB. The only real difficulty with the UOAB is typical of any high-gain, wideband feedback amplifier—oscillation. Care must be taken to insure the adequate grounds and other conditions necessary for good stability.

The maintenance record of the UOAB has been excellent. Nearly 850 boards have been in heavy use for several months. So far, fewer than ten boards have failed—a rate of approximately one-tenth of one percent; furthermore, when a failure does occur, the equipment is down only as long as required to isolate the faulty stage and plug in a replacement board.

The advantages offered by the UOAB should lead to its use in other amplifier applications where ease of design, high reliability, and simplified maintenance are desired.

Acknowledgment

The author wishes to thank H. Meurer, L. O'Hare, and J. Stupak for their valuable assistance in preparing this paper.

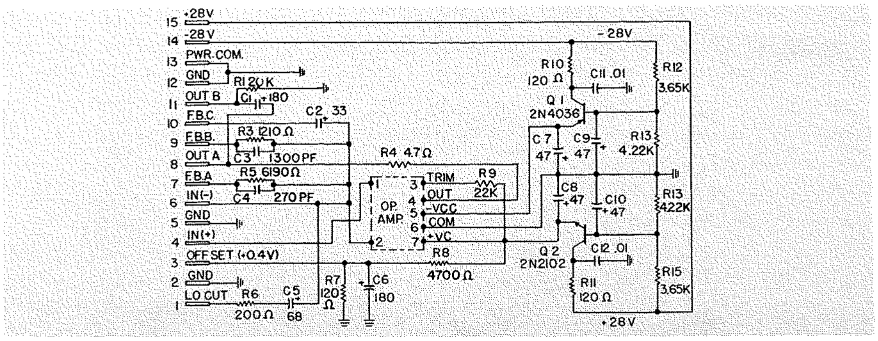


Fig. 1—Universal operational amplifier board circuit diagram (capacitor values in μF unless otherwise indicated).

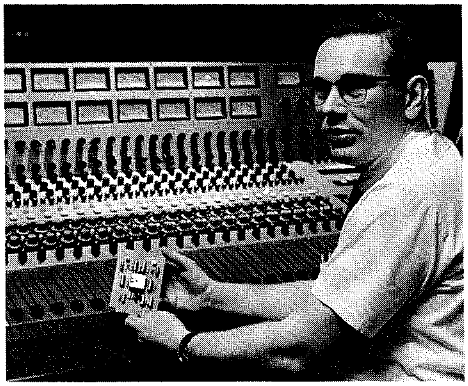


Fig. 2—Author holding UOAB used in tape mastering console.

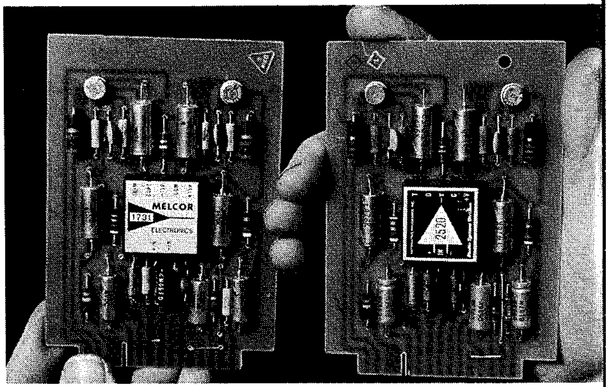


Fig. 3—UOAB's using the two different amplifier modules.

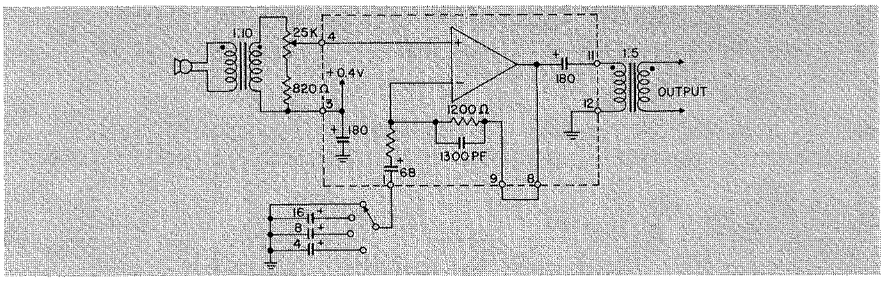


Fig. 4—Microphone preamplifier.

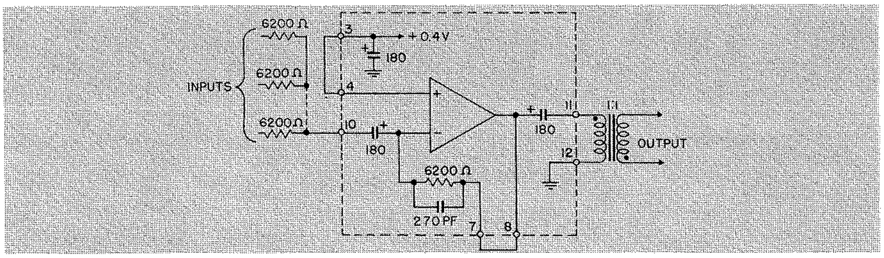


Fig. 5—Combiner amplifier.

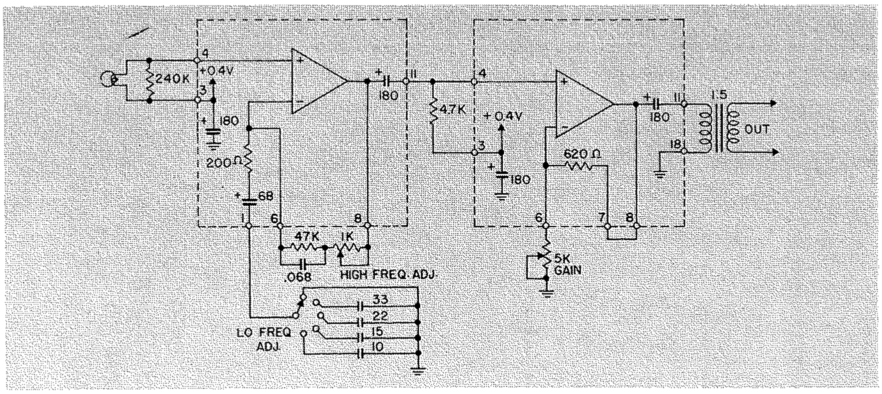
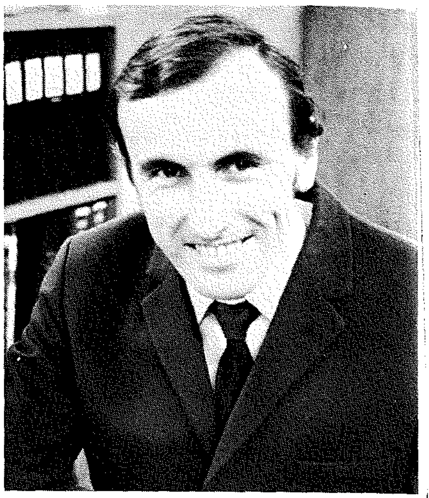


Fig. 6—Tape playback amplifier.

Computer-aided waveguide-limiter design

R. O. Schlaefli

An interesting application of ferrites is their use in limiters of pulsed high-power transmission systems. This paper describes an easy-to-build ferrite waveguide limiter. The design can be used at any frequency within the range from C to X band, inclusive, and the limiting thresholds can be varied over several decades of input power in the kW range. A computer program has been written to help design the limiter. The waveguide size, center frequency, and threshold power are supplied to the computer. The computer then helps select the right ferrite and calculates all the dimensions of the limiter and the magnetic DC bias.



Reinhard O. Schaefli
Industrial Tube Division
Electronic Components
Harrison, N.J.
received the MSEE in 1964 from the *Eidgenoessische Technische Hochschule* in Zurich, Switzerland. He joined ITT in 1964 as a group leader for the design and development of local oscillators in line-of-sight equipments. At ITT, he designed various solid-state sources from VHF to S-band. Mr. Schaefli joined RCA in 1967 as an associate engineer in the Microwave Solid-State Production Engineering activity. He first worked in the field of high power wideband VHF oscillators, amplifiers, and varactor-multipliers and wideband, low noise X-Band TDA's. Since 1968, he has been responsible for the product development of the X- and C-band solid-state TR's for use in RCA's new weather radar system AVQ-30. Mr. Schaefli is currently working on electronically tunable TEO devices and multiport miniature circulators at X-Band. He is an Associate Member of the IEEE.

Mechanically, the limiter shown in Fig. 1 is a fully symmetrical arrangement consisting of a ferrite centerpiece, dielectric matching pieces, and a waveguide-height transformer on both sides. Magnetic DC bias is applied in the x direction. Table I defines the symbols used throughout the paper.

Physical and mathematical background

Limiting

The dimensions of the limiter and its biasing are chosen so that $TE_{1,0}$ propagation can be assumed. With this limiter configuration, the RF magnetic component in the x direction determines the threshold point for limiting. The value at which limiting starts is given by

$$h_{xcrit}=\frac{f_0\Delta H_k}{\gamma 4\pi M_s} \qquad (1)$$

For $h_x > h_{xcrit}$, spin waves are excited which extract RF energy and dissipate it in the lattice in the form of heat. Because h_x is parallel to the magnetic DC bias, this type of limiting is called *parallel pump limiting.*

The maximum value of the RF magnetic x component h_{xmax}, in terms of the power carried through the waveguide and loaded with the ferrite material, is given (see Appendix I) by[1,2]

$$h_{xmax}=2\,(0.495)\left[\frac{P}{\mu_F\zeta_0 w_F h_F}\right]^{1/2}\left[\mu_F\varepsilon_F-\frac{\lambda_0}{2w_F}^{\,2}\right]^{1/4} \qquad (2)$$

and appears at the center of the waveguide. From Eqs. 1 and 2, the value of ΔHk at the threshold power P_{crit} is obtained, as follows:

$$\Delta H_k=\left[\frac{2\gamma\,(0.495)\,4\pi M_s}{f_0}\right]\left[\frac{P_{crit}}{\mu_F\zeta_0 w_F h_F}\right]^{1/2}\left[\mu_F\varepsilon_F-\left(\frac{\lambda_0}{2w_F}\right)^2\right]^{1/4} \qquad (3)$$

It is therefore possible from Eq. 3 to select a ferrite which starts limiting at P_{crit} mainly on the basis of its ΔH_k. For today's available ferrites, ε_t lies in the vicinity of 15, and $4\pi M_s$ is arbitrarily predetermined for the program as $f_0/5$ (see appendix III). The question arises as to what value should be taken for μ_F. It is shown in appendix II that, for the limiter configuration used, a good approximation is

$$\mu_F=1-\tfrac{1}{2}(\gamma 4\pi M_s/f_0)^2 \qquad (4)$$

Practical considerations lead to the selection of the length of the ferrite l_F. With increasing l_F higher limiting values can be achieved. However, the insertion loss (below the threshold) also increases with increased l_F, and excessive ferrite lengths tend to be more sensitive to spurious-mode propagation.[3]

The figure of merit of a limiter, which can be defined as the ratio of limiting (dB) to insertion loss (dB) below the threshold, should be made a maximum at the working input-power level and frequency. As shown later, it is better to achieve a certain amount of limiting by cascading short lengths of ferrites with cascaded thresholds rather than by using one very long ferrite piece and operating it much above the threshold.

In the computer program, l_F is taken to be three times the guide wavelength in the biased ferrite (λ_{gf}), resulting in good figures of merit and low sensitivity to spurious modes.

The magnetic DC bias at which Eq. 1 holds is given by

$$H_{DC}=f_0/7.3 \qquad (5)$$

if $4\pi M_s=f_0/5$ (see appendix III).

Dielectric Matching

To match into the ferrite-loaded center portion of the limiter, a dielectric slab is placed on both ends of the ferrite. The dielectrics act as quarter-wave transformers.

The length of the slab is given from impedance considerations once the ferrite has been selected and dimensioned (see appendix IV). To determine the width of the slab, it is necessary to solve the usual transcendental equation occurring in partially dielectrically-loaded waveguides (see appendix IV).

The dielectric constant of the slab should be somewhere between 1 and

---

Reprint RE-16-1-3
Final manuscript received October 1, 1969.

a	width of regular waveguide (inch)
b	height of regular waveguide (inch)
f_0	center frequency (MHz)
h_F	ferrite height (inch)
h_D	dielectric height (inch)
h_T	transformer height (inch)
h_{xcrit}	critical magnetic RF component in x direction (oersted)
h_x	magnetic RF component in x direction (oersted)
h_{xmax}	maximum magnetic RF component in x direction (oersted)
ΔH_k	spin-line width (oersted)
$4\pi M_s$	saturation magnetization (gauss)
I_P	peak current, $TE_{1,0}$ mode (ampere)
I'_P	peak-mode current (ampere)
l_F	ferrite length (inch)
l_D	dielectric length (inch)
l_T	transformer length (inch)
P	power carried through waveguide (watts)
P_{crit}	threshold power for absorption (watts)
V_P	peak voltage, $TE_{1,0}$ mode (volt)
V'_P	peak-mode voltage (volt)
H_{DC}	magnetic DC bias (oersted)
H'_{DC}	magnetic DC bias for gyromagnetic resonance at f_0 (oersted)
w_F	ferrite width (inch)
w_D	dielectric width (inch)
w_T	transformer width (inch)
x	x coordinate
y	y coordinate
z	direction of propagation and z coordinate
ε_F	real part of dielectric constant of ferrite
ε_D	real part of dielectric constant of dielectric
μ_F	effective ferrite permeability
λ_0	free-space wavelength (inch) at f_0
λ_F	*TEM* wavelength in ferrite (inch) at f_0
λ_{gA}	guide wavelength in air (inch) at f_0
λ_{gD}	guide wavelength in partially dielectrically filled guide (inch) at f_0
λ_{gF}	guide wavelength in ferrite (inch) at f_0
ζ_F	intrinsic-wave impedance in ferrite (ohm)
ζ_0	intrinsic-wave impedance in air (ohm)
γ	gyromagnetic factor (=2.8)
$\tan\delta_F$	loss tangent of ferrite at f_0
$\tan\delta_D$	loss tangent of dielectric at f_0

Table I—Symbols and units used.

ε_F to obtain reasonable dimensions. A good value to choose is $\varepsilon_F/2$.

Waveguide-height transformer

The waveguide-height transformer is also a quarter-wave transformer. The height h_T is given by

$$h_T = (bh_D)^{1/2} \qquad (6)$$

The length is a quarter of the guide wavelength λ_{gA} because there is no width transformation involved.

Computer program

Based on the above considerations, a FORTRAN program has been written for use on the RCA time-sharing system. Fig. 2 shows the flow chart of the program, and an identification of the variables used in the program. Fig. 3 shows an actual computer session in which a limiter was calculated.

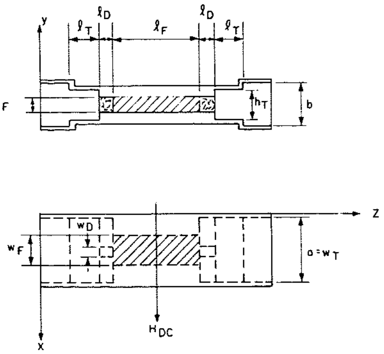
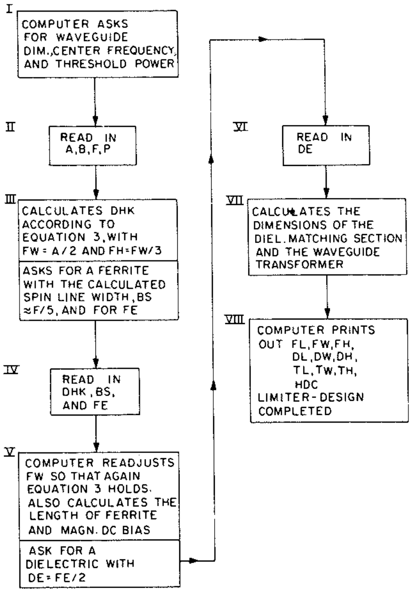


Fig. 1—Configuration of limiter; symbols used are defined in Table I.



	corresponds to
A	a
B	b
F	f_0
P	P_{crit}
DHK	ΔH_k
BS	$4\pi M_s$
FE	ε_F
DE	ε_D
HDC	H_{DC}
FL,FW,FH	l_F,w_F,h_F
DL,DW,DH	l_D,w_D,h_D
TL,TW,TH	l_T,w_T,h_T

Fig. 2—Flowchart and identification of program variables.

The computer program first asks for the waveguide inner dimensions, the center frequency, and the threshold power level; these values are then read in. The center frequency and threshold power are given by the specific application. The size of waveguide should be chosen for which $1.6\lambda_0 \geqslant a \geqslant 1.2\lambda_0$. In cases in which very high power capability is needed, the largest possible guide should be selected.

```
   I. READ IN THE GUIDE INNER DIMEN-
      SIONS A & B IN INCHES, THEN THE
      CENTER FREQUENCY F IN MHZ &
      THEN THE THRESHOLD POWER P IN
      WATTS
  II. A=1.122
      B=.497
      F=9345
      P=200
 III. CHOOSE A LOW LOSS FERRITE HAV-
      ING A SPIN LINE WIDTH DHK IN
      OERSTED OF: 2.4394
      4PIMS(=BS IN GAUSS) SHOULD BE
      NEAR TO F/5.READ IN DHK,BS & FE
      (DIEL.CONST. OF FERRITE)
  IV. DHK=2.7
      BS=1780
      FE=15
   V. TAKE A DIEL. WITH A DIEL.KONST.
      DE OF APPROX.FE/2 & READ THIS
      VALUE IN.
  VI. DE=6
 VII. FL=  .1131099E+01
 AND FW=  .4924685E+00
VIII. FH=  .1641561E+00
      DL=  .1757479E+00
      DW=  .1767083E+00
      DH=  .1641561E+00
      TL=  .3820200E+00
      TW=  .1122000E+01
      TH=  .2856319E+00
      HDC=  .1282062E+04
      THESE ARE THE LENGTH, WIDTH &
      HEIGHT OF THE FERRITE,DIEL. &
      THE HEIGHT TRANSFORMER, ALL IN
      INCHES & THE MAGN.DCBIAS IN
      GAUSS,TO BE APPLIED IN THE X
      DIRECTION
      STOP AFTER *920
        930
```

Fig. 3—Computer session for designing and calculating a limiter.

The computer then solves Eq. 3 (section III of the program) assuming a ferrite with $\varepsilon_F=15$, $\mu_F=0.9$, $4\pi M_s=f_0/5$, $w_F=a/2$, $h_F=w_B/3$ and asks for a ferrite having a calculated ΔH_K according to Eq. 3. At this point, based on available ferrite data sheets, the best material for the wanted application is chosen and ΔH_k, $4\pi M_s$ and ε_F are read into the computer (section IV). Tan δ_F should be less than 0.0005 for low insertion loss. With these values supplied to the computer, a new w_F is calculated, slightly different from the prior value, because the selected material probably does not fulfill exactly the requirements as computed earlier in the program (section III). In case the supplied ΔH_k would lead to extreme ferrite dimensions, the computer would come back and ask for a larger or smaller value of ΔH_k. In section V the computer also calculates the length of the ferrite, and the value of the magnetic DC bias. The ferrite-length choice is based on considerations mentioned earlier. At the end of section V, the computer asks for the dielectric material to be used for matching. Again, tan δ_D should be less than 0.0005. In section VI of the computer program this value is read in, and the computer

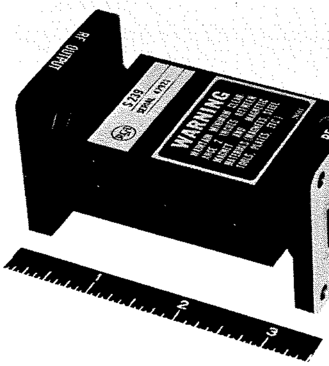


Fig. 4—X-band limiter.

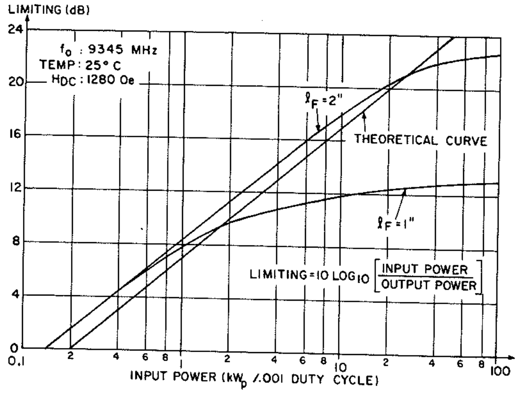


Fig. 5—Limiting of 1-in. and 2-in. limiter vs. input power.

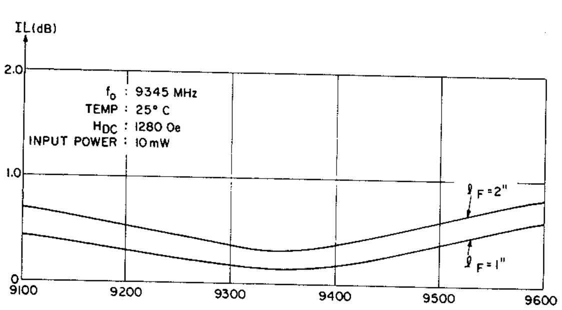


Fig. 6—Insertion loss of 1-inch and 2-inch limiters versus frequency.

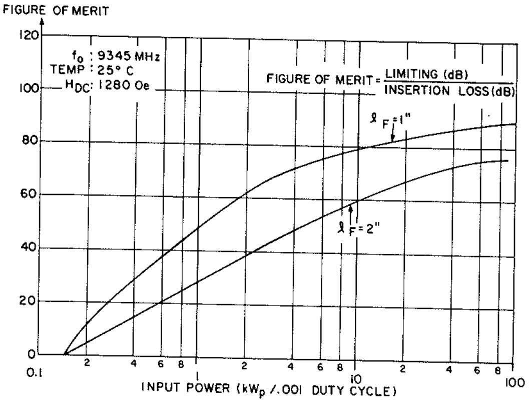


Fig. 7—Figure of merit for 1-inch and 2-inch limiters versus input power.

does all the remaining calculating in section VII and prints out all the values for fabricating the limiter in section VIII.

Experimental results

Limiters, for an f_0 of 9345 MHz and a threshold power of 0.2kW peak in a WR112 guide, have been calculated on the computer, have been fabricated, and tested. Fig. 4 shows an actual X-band unit. Based on the computer calculations in section III of the program, a ferrite with a ΔH_k of 2.7 oersted, a $4\pi M_s$ of 1780 gauss, and an ε_F of 15 was chosen. Tan δ_F is less than 0.00025. Because the length of the ferrite l_F does not strictly follow any equation, two limiters having different l_F were compared. Fig. 5 shows the limiting obtained from limiters with $l_F = 1$ in. and 2 in. Except for l_F, the two limiters were identical. The data in Fig. 5 were obtained using a pulsed magnetron with a duty cycle of 0.001. The magnetic bias was applied with permanent magnets giving an H_{DC} of 1280 oersteds in the center of the waveguide.

Good agreement between theory and experiment was obtained. However, two deviations from the theoretical curve are visible:

1) The threshold power obtained is lower than predicted. This difference is probably caused by a μ_F value which is slightly in error; H_{DC} has been derived for the case where there is no demagnetizing factor present in the x direction (see appendix III). It has been found that the threshold can be changed by changing the value of H_{DC}. A slightly higher value of H_{DC} than the one calculated yields a slightly lower threshold and vice versa. However, H_{DC} should not be increased by more than 25%, approximately, from the calculated value, or parameters such as the VSWR would start to be affected considerably.

2) The slopes of the experimental curves start to deviate from the slope of the theoretical curve at some power level above the threshold. This deviation is caused mainly by thermal effects. The roll-off point is a function of the ferrite used, its volume and length, the thermal resistance between the ferrite and the waveguide, and the external cooling used. This thermal behavior has not been investigated.

However, Fig. 5 can give performance guidelines for limiters at other frequencies within *C* and *X* bands having approximately the same absorption density (watts per cubic inch) and using the same construction. Fig. 6 shows the insertion loss of the two limiters versus frequency. Fig. 7 shows the figures of merit of the two limiters versus input power level at f_0.

It can be seen from Fig. 7 that the 2-in. limiter must be operated at higher powers than the 1-in. limiter to obtain the same figure of merit.

Considerable difficulties were encountered in getting the 2-in. limiter to work without spurious-mode propagation. It is therefore suggested that the ferrite length be kept short and the device be operated not too far above the threshold—typically 1.5 decade above. In applications where a very high amount of limiting is required, limiters of this type can be cascaded by cascading the thresholds, too. This cascading can be accomplished either by narrowing the cross-section of the ferrite-loaded waveguide or by selecting different ferrites with cascaded ΔH_k. The second method results in a mechanically less complex design than the first.

Using the design described, it is possible to build limiters with a threshold between 0.01 and 100 kW peak with today's available ferrites. Limiters of this type have a spike leakage as shown in Fig. 8. The question must be examined whether this leakage energy is dangerous to the devices following the limiter.

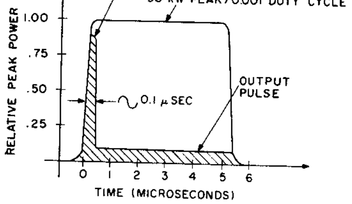


Fig. 8—Typical spike leakage of a 1-in. limiter at 9345 MHz.

Conclusion

A computer-aided limiter design has been described and experimental results have been compared to theoretical predictions. By use of the design outlined, limiters at any frequency within the C- to X-band range and with threshold powers anywhere between 0.01 to 100 kW peak are easily designed by just reading the waveguide dimensions, the center frequency, and the threshold power into the computer. A high amount of limiting should be realized by cascading short lengths of ferrites rather than using one very long piece of ferrite. Thus, a high over-all figure of merit and insensitivity toward spurious responses can be obtained.

Appendix I—Derivation of maximum x component of RF magnetic vector in a ferrite-loaded waveguide section.

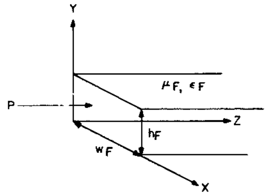


Fig. 9—Power propagation down the waveguide.

If power P is carried down the waveguide as shown in Fig. 9, then it can be expressed in terms of the peak-mode voltage and current as follows:[4]

$$P = \tfrac{1}{2} V'_P I'_P \tag{7}$$

Assuming $TE_{1,0}$-mode propagation, Eq. 7 can be rewritten as

$$P = \frac{h_F \zeta_F I_P^2}{w_F \left[1 - \left(\frac{\lambda_F}{2w_F}\right)\right]^{1/2}} \tag{8}$$

where

$$I_P = \frac{2h_F}{w_F} I'_P$$

and

$$V'_P = I'_P \left[\frac{\zeta_F}{[1-(\lambda_F/2w_F)^2]^{1/2}}\right]$$

the latter being "ohms law" in the waveguide.

Eq. 8 can be solved for I_P to yield:

$$I_P = \left[\frac{w_F P}{h_F \zeta_F}\right]^{1/2} \left[1 - \left(\frac{\lambda_F}{2w_F}\right)^2\right]^{1/4} \tag{9}$$

The maximum RF magnetic x-vector in the $TE_{1,0}$ mode is given by

$$h_{xmax} = \frac{2I_P}{w_F} \tag{10}$$

and accurs at $x = w_F/2$.

Substitution of Eq. 9 into Eq. 10 yields

$$h_{xmax} = 2\left[\frac{P}{w_F h_F \zeta_F}\right]^{1/2} \left[1 - \left(\frac{\lambda_F}{2w_F}\right)^2\right]^{1/4}$$

because $\zeta_F = \zeta_0 (\mu_F/\varepsilon_F)^{1/2}$ and $\lambda_F = \lambda_0/(\varepsilon_F \mu_F)^{1/2}$.

(11)

Eq. 11 can be rewritten as follows:

$$h_{xmax} = 2\left[\frac{P}{\mu_F w_F h_F \zeta_0}\right]^{1/2} \left[\varepsilon_F \mu_F - \left(\frac{\lambda_0}{2w_F}\right)^2\right]^{1/4} \tag{12}$$

Eq. 12 corresponds to Eq. 2. The factor 0.495 is due to the transition from the MKS system into the system using the units defined in Table I.

Appendix II—μ_F of ferrite medium

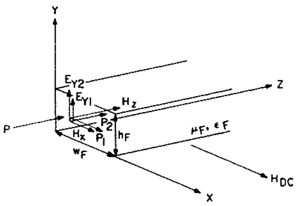


Fig. 10—Resolution of power into two plane waves.

If the magnetic DC bias is applied in the x direction and the $TE_{1,0}$-mode propagation along the z axis is assumed, it is very difficult to give an exact solution for the Maxwell equation. However, at any point within the ferrite, and at any time, the $TE_{1,0}$ mode can be thought of as a sum of two plane waves: 1) P_1 consisting of E_{y1} and H_z traveling in the x direction and 2) P_2 consisting of E_{y2} and H_x traveling in the z direction (see Fig. 10).

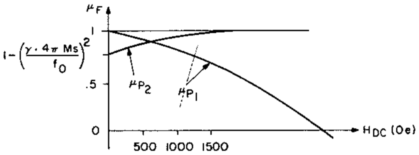


Fig. 11—Permeabilities as functions of H_{DC}.

These two plane waves see a different effective permeability. In Fig. 11, these two permeabilities are shown as functions of the value of H_{DC} for a typical limiter ferrite.

The two different permeabilities can be averaged over the whole ferrite volume; a good approximation for the effective permeability at the H_{DC} values used is

$$\mu_F = 1 - \tfrac{1}{2}\left(\frac{\gamma 4\pi M_s}{f_0}\right)^2$$

There are two more indications that the above approximation can be made: 1) The VSWR's of the limiter with and without H_{DC} applied differ only very slightly; 2) The above approximation is in line with work of other authors who deal with magnetic tuning of resonant cavities.[5,6]

Appendix III—Calculation of H_{DC}

The H'_{DC} which would be needed to obtain gyromagnetic resonance at f_0 could be obtained from the following equation:[7]

$$f_0 = \gamma [H'_{DC}(H'_{DC} + 4\pi M_s)]^{1/2} \tag{13}$$

Because the limiter configuration described works at subsidiary resonance, H_{DC} is usually taken to be half the value of H'_{DC}. Hence, Eq. 13 can be rewritten as follows:

$$f_0 = \gamma [2H_{DC}(2H_{DC} + f_0/5)]^{1/2} \tag{14}$$

where $4\pi M_s$ has been chosen to be $f_0/5$ If Eq. 14 is solved for H_{DC}, the value obtained corresponds to Eq. 15 as follows:

$$H_{DC} = f_0/7.3 \tag{15}$$

In most cases, $4\pi M_s$ is not exactly $f_0/5$, and the computed value of H_{DC} differs slightly from the value in Eq. 15.

Appendix IV—Calculation of the dielectric matching section.

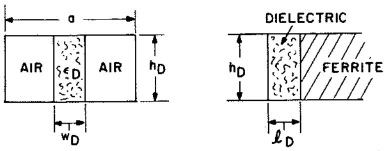


Fig. 12—Waveguide with low-loss dielectric.

Fig. 12 shows a waveguide partially filled with a low-loss dielectric (ε_D real). From a transverse-impedance consideration at the air-dielectric boundary, the following transcendental equation[4] is obtained:

$$\frac{2\pi}{\lambda_0}\left[1-\left(\frac{\lambda_0}{\lambda_{gD}}\right)^2\right]^{1/2} \cot\left\{\frac{2\pi}{\lambda_0}\left[1-\left(\frac{\lambda_0}{\lambda_{gD}}\right)^2\right]^{1/2}\left[\frac{a-w_D}{2}\right]\right\} = \frac{2\pi}{\lambda_0}\left[\varepsilon_D-\left(\frac{\lambda_0}{\lambda_{gD}}\right)^2\right]^{1/2} \tan\left\{\frac{2\pi}{\lambda_0}\left[\varepsilon_D-\left(\frac{\lambda_0}{\lambda_{gD}}\right)^2\right]^{1/2}\frac{w_D}{2}\right\} \tag{16}$$

In the application described, λ_{gD} is known from the amount of impedance transformation that is required to match from the air-filled into the ferrite-filled waveguide. Because the dielectric-matching section acts as a quarter-wave transformer, the following equation can be written:

$$4l_D = \lambda_{gD} \approx (\lambda_{gA}\lambda_{gF}\mu_F)^{1/2} \tag{17}$$

where

$$\lambda_{gA} = \lambda_0/[1-(\lambda_0/2a)^2]^{1/2} \tag{18}$$

and

$$\lambda_{gF} = \lambda_0/[\mu_F \varepsilon_F - (\lambda_0/2w_F)^2]^{1/2} \tag{19}$$

The only unknown in Eq. 16 is, therefore, w_D, which is solved numerically in the computer program described.

Acknowledgment

The author thanks T. E. Walsh and W. W. Siekanowicz for designing and evaluating the first model of this type of limiter and D. D. Mawhinney for many helpful discussions and for technical assistance.

References

1. von Aulock, W. H. *Handbook of Microwave Ferrite Materials* (Academic Press, New York).
2. Schlomann, E., "Recent Developments in Ferromagnetic Resonance at High Power Levels" *Journal Appl. Phys.* Suppl. Vol. 31, No. 5 (1960).
3. Gagne, R. T., "The Paradoxical Surface Wave in Ferrite-Filled Waveguides" *IEEE Transactions on Microwave Theory and Techniques* Vol. MTT-16, No. 4 (1968).
4. Marcuvitz, N. *Microwave Handbook* (MIT Rad. Lab. Series No. 10).
5. Fay, Clifford, "Ferrite Tuned Resonant Cavities" *Proc. IRE* (Oct. 1956).
6. Jones, G. R., "Magnetic Tuning of Resonant Cavities and Wideband Frequency Modulation of Klystrons" *Proc. IRE* (Oct. 1956).
7. Trans-Tech "Tech Brief No. 6510".

Computer solution of nonlinear simultaneous equations

G. P. Kirkpatrick

Many studies in scientific and engineering research and development involve sets of nonlinear simultaneous equations. By use of the Newton-Raphson method,[1] the sets can be reduced to linear simultaneous equations and solved by successive approximations. Desk-calculator solutions of sets, even for two equations, are time-consuming and laborious. On the other hand, use of a computer, particularly through time sharing, is a very efficient approach. This paper discusses the complete solution of two simultaneous nonlinear equations by use of Newton-Raphson method.

George P. Kirkpatrick
Information Systems and Services
Electronic Components
Harrison, N.J.

received the BS in Physics in 1941 from the College of the City of New York and the MS in Physics from Brooklyn Polytechnic Institute. He worked from 1941 to 1944 for the Electrical Testing Laboratories. He was a Research Associate in Physics at Brooklyn Polytechnic Institute during 1944-1945, and was an Instructor in Physics (evenings) from 1945 to 1948. He worked as a physicist for U.S. Radium Corporation from 1945 to 1951. From 1951 to 1961, he was with the Chemical and Physical Laboratory at RCA Lancaster, specializing in problems in colorimetry, spectroradiometry, and secondary-emission phenomena. Since 1961, he has been engaged in programming scientific and engineering problems for the RCA computers at RCA in Harrison.

THE GENERALIZED FORM for two nonlinear simultaneous equations is as follows:

$$\begin{aligned}\theta(x,y)&=0\\ \psi(x,y)&=0\end{aligned} \tag{1}$$

By use of the Newton-Raphson method these equations become:

$$\begin{aligned}\theta(x_0,y_0)+h\left(\frac{\partial\theta}{\partial x}\right)_0+k\left(\frac{\partial\theta}{\partial y}\right)_0&=0\\ \psi(x_0,y_0)+h\left(\frac{\partial\psi}{\partial x}\right)_0+k\left(\frac{\partial\psi}{\partial y}\right)_0&=0\end{aligned} \tag{2}$$

The squares, products, and higher powers of h and k are neglected, because both constants are less than one.[1]

Eqs. 2 are linear with respect to h and k and can be solved for h and k if the values of x_0, y_0 are estimated. In this case, better values are then obtained, as follows:

$$\begin{aligned}x&=x_0+h\\ y&=y_0+k\end{aligned} \tag{3}$$

The true values of x and y, therefore, can be approached through repeated applications of the Eqs. 2 and 3.

This method can be illustrated by means of a practical problem involving rim bands used on television picture tubes. Fig. 1 shows a section of a picture-tube faceplate viewed from the front. The following elements are known:

A, B, and RA—the elements of the circle WA;

C, D, and RC—the elements of the circle WC; and

RE—the radius of a circle of unknown origin tangent to WA and WC.

The problem is to find the coordinates of the origin of the circle described by RE and the points of tangency of that circle with the circles WA and WC.

Solution

For some time, this problem was solved graphically by use of scales of 1, 10, 100, and 1000 to 1 and numerous intermediate calculations that consumed as much as two work weeks. Recently, however, a numerical solution was attempted.

Initially, it appears that such a solution would involve a set of six nonlinear, simultaneous equations (six unknowns). However, examination of Fig. 1 shows that the solution for the circle of known radius (RE) but of unknown origin should be accomplished first. Instead of six simultaneous equations, now there are three sets of equations, each having two unknowns.

The first equation is derived from the fact that the center of any circle internally tangent to the arc WA and of radius RE lies on the arc W3, i.e.,

$$(X-A)^2+(Y-B)^2=(RA-RE)^2 \tag{4}$$

where X and Y are the coordinates of the origin of the circle in question.

Similarly, for circles tangent to the circumference WC, the centers lie on the circumference WC1 and have the radius RE, as follows:

$$(X-C)^2+(Y-D)^2=(RE-RC)^2 \tag{5}$$

It follows that the intersections of WC1 with the circumference W3 are the desired solutions.

Because Eqs. 4 and 5 are quadratic, there are, in general, two possible solutions. Therefore, an estimate must be made of the values of X and Y. These solutions may be denoted by GX, GY in computer notation. Eqs. 4 and 5 may now be rewritten as follows:

$$\begin{aligned}(X-A)^2+(Y-B)^2&=(RA-RE)^2\\ (X-C)^2+(Y-D)^2&=(RE-RC)^2\end{aligned}$$

By use of the Newton-Raphson method, these equations assume the following form:

Reprint RE-16-1-12
Final manuscript received January 28, 1970.

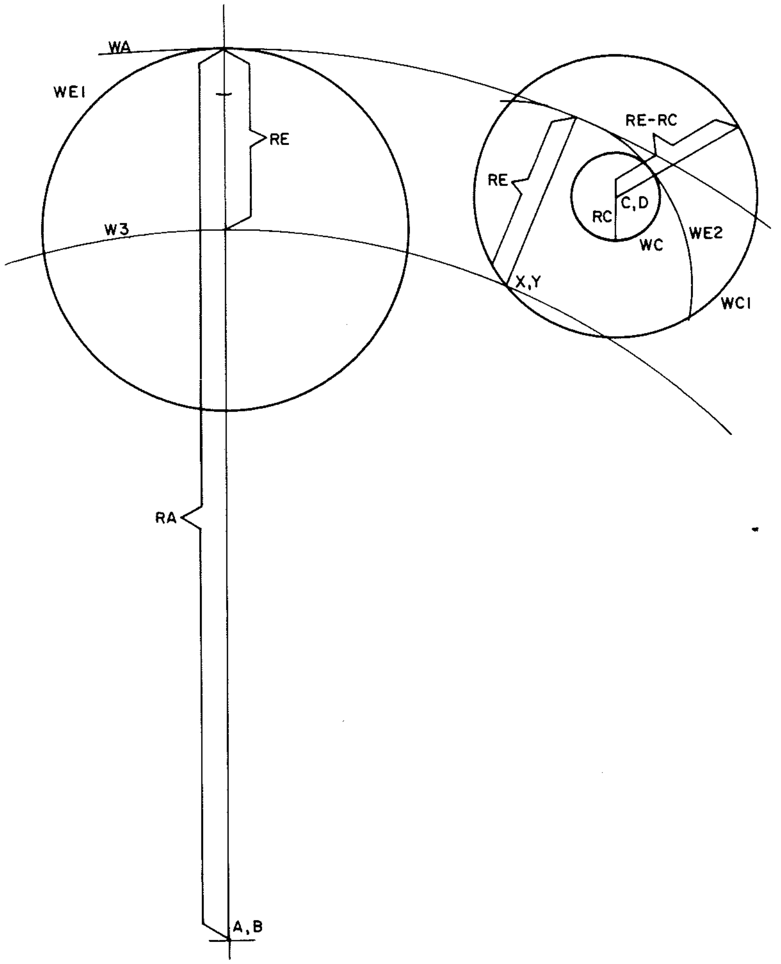


Fig. 1—A section of a picture-tube faceplate viewed from the front.

```
/PRINT# GPK
  10 COMMOND.P.A,B, C, D,RA,RC,RE,GX,GY,ERR,DN,PHI,THETA,PAH,AH,PAK,GX1,
     GY1,AK,G,X,Y,P,T,PAL,AL
  20 COMMONI
  30 10 FORMAT(8E10.0)
  40 1READ10A,B, C, D,RA,RC,RE,GX,GY
  50 ERR=1.E-13
  60 DO100I=1,1000
  70 DN=4.*((GX-A)*(GY-D)-(GY-B)*(GX-C))
  80 PHI=(GX-A)**2+(GY-B)**2-(RA-RE)**2
  90 THETA=(GX-C)**2+(GY-D)**2-(RE-RC)**2
 100 PAH=-2.*PHI*(GY-D)+2.*THETA*(GY-B)
 110 AH=PAH/DN
 120 PAK=-2.*THETA*(GX-A)+PHI*2.*(GX-C)
 130 AK=PAK/DN
 140 GX1=GX+AH
 150 GY1=GY+AK
 160 G=SQRT((GX1-GX)**2+(GY1-GY)**2)
 170 IF(G-ERR)200,200,15
 180 15GX=GX1
 190 100GY=GY1
 200 200PDUMPGX1,GY1,G,I,GX,GY,THETA,PHI
 210 X=0
 220 Y=0
 230 CALL CAL
 240 PDUMPX,Y,G,I
 250 A=C
 260 B=D
 270 X=0
 280 Y=0
 290 RA=RC
 300 CALL CAL
 310 PDUMPX,Y,G,I
 320 GOTO1
 330 END
 340 SUBR.CAL
 350 COMMOND.P.A,B,C,D,RA,RC,RE,GX,GY,ERR,DN,PHI,THETA,PAH,AH,PAK,GX1,
     GY1,AK,G,X,Y,P,T,PAL,AL
 360 COMMONI
 370 DO1000I=1,1000
 380 DN=4.*((X-A)*(Y-GY)-(Y-B)*(X-GX))
 390 P=(X-A)**2+(Y-B)**2-RA**2
 400 T=(X-GX)**2+(Y-GY)**2-RE**2
 410 PAH=-2.*P*(Y-GY)+2.*T*(X-B)
 420 AH=PAH/DN
 430 PAL=-2.*T*(X-A)+2*P*(X-GX)
 440 AL=PAL/DN
 450 G=AL**2+AH**2
 460 IF(G-ERR)220,220,115
 470 115 X=X+AH
 480 Y=Y+AL
 490 1000 CONTINUE
 500 220 RETURN
 510 END
```

Fig. 2—A program for the solution of the rim-band problem.

```
/CODE GPK
   520 -
A=1.E-26
B=-54.0685
C=8.257
D=5.86
RA=62.7
RC=2.158
RE=15.7
GX=5
GY=-7
GX1= .54257799436155496E+01
GY1=-.73827322329014277E+01
G= .20379775921213205E-13
I=6
GX= .54257799436155296E+01
GY=-.73827322329014233E+01
THETA= .35527136788005009E-14
PHI= .17053025658242404E-12
X= .72750189128268405E+01
Y= .82101698953840340E+01
G= .86185130732023274E-13
I=42
X= .89811308896220976E+01
Y= .79414574495306400E+01
G= .55920086575432614E-13
I=39
A=
```

Fig. 3—A solution of the rim-band problem.

$$\theta = (\mathrm{GX}-\mathrm{A})^2 + (\mathrm{GY}-\mathrm{B})^2 - (\mathrm{RA}-\mathrm{RE})^2$$
$$\psi = (\mathrm{GX}-\mathrm{C})^2 + (\mathrm{GY}-\mathrm{D})^2 - (\mathrm{RE}-\mathrm{RC})^2$$

Further expansion produces the following set of equations:

$$(\mathrm{GX}-\mathrm{A})^2 + (\mathrm{GY}-\mathrm{B})^2 - (\mathrm{RA}-\mathrm{RE})^2 + 2h\ (\mathrm{GX}-\mathrm{A}) + 2k\ (\mathrm{GY}-\mathrm{B}) = 0$$
$$(\mathrm{GX}-\mathrm{C})^2 + (\mathrm{GY}-\mathrm{D})^2 - (\mathrm{RE}-\mathrm{RC})^2 + 2h\ (\mathrm{GX}-\mathrm{C}) + 2k\ (\mathrm{GY}-\mathrm{D}) = 0$$

By the application of determinants, it can be shown that if $\mathrm{DN} = 4\ [(\mathrm{GX}-\mathrm{A})\ (\mathrm{GY}-\mathrm{D}) - (\mathrm{GY}-\mathrm{B})\ (\mathrm{GX}-\mathrm{C})]$, then:

$$h = \frac{-2\theta\ (\mathrm{GY}-\mathrm{D}) + 2\psi\ (\mathrm{GY}-\mathrm{B})}{\mathrm{DN}}$$
$$k = \frac{-2\psi\ (\mathrm{GX}-\mathrm{A}) + 2\theta\ (\mathrm{GX}-\mathrm{C})}{\mathrm{DN}}$$

The improved values for X and Y are then determined as in Eq. 3:

$$\mathrm{X} = \mathrm{GX} + h$$
$$\mathrm{Y} = \mathrm{GY} + k$$

The time-sharing program to solve this rim-band problem is given in Fig. 2.

The points of tangency are calculated with the same method. For a given set of input parameters, the double-precision program of the problem executed on the time-sharing system, appears in Fig. 3. Six iterations were needed for the coordinates of the center of the circle and 42 and 39 iterations for the points of tangency to obtain errors less than or equal to 10^{-13} (ERR in the program). This operation is formidable if carried out on a desk calculator, but takes only five minutes on the time-sharing system.

Reference

[1] Scarborough, J. B., *Numerical Mathematical Analysis*, Johns Hopkins.

AUTEC—Atlantic undersea test and evaluation center

J. W. Martin | Dr. L. E. Mertens

On Andros, the largest of the picturesque Out Islands of the Bahamas, the U.S. Navy (in cooperation with the United Kingdom) has established a unique facility for testing new undersea technology and for weapons testing. AUTEC (Atlantic undersea test and evaluation center) contains three specialized ranges: a weapons-testing range, an acoustics measurements range, and a sonar-calibration range. All of the instrumentation and extensive support facilities required for AUTEC are maintained and operated by the RCA Service Company.

SUBMARINES, SURFACE SHIPS, TORPEDOES, and even remotely controlled torpedo-carrying helicopters have already been put through their paces at the mile-deep ranges off shore from Andros Island. Weapons systems of the British Royal Navy, as well as the U.S. Navy, are evaluated by AUTEC's complex network of acoustics, optics, and radar measuring instrumentation.

Purpose

The primary function of AUTEC is to measure accurately the performance of ASW (antisubmarine warfare) systems. The AUTEC mission, however, includes service to all undersea research and development programs of the U.S. Navy. The actual performance of complex undersea warfare systems is measured by high-precision instrumentation including independent radar, theodolite, and hydrophone networks and equipment to display, in near real time, positions of both in-air and in-water targets. The data obtained from such measurements can be used to:

1) Compare actual performance with intended performance and reveal deficiencies or weaknesses in the system.
2) Evaluate individual unit, component, and subsystem contribution to total system performance.
3) Identify improvements required in mission tactics, system parameters, personnel training, or operating procedures to enhance system performance.
4) Demonstrate the effectiveness of a system to perform as required in a real-world environment and assess its operational worth.

Location and facilities

The AUTEC ranges are located along the east coast of Andros Island only 150 miles southeast of Miami and 33 miles southwest of Nassau (Fig. 1a). A long narrow finger of the deep Atlantic Ocean, known as the Tongue of the Ocean (TOTO), penetrates far into the Bahama Banks in this area. The mile deep TOTO provides an almost ideal location for underwater testing. The TOTO is protected on all sides from the rough Atlantic by chains of islands and has relatively little ship traffic to disturb the sensitive testing instruments. Mile deep water closely parallels the entire eastern Andros shoreline. A near vertical escarpment plummets to these ocean depths within only one-half mile of the beach at many places.

Although Andros is the largest of the Bahama Islands, there is little industry, and the approximately 8,000 natives exist mainly on fishing. The island is cut by many shallow streams and bights making it impossible to drive from one end of the island to the other. In fact, it is impossible to drive between most of the down range instrumentation sites (see Fig. 1b). Supplies and personnel are transported by shallow-draft boats and helicopter from site 1 (called main base) to the remote stations.

Crystal-clear blue-green water surrounds the island. A live coral barrier reef, abounding with colorful tropical marine life, extends along almost the entire East Coast of Andros. This reef has been claimed to be second only to Australia's famous barrier reef. The island itself is a low lime rock formation pockmarked with large marshy

J. W. Martin, Mgr.
AUTEC Ranges
RCA Service Company
Cocoa Beach, Florida
holds the BS and MS in Physics with a minor in Business Administration. He joined RCA at the Missile Test Project, Cape Kennedy, Florida, in 1956 as Leader, Electronic Systems Development Engineering. In 1960, he transferred to BMEWS as Operations Manager for installation and evaluation of computer and display equipment. He returned to the Missile Test Project in 1961 as Manager, Radar Engineering. In 1964 he was promoted to Manager Signature Systems Engineering Support and then to Manager of Apollo Systems Project. He joined the AUTEC project in 1967 as Task-Force Manager reporting to the Vice President, RCA Government Services. Mr. Martin is a member of the IEEE.

Dr. L. E. Mertens
Chief Scientist
Missile Test Project
Eastern Test Range
RCA Service Company
Cocoa Beach, Fla.
has a staff responsibility for the RCA Scientific and technical work on the range. He is a technical consultant on the ARPA Advanced Sensors Programs and on range calibration for the AUTEC range. Prior to his present assignment he held a variety of positions with Defense Electronic Products, including Manager, Systems Engineering, Manager, Digital Communications Equipment Engineering, and on the technical staff of the Chief Defense Engineer.

Reprint RE-16-1-5
Final manuscript received January 15, 1970.

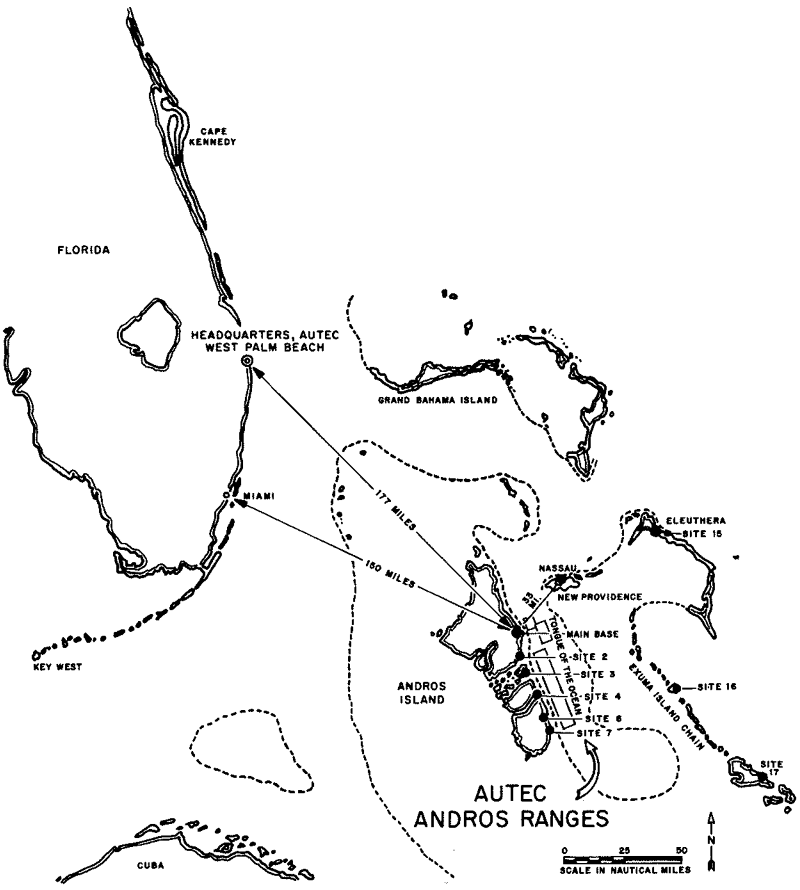


Fig. 1a—Autec area.

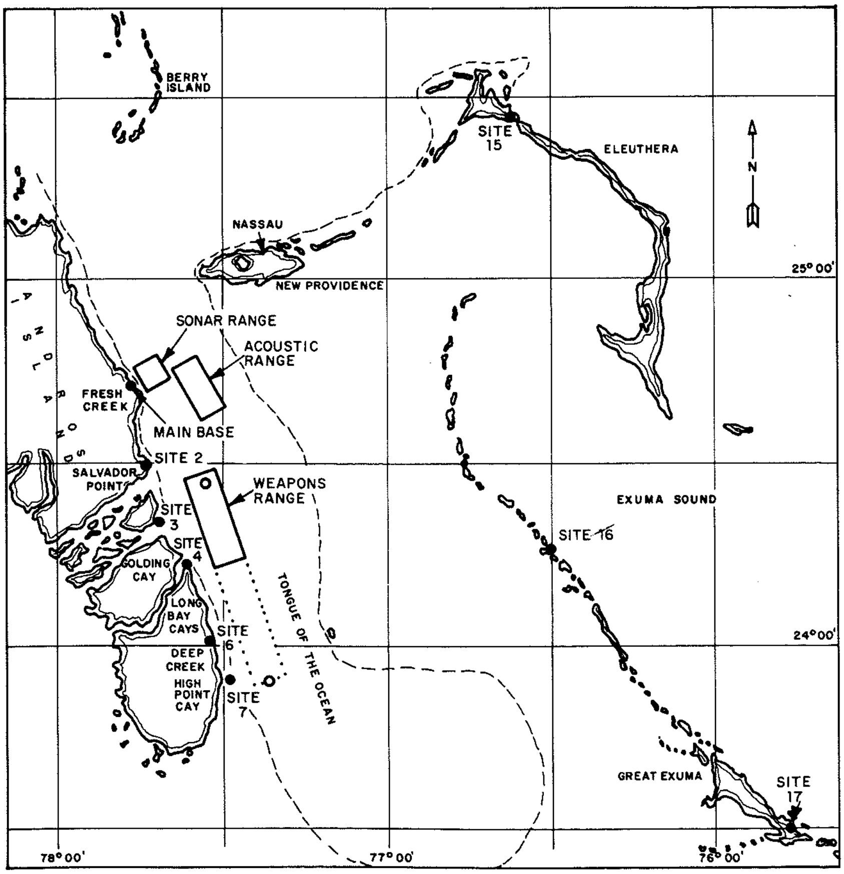


Fig. 1b—Andros ranges.

areas and numerous sink holes, which are enchanted according to many of the local inhabitants.

The Main Base is located near Androstown. Navy and RCA personnel are housed in modern air-conditioned barracks and a BOQ. Other Main Base facilities include a cafeteria, a waitress-service restaurant, snack bar, club, theater, base exchange, tennis courts, and a baseball field. A few houses and a small school are available in Androstown for those who have brought their families to the island. The Main Base (see Fig. 2) has a large harbor and channel dredged to 20 feet which is used for the AUTEC fleet of AVR's and TRB's (air/sea rescue vessels and torpedo recovery boats). These boats are used to support tests, recover torpedoes, make oceanographic measurements, deliver supplies, etc. Androstown has an airfield which was recently paved and features scheduled commercial service by Bahamas Airways and Mackey Air Taxi. In addition, AUTEC runs a DC-3 aircraft on a one or two round-trip/day schedule to West Palm Beach, Florida, where the AUTEC Headquarters is located.

Communications, data processing, and command control facilities are located at the "CC" building at the Main Base. An extensive weapons shop with capability for machining and assembly of mechanical parts as well as repair and calibration of electrical systems is also available (Fig. 3).

Weapons range

The Weapons Range is five miles wide and stretches 35 miles southward along the western edge of the TOTO. Surface ships and aircraft are tracked by shore-based instrumentation at five "down range" stations which are all located south of the Main Base. Fig. 4 shows that these stations—numbered 2, 3, 4, 6 and 7 (there is no Site 5)—form a tracking chain with a spacing of about 10 to 15 miles. Salvador Point, Gibson Cay, Golding Cay, Deep Creek, and High Point Cay are some of the fascinating Bahamian names used to identify the station locations. The Cays are all uninhabited except for the AUTEC technicians and can be reached only by boat or helicopter. Salvador Point and Deep Creek have small villages with only a few hundred inhabitants and virtually no facilities.

Only Salvador Point can be reached by road from the Main Base.

Optical tracking

All five of the down-range sites have Contraves Cine Theodolites for high accuracy in-air tracking (Fig. 5). Film from the theodolites is returned to the Main Base for photo processing, machine reading of the *x, y* target coordinates, and data reduction on the two CDC 3400 digital computers.

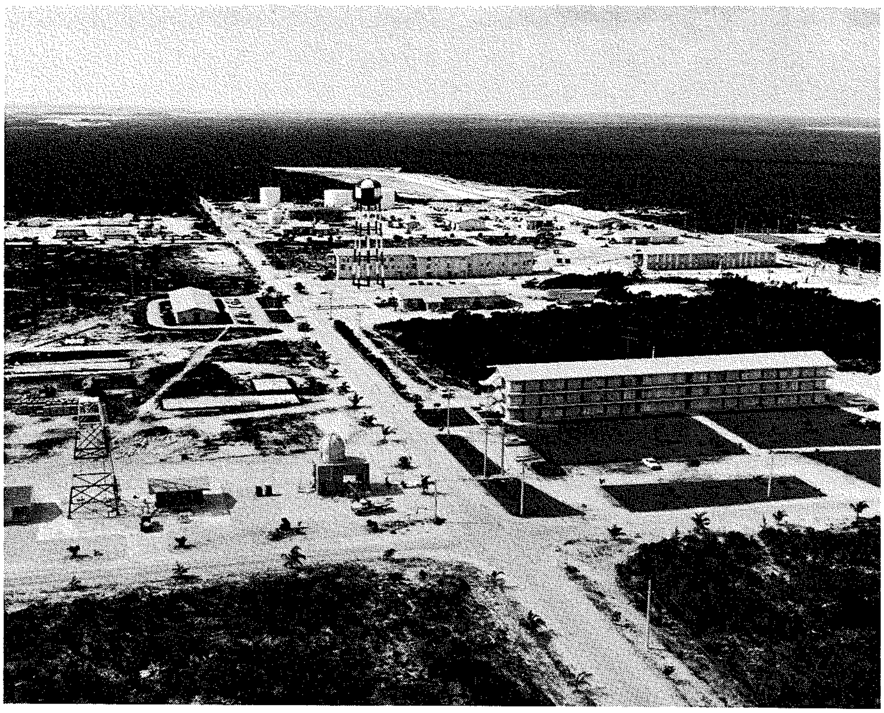
Radar tracking

Real-time in-air track is provided by MOD-V *X*-band tracking radars located at Sites 2 and 7. The radar data is sent by microwave relay to the Main Base where it is decoded, processed, and displayed on plotting boards in the control room. Radar data is also stored for later post-test processing and comparison with other test data.

Sonar tracking

In-water tracking is performed by networks of bottom-mounted hydrophones. The hydrophones are staggered so that each interior hydrophone is surrounded by 6 other hydrophones in the form of a hexagon. Signals from the hydrophones are amplified and filtered and sent by underwater cable to sites 3 and 4 for the large network and site 7 for the small network. The signals are further amplified, filtered, shaped, and recorded at the land-based stations. Times of arrival of acoustic pulses (pings) are encoded and sent by microwave to the Main Base where digital computers determine the *x, y, z* position of multiple targets in near real time. This position data can be displayed, along with the radar data, in the control room for use in conducting the test. Hydrophone data is also stored, in digital form, on magnetic tape for post-test analysis. Sufficient hardware does not exist to process simultaneously all target channels for all hydrophones. Consequently, computer control (or an optional manual control) is used to select the specific hydrophone arrays to be used for computation of trajectories.

Since tracking on the Weapons Range, for high accuracy, requires a large-signal-to-ambient-noise ratio, the target to be tracked through the hydrophone system (whether a submarine, surface vessel, or torpedo) must incorporate an acoustic pulse transmitter (pinger). The pinger sound projector, rather than the vehicle, is the point of track by the Weapons Range Hydrophone System as it moves through the TOTO. To allow coherent spherical computations of a target for each ping, a surface-vessel pinger may be synchronized with the range master and computer timing via a portable timing system and radio link to shore.



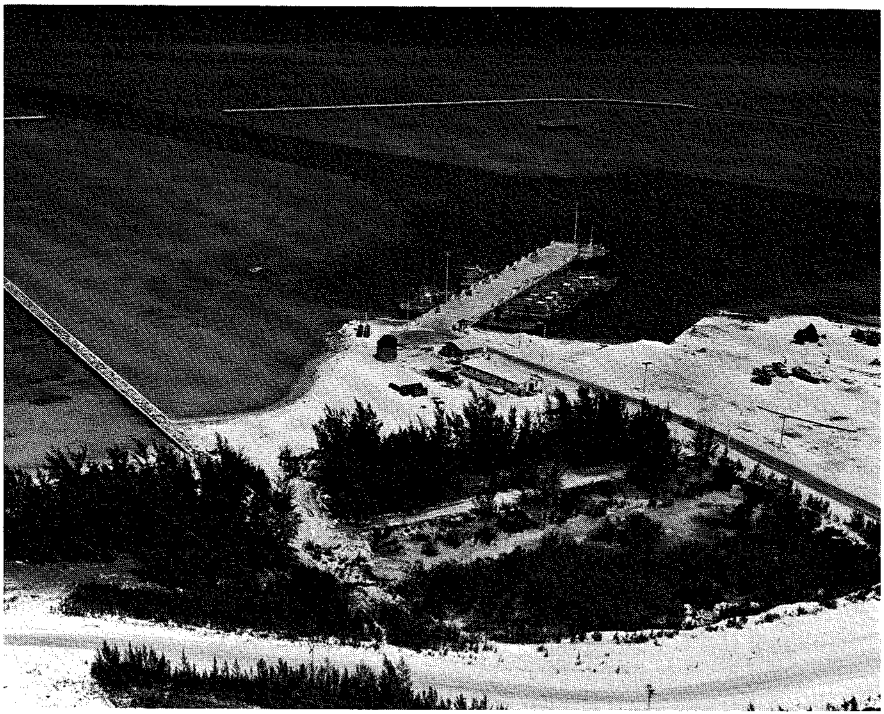


Fig. 2—Top photo is Main Base; bottom photo shows the harbor, channel, and breakwater at the Main Base.

The spherical tracking mode requires only three hydrophones to determine the target's position in three dimensions. Spherical tracking, however, requires synchronized time between the computer clock and pinger clock (i.e., a pinger for which the time of pulse emission is accurately established in relation to the computer timing). By knowing the pinger emission time and the pulse arrival times at three hydrophones, the sound travel times to each of these hydrophones can be determined. The three travel times are converted to corresponding slant ranges by means of accurate sound velocity profiles. The target position is then computed by trilateration from the three slant ranges and the accurately surveyed hydrophone positions.

Hyperbolic tracking is used when the "time-of-ping" is unknown; that is, the target's pinger is not synchronized with computer timing. In this case, the "time-of-reception" of the ping by each of four hydrophones is used to determine target location. The target is located by knowing the time difference of the pulse arrival at each of four hydrophones.

The process is quite similar to that used by interferometer baseline (range difference) cw radar systems. The four hydrophone-signal arrival times are used to determine three time differences which, in turn, are converted to three range differences using the sound-velocity profile. Each range difference can be considered to define a hyperboloid surface upon which the target pinger must lie. The common intersection point of the three hyperboloid surfaces is thus the pinger position. In the AUTEC system, a digital computer is used to solve the three range difference equations simultaneously for the three unknown coordinates (*x*, *y*, *z*) of the pinger.

The hyperbolic solution can also estimate the actual time of emission of the pinger pulse. If the pinger has a stable and known PRF, the emission times of succeeding pulses can also be predicted with good accuracy and spherical solutions can be then used for these pulses once the bias in time is determined and removed.

In-water tracking is, of course, more complex than indicated in this simple description: the relatively large variation of sound velocity with depth; the existence of large echoes or reverberations from the water surface and sea floor; and the many external noise sources are only a few of the problems encountered. A large portion of the real-time in-water tracking program involves selecting the best set of hydrophones, and insuring track on valid targets rather than echoes. Post-test processing programs have more computing time available; therefore, they can use more sophisticated selection logic, filters, and error-model data corrections to produce higher accuracy position and velocity data.

Other instrumentation

The Weapons Range contains other instrumentation including telemetry receivers, radio timing systems, an underwater communication system, and microwave communication for voice, as well as data, between the down range sites and the Main Base.

Future plans for Weapons Range

By the end of 1970, the Weapons Range test schedule should be fully saturated. Consideration has been given to extending the length of the range, and an additional range may also be required in nearby Exuma Sound which, like the TOTO range, has quiet, land-locked waters and allows opportunity for expansion.

There are plans to develop standard pingers for vessels and weapons. This would allow all the benefits of standardization, such as fewer items in inventory and easier maintenance.

Development of less expensive and more reliable hydrophones is planned. Experience gained in utilizing the present hydrophones will help to develop better deep-water instrumentation. To date all hydrophones have been 100% reliable. However, replacement of hydrophones is foreseen as a potential problem. The services of a deep submersible will be required to remove and replace a defective hydrophone—preferably in the same position.

Fig. 3—Inside the Weapons Shop.

Other future improvements to the range will include real-time calibration of the speed of sound. Hydrophone locations, water pressure, current velocity, and the speed of sound must be measured more accurately at key points to increase the total underwater-tracking accuracy.

Acoustics range

The Acoustics Range, north of the Weapons Range in the TOTO is near the Main Base (Fig. 1b). It is used to accurately measure and record the underwater acoustic noise radiated from ships, submarines, and torpedoes at various depths. The range is capable of tracking and recording the position of the vessel under test, thereby permitting the necessary sound propagation corrections to be applied. A sur-

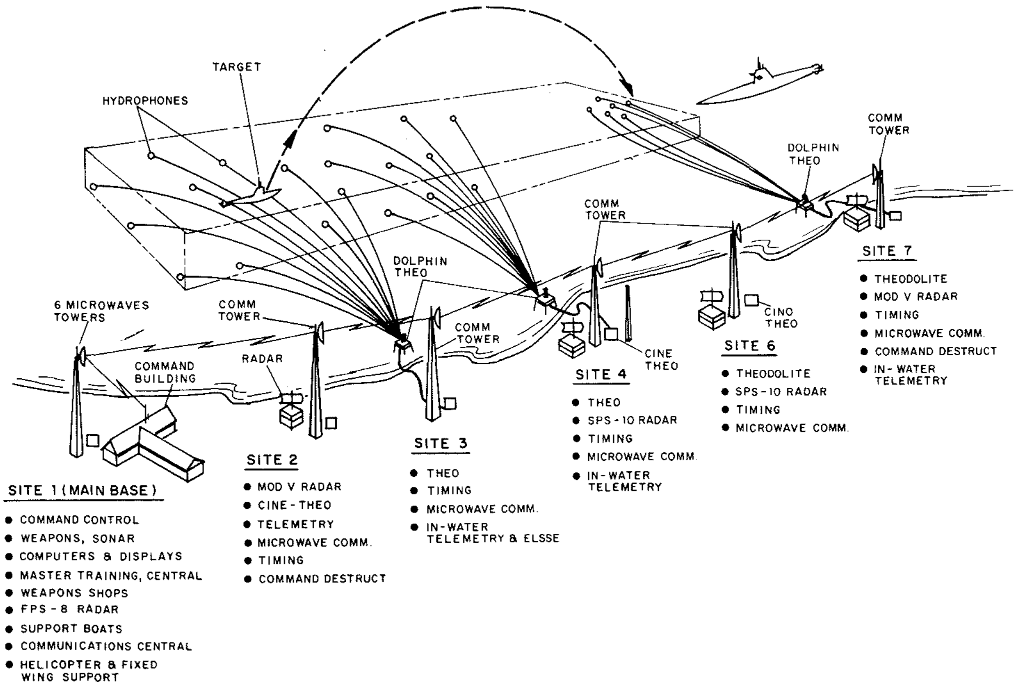


Fig. 4—The Weapons Range (5 miles wide x 35 miles long).

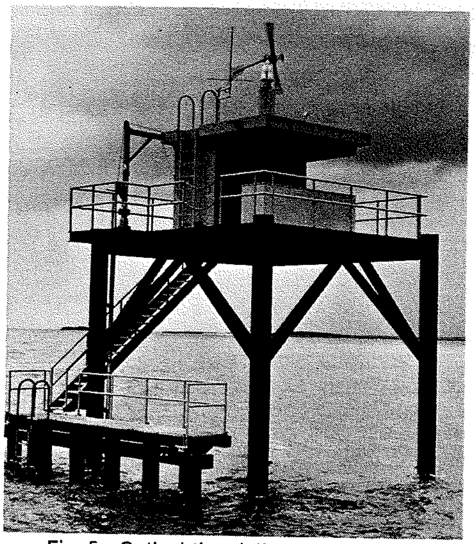


Fig. 5—Optical theodolite tower at the Sonar Range.

face area 5x10 nm and a depth of 6,000 feet are available to the Acoustics Range.

The principal instrumentation for this range is the AUTEC acoustic array which consists of one large, complex, bottom-mounted, vertical taut-wire array of cables, hydrophones, sensors, sonar targets, sonar beacons, underwater communication elements, a tracking array, anchors, and buoys. The array was installed in 6,000 feet of water in July 1962 and is connected into the Main Base computers via submarine cable. The mooring subsystem is permanently anchored to the bottom but is connected to the array in such a way that the array can be easily removed from the ocean and its acoustic devices replaced.

A series of vertically spaced hydrophones for measuring the noise spectrum at various aspect angles and depths are mounted on the array. The array is held in a nearly vertical position by means of a buoy which floats just below the sea surface. In addition to the hydrophones, the array includes communication transducers, passive sonar reflectors, acoustic beacons, and a tracking arm. This tracking arm is located near the bottom and has hydrophones capable of measuring arrival times from a pinger on the target ship for range-difference solutions of direction between the target and tracking arm. Deep sea currents can change the direction of the tracking arm; therefore, its orientation is monitored with a flux-gate compass.

Tracking information, together with the noise data, are sent to two CDC 1700 computers at Main Base by means of an underwater cable. The computers provide the range user with the intensity of the acoustic signal in one-third octave frequency bands throughout the spectrum of interest. Narrow-band analyses, using fast-Fourier transform techniques, can also be provided.

Sonar range

The Sonar Range, located northwest of the Acoustics Range, has a 5×5-nm surface area and depths to 4,000 feet (see Fig. 1b and 5). The Sonar Range first increment (SR-1) is fully operational and provides bearing and range calibration of shipborne:

Sonar,
Radar (both fire control and surface search),
Gyrocompass, and
Optical instruments (e.g., peloruses, periscopes, directors)

The SR-1 installation includes:

Three manually-operated optical tracking stations located offshore near the reef line;
A transit mounted on the deck and aligned to the centerline of the ship being tested and used as a bearing reference to compute the ship's true heading ;
Two passive radar targets;
Two deep sonar targets;
Two shallow sonar targets; and
An operating station in the Command Control Building, housing the sonar target receiver/transmitter electronics (transponder) and the computers.

Each sonar transponder can receive a ship's sonar pulse, add precise doppler shift and time delay, and retransmit the pulse back to the ship. This allows the ship's sonar operator to resolve the return pulse from reverberations without difficulty.

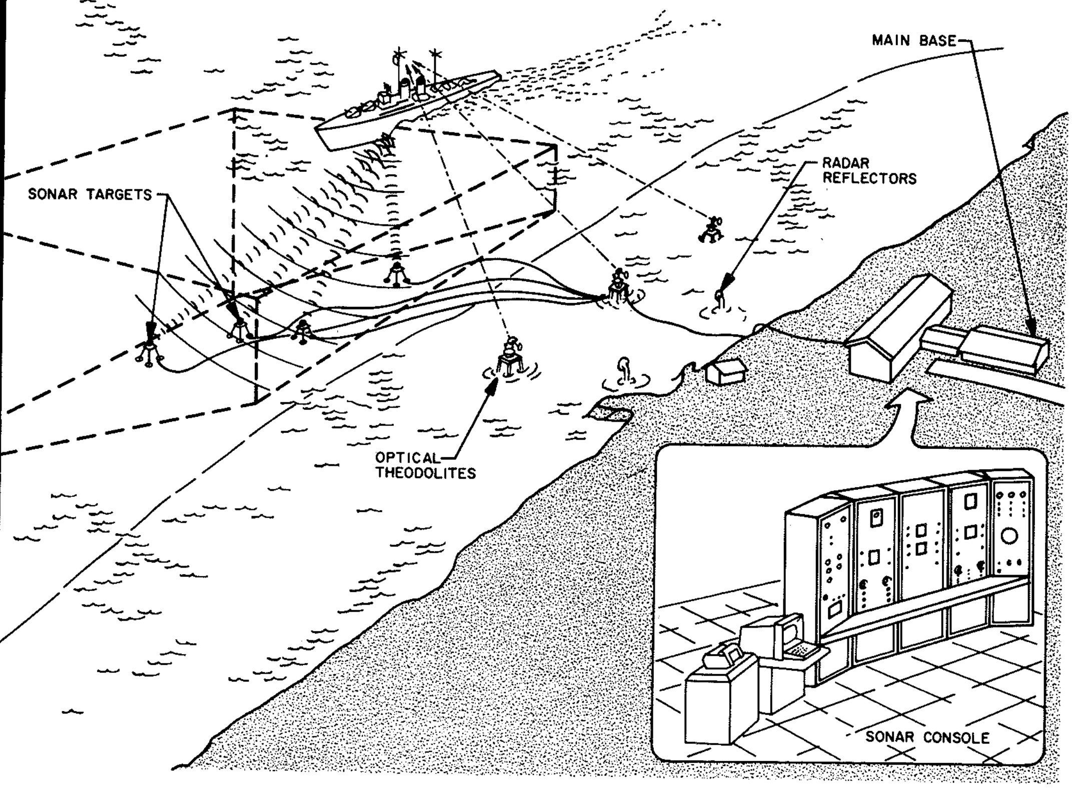


Fig. 6—Sonar Range operations.

An evaluation of the ship's passive sonar capabilities can be accomplished by detecting either of two types of transmissions:

1) A pure tone centered in the bandwidth of the ship's sonar.
2) A white noise signal with a 1-kHz bandwidth.

Sonar range and bearing error is determined from optical tracking data as the primary standard (one of the theodolite towers is shown in Fig. 6). The errors in ship fire control radar can be determined since its geometric position aboard ship is known with respect to the theodolite target (also on board). Sufficient tracking data is accumulated to allow statistical error analysis.

During the test, ship's courses are selected to provide (through variation in test geometries) relative bearings, sonar display options, sonar depression angles, and ship's headings.

Submerged submarines cannot be tracked for sonar calibration unless operating at periscope depth allowing the periscope to be tracked optically.

A sonar passive array is planned for addition to the Sonar Range. This will be a vertical taut-wire array with fixed bottom moor and top buoy just below the surface. The purpose of the Sonar Range extension will be to provide sonar directivity pattern measurements for ship or submarine sonars. A capability will then exist for both active and passive modes of testing.

The sonar passive array will be connected to shore-based instrumentation by submarine cable. Shore-based and shipboard data processors will reduce and record two types of data: ship's tracking information and sonar evaluation data. Tracking data will include ship's attitude from an on-board reference sensor and timing from AUTEC's central timing station. The shore-based reduction and recording facility will monitor data quality in real time and provide post-test reduction, including least-squares analyses. Also, the array will be used to investigate non-linearities and distortion in sonar signal patterns. This type of distortion could result from poor interfaces, such as is caused by hull, dome, transducer, medium, and display interdependencies.

Range safety

A Range Safety Officer (RSO) is stationed, during weapons range tests, at in-water and in-air displays located in the Main Base Command Control Building (see Fig. 7). Tracking information is provided to the RSO from the Weapons Range via microwave link. These data are provided from the Weapons Range hydrophones, the Main Base air search radar, sites 4 and 6 surface search radars, and the precision tracking radars at sites 2 and 7.

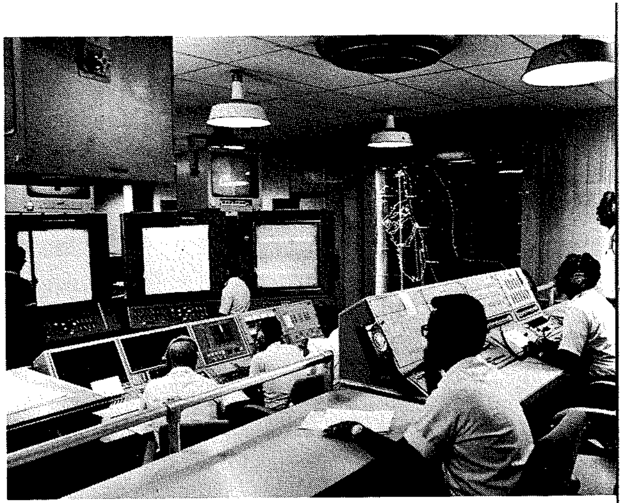


Fig. 7—Range safety and test control.

Surface craft

AUTEC has eleven surface craft stationed at the Main Base:

Five air/sea rescue personnel carriers (AVR), used to patrol the TOTO, clear the operating areas, and deliver supplies down range in emergencies;
One AVR, equipped with velocimeter and bathythermograph equipment to make measurements of the TOTO;
Two Torpedo Recovery Boats (TRB) for torpedo pickup capability (see Fig. 8).
A harbor freighter (YFRT) used as a range tender and to fire torpedoes.
A utility landing craft (LCM), used as a tug to dock the YFRT and, together with an LCU, can deliver water to down range sites.
A harbor tug (YTM-272) which can be converted for uses such as for oceanographic measurements.

Deep-moored test panel

During 1962, a Deep-Moored Test Panel Array was anchored by the Naval Research Laboratory in 5650 feet of water in the TOTO for three months to test corrosion and biological fouling. Various metal and non-metal panels were placed at different levels along a vertical length of ⅝ inch polypropylene line. Steel panels, some cathodically protected, were exposed in aluminum racks. Asbestos board and white pine panels were also used. At the end of the three-month test period the Deep-Moored Test Panel Array was removed; test panels were photographed and analyzed grossly in the field, then preserved in alcohol, and shipped to the Naval Oceanographic Office for more detailed study. Fouling organisms were found attached to the polypropylene line in moderate to severe amounts in the upper 325 feet, becoming slight to moderate to a depth of about 1,000 feet, and slight thereafter to about 5,200 feet. There was no attachment between 2,900 and 3,900 feet or below 5,200 feet. Test boards exposed directly on the bottom contained a boring mollusc.

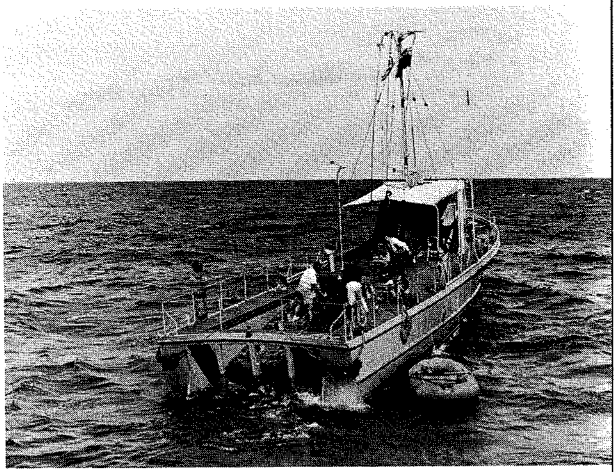


Fig. 8—Torpedo recovery boat.

These test material array studies are continuing in the TOTO. Two such arrays were installed during April 1967 at a depth of 4,200 feet. They will be exposed for a period of five years with alternate retrievals scheduled at yearly intervals. (Each year one of the arrays is to be removed from the ocean, investigated, and returned to its ocean station).

Summary

Activities of the Navy in the TOTO, although primarily for defense, promise to advance our knowledge of ocean environmental actions on materials and equipment.

The rapidly increasing number of test programs being assigned to AUTEC substantiates the need for such ranges. The benefits to oceanography will result from studies of the deep ocean, its topography, currents and acoustic properties. Benefits to ships and weapons design and development will insure rapid improvement in this state-of-the-art.

Combed aperture equalization for color TV cameras

R. R. Brooks | W. J. Cosgrove

Some types of luminance signals have strong frequency components that interfere with the chroma sidebands in a standard color TV signal. This paper describes a "combing" filter technique which effectively strengthens the luminance signal and reduces noise in that portion of the spectrum which coincides with the chroma sidebands.

THE COLOR AND LUMINANCE frequency components of the standard NTSC signal are spaced so that band sharing is optimized by interference cancellation by frequency interleaving. The relationship between the color subcarrier and the line-scanning rate is such that the chroma sidebands fall into spaces seldom used by the luminance signal. The two types of undesired luminance signals are:

1) Low visibility luminance components resulting from incomplete interference cancellation and
2) Luminance components that are very close in frequency to the chroma sidebands causing beats or scintillating effects when viewed on the color receiver. This also applies to the noise that may be present with the luminance signal.

This paper treats the latter problem. Unselective aperture equalization can strengthen luminance frequency components and noise in the spectrum that coincide with chroma sidebands.

By "combing" the aperture-correcting signal, pictures may be enhanced by an amount previously considered impractical without increasing the edge beats or luminance-chroma heterodyning.

The comb filter

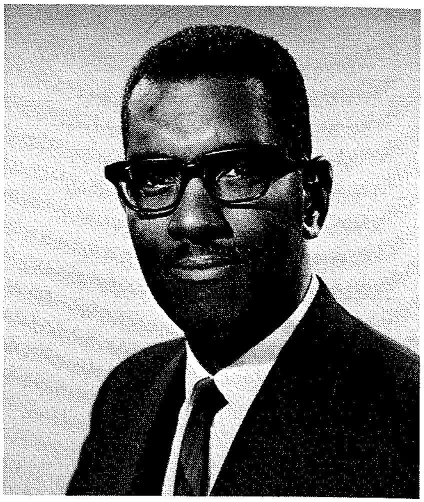
If the spectrum of a waveform is passed through a combed aperture equalizer which does combing at the nominal chroma sideband frequencies, those frequency components that would be coincident with sidebands of the chroma signal are eliminated. Thus, by "combing" the aperture-correcting signal, pictures may be enhanced by an amount heretofore considered impractical without increasing the edge beats or luminance-chroma heterodyning.

Fig. 1 shows a periodic filter with nulls occurring at 2τ intervals. If τ equals one horizontal line, the circuit becomes a vertical detail generator. If τ equals a small fraciton of a horizontal line, the circuit enhances horizontal transitions.

The periodic characteristic of the aperture equalizer is of particular interest when one considers that the chroma sidebands in a color TV system are interleaved in the spectrum for minimum interference.

The modulation envelope on the color subcarrier repeats itself every 1/30 second, so that all sidebands are separated in frequency from the carrier by multiples of 30 Hz. The color subcarrier is an odd multiple of 15 Hz, and the line scanning frequency is an even multiple of 15 Hz, (when locked to subcarrier as prescribed by the NTSC System). Hence, for video information that is the same every line, such as a color-bar pattern, the luminance and chrominance spectra are interleaved. An example of an interleaved spectrum is shown in Fig. 2.

For a stationary scene, the scanning process gives rise to signal components at harmonics of the 30-Hz picture rate. The largest components represent the vertical detail in the picture and are in groups centered about harmonics of the line scanning frequency. From the standpoint of band sharing between luminance and chroma components, those centered about harmonics of the line-scanning frequency are of interest.



R. R. BROOKS
Camera Engineering
Commercial Electronics Systems Division
Camden, N. J.

graduated from Hampton Institute in Virginia in 1952 receiving a BS in Industrial Arts and an ROTC commission; this was followed by two years of military service as an Army Artillery Communications officer. He received the BSEE from Howard University in 1959, and as a participant in RCA's Graduate Study Program, received an MSEE in 1964 from the University of Pennsylvania. In 1959, he joined the Industrial Electronics Products Division as a Design and Development Engineer. Subsequent assignments included work in the Communications Systems Division where he was granted patents for work on a digital frequency synthesizer for the AN/ARC-104. He has been associated with CESD camera engineering since 1964. His contributions since then have resulted in four patents for work on color camera, and a joint disclosure of the concept discussed in this paper.

W. J. COSGROVE
Camera Engineering
Commercial Electronics Systems Division
Camden, N. J.

received the BSEE from Pennsylvania Military College in 1957, and was employed by Frankford Arsenal in Philadelphia where he worked in the Advanced Development Group on a low-light level TV system for fire control. In 1960, he joined the RCA Camera Advanced Development Group in Camden where he worked on the development of a 4-tube camera system. Since 1962, he has been in the Camera Design Group in Camden where his prime responsibilities have been circuit design and evaluation for TK-12, TK-42 and TK-44A Camera Systems. He has completed courses for a MSEE at the University of Pennsylvania and holds four U. S. patents.

Reprint RE-16-1-15
Final manuscript received November 18, 1969.

Moving images lead to the possibility of frequency components anywhere in the video spectrum—the fundamental frequency depending on the amount of motion. The interference produced in this case, however, is less noticeable because it is moving. Of particular interest for this paper is the interference that can occur for certain types of stationary signals.

Fourier analysis shows that a luminance signal with frequency components that are very close to the chroma sidebands may be obtained with a repetitive burst of sinusoids. Diagonal lines, stripes, or wedges in any direction also cause interference patterns due to their diffuse spectra.

It can also be shown that, because of the periodic nature of the aperture corrector, the luminance frequency components in the interference-type pattern that coincide with the chroma sidebands may be made stronger. This, of course, will make the noise and beat patterns more objectionable.

To illustrate this, consider first the vertical stripes shown in Fig. 3. The stripes are chosen with black-to-white-to-black periods equal to 0.3 μs. For this analysis the horizontal vertical blanking interval will not be considered. However, the contribution of pedestal, sync pulses and the vertical blanking interval to the spectra has been shown in the literature.[1] The most significant of these is the vertical blanking which, when included, occurs as sidebands around each of the 15.734-kHz harmonics at multiples of 60 Hz with amplitudes significantly below the 15.734-kHz component. The type of signals that we considered here are stationary and are repeated every 1/30 second. Since the luminance-signal scanning rate is an even multiple of 15 Hz and the chroma sidebands are odd multiples of 15 Hz, the two signals can never, for stationary signals, become closer to each other than 15 Hz. However, 15 Hz is close enough to cause the undesired visible effects described as beats and scintillation. The Fourier Analysis of the continuous signal will show as "coincident" those components that are within 15 Hz of each other.

The coefficients, A_n and B_n, of the Fourier series for the periodic bursts of sinusoids shown in Fig. 4, are derived in the Appendix and are

$$A_n=\frac{1}{T}\left[\frac{\sin \chi\, t_c}{\chi}+\frac{\sin y\, t_c}{y}\right] \tag{1}$$

$$B_n=\frac{1}{T}\left[\frac{1-\cos \chi\, t_c}{\chi}+\frac{1-\cos y\, t_c}{y}\right] \tag{2}$$

The components of the series

$$X(t)=\frac{A_o}{2}+\sum_{n=1}^{\infty}(A_n \cos n\omega t+B_n \sin n\omega t) \tag{3}$$

for $n = 355$ to $n = 556$ were calculated with the aid of a computer and are shown in Fig. 5. Notice that the spectral lines are interleaved with chroma sidebands. Every tenth component is plotted for clarity.

Now, if the stripes are turned on a diagonal, the duration between corresponding pulses of adjacent lines would be one horizontal line, plus or minus the displacement due to the slant, as illustrated in Fig. 6. The distance Δt between a point on a sinusoid of the burst and a corresponding point on its neighbor on the next line can be calculated as:

$$\Delta t=\left[\frac{\tan \theta}{(245)\,(1.33)}\right](53\times 10^{-6})$$
$$=0.162 \tan^{\theta} \tag{4}$$

where 245 is the number of active lines, 1.33 is the aspect ratio, and 53×10^{-6} is the duration of active lines.

The angle of interest is the angle, θ, that would cause a $\Delta t = ½$ subcarrier period (or $\Delta t = 0.139683$):

$$\theta=\tan^{-1}\frac{\Delta t}{0.162}=40.8° \tag{5}$$

If we, therefore, position the stripes at 40.8° from the vertical axis, spectral lines will occur for which many will fall coincident with chroma sidebands. For the diagonal stripes of Fig. 6 with the angle of 40.8°, the time between successive bursts would be $T = 63.5555 + \Delta t = 455\ (0.139683 + 0.139683/455)$ microseconds.

To calculate the effect of rotating the stripes for observing the shift of the frequency components let

$$T=(455)\,(0.139683)\,[1+(\cos \Phi)/455] \tag{6}$$

By substituting values of T from Eq. 6 into Eq. 3, a series for each of four different angles were computed.

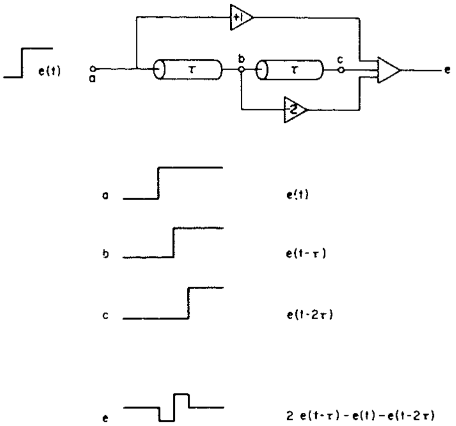


Fig. 1—Functional notation identifying aperture equalizer signals; $e(t)$ = undelayed signal; $e(t-\tau)$ = signal delayed $\tau\mu$s.

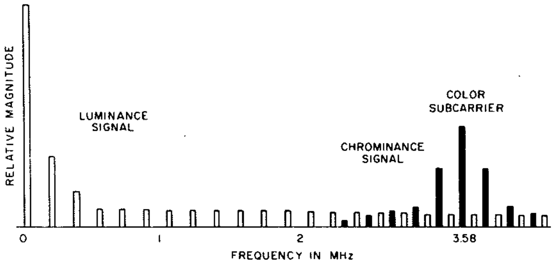


Fig. 2—Video spectrum showing interleaved luminance and chrominance components.

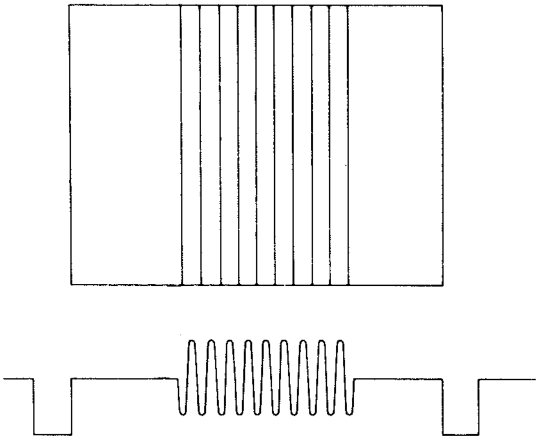


Fig. 3—Vertical stripes and electrical waveform at line rate.

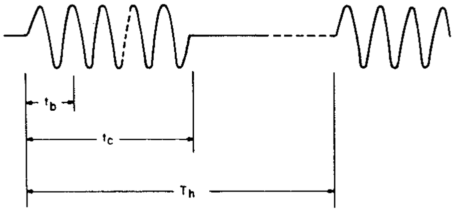


Fig. 4—Repetitive burst of sinusoids.

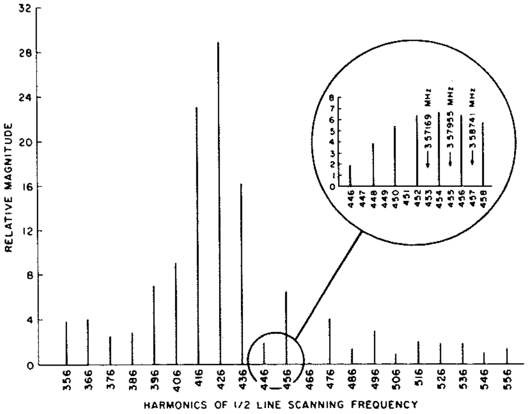


Fig. 5—High frequency portion of spectrum of vertical stripes. Every 10th harmonic shown. Balloon shows every harmonic between 446 and 458.

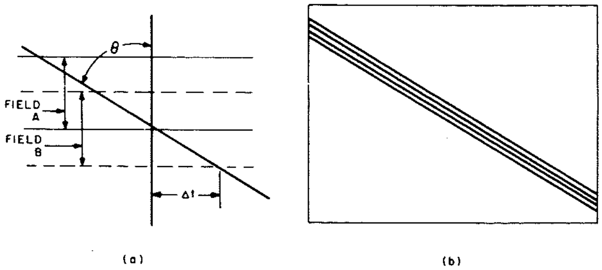


Fig. 6—(a) detail of CNE transition for stripes at (b).

Fig. 7 shows the movement of the frequency components of the diagonal lines for Φ = 0° (critical angle), 30°, 60°, and 90°.

The actual angles to which the lines have been rotated may be calculated from Eq. 5 as

$$\theta = \tan^{-1} \frac{\Delta t}{0.162}$$

$$\theta = \tan^{-1} \frac{0.139683 \cos \Phi}{0.162} \qquad (7)$$

Hence, for

$\Phi = 0°$, $\theta = 40.8°$
$\Phi = 30°$, $\theta = 36.7°$
$\Phi = 60°$, $\theta = 23.3°$
$\Phi = 90°$, $\theta = 0°$ (vertical stripes)

Note that now there occur lines in the frequency spectrum, when θ = 40.8°, where the chrominance sidebands would be.

At this point it would be of interest to pass this signal through a horizontal-aperture corrector that has as its frequency of maximum boost 3.58 MHz. The subcarrier frequency was used for illustration. It should be noted that frequency components are generated that would interfere with chroma sidebands at all angles for which Δt is a period equal to any odd multiple of one half the line scanning frequency.

Recall that the circuit of Fig. 1 has, as its frequency of maximum boost, the reciprocal of twice the delay-line length. Thus, for boost at 3.58 MHz,

$$\tau = 1/(2 \times 3.579545) = 0.139683 \qquad (8)$$

The spectra of the horizontal stripes after passing through the aperture corrector may be obtained by vector addition of harmonics of like frequency as they appear at the output. Vector addition requires knowledge of the relative phase angles of each of the harmonics being added.

Applying the notation introduced in Fig. 1 to the diagonal stripes to obtain Fourier-series coefficients with the correct phase relationships we get the following:

$$e_o = 2\, e(t-\tau) - e(t) - e(t-2\tau) \qquad (9)$$

By introducing a change of variable [$t = t' - x$] in Eq. 3:

$$X(t'-\chi) = \sum_{n=1}^{\infty} \frac{a_n \exp\left[-j\,\frac{2_n\pi(t'-\chi)}{T}\right]}{n} \qquad (10)$$

where $\chi = 0$, τ, or 2τ, and a_n is the complex form of the Fourier coefficient defined in Eq. 1.

Using the result of equation (10), the output spectrum can be obtained by vector addition of all components as they appear at the output.

The computed results for the horizontal aperture corrector is plotted Fig. 8. Note that the amplitude of the frequency components remain relatively constant when the stripes are rotated. A vertical aperture corrector would, in practice, normally be narrow banded but it would be instructive to see what the spectral content of this same signal would be through a wideband vertical aperture corrector. To do this refer to Fig. 1 again and let τ = one horizontal line.

The computed results are shown plotted in Fig. 9. It is interesting to note that the detail signal is now "combed" but the frequency components are strongest that coincide exactly with the chroma sidebands. To illustrate this effect spatially, the phase relationship on adjacent lines of a continuous sinusoid subcarrier, broken up by the scanning system, is shown in Fig. 10.

In the vertical aperture corrector, line 2 is inverted and added to ½ the sum of lines 1 and 3. The result is a maximum for the chroma subcarrier and all frequencies that are odd multiples of ½ the line-scanning frequency. But observe what happens if line 2 is delayed 180°. The sum described above becomes zero for subcarrier and every multiple of ½ the line frequency. We have just described the basic element of the combed aperture equalizer.

The functional block diagram of the combed aperture equalizer is shown in Fig. 11. "Combing" and horizontal aperture correction are accomplished by inserting a delay line between the output circuit of amplifier 2 and the output terminal. The receiving end of the delay line is terminated by a resistor which is of a value relative to the characteristic impedance of the line to prevent reflections of the wave energy impressed on the sending end of the delay line. The sending end of the delay line is terminated by an impedance higher than the characteristic impedance of the line, to cause reflections of wave energy impressed on the receiving end of the line.

Delay line 3 must be selected to have a delay time substantially equal to the time of 180° of the frequency to be combed. In this case, the subcarrier frequency, approximately 3.58 MHz, is to be "combed" so the length

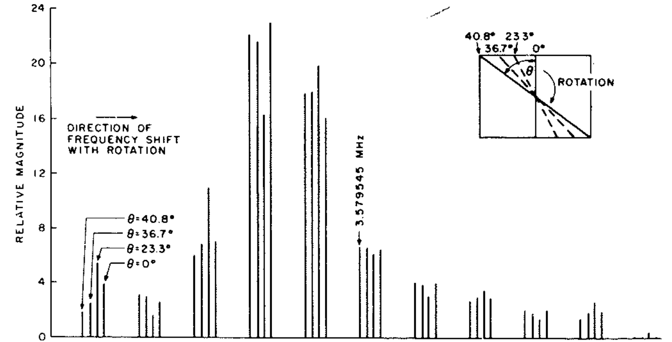


Fig. 7—High frequency portion of spectra of diagonal stripes as they are rotated away from an angle that generates components coincident with chroma sidebands. Spectra for four discrete angles are shown.

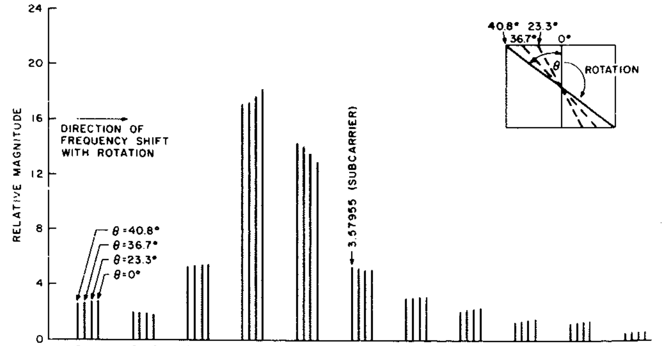


Fig. 8—High frequency portion of diagonal stripes through horizontal aperture corrector. Spectral lines move to the right as stripes are rotated.

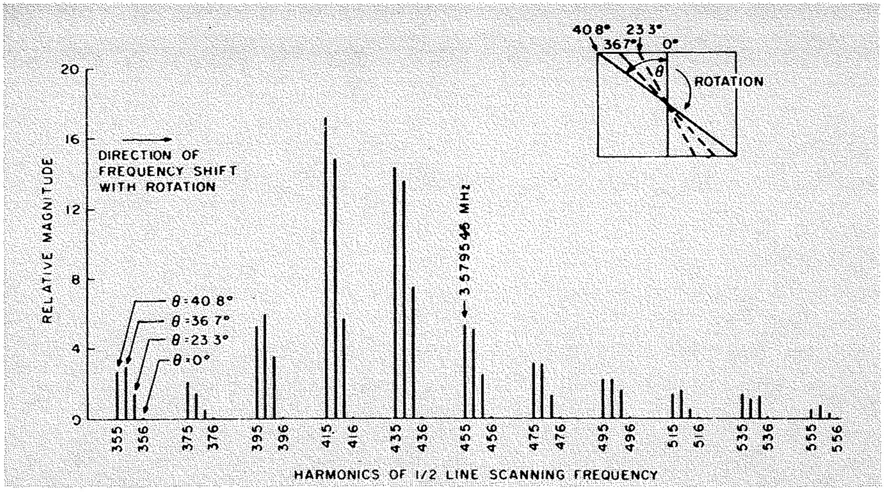


Fig. 9—High frequency portion of spectrum of diagonal stripes at output of a wide band vertical aperture equalizer.

of the delay line is equal to one-half the period of that frequency, or approximately 0.140 microsecond.

The subcarrier frequency is an odd multiple of one-half the line scanning frequency and is, therefore, 180° out of phase on alternate lines in a given field. The video signals appearing at inputs *B*, *A*, and *C* of amplifiers 1 and 2 are derived from the line under consideration and the lines immediately preceding and succeeding the line under consideration, respectively.

$$2_n \quad (t-\chi)$$

The delay line 3 is inserted in the *B* input circuit path before the summation of the signals appearing at input circuits *A*, *B*, and *C*. Thus, the signal appearing at the *B* input circuit is delayed 180° at the subcarrier frequency. At the subcarrier frequency and at multiples of the line scanning frequency intervals around the subcarrier frequency the function $B - \frac{1}{2}(A + C)$ is equal to zero. The signals from the amplifier 1 are impressed on delay line 3, and travel to the sending end from which they are reflected back to the receiving end where they additively combine with the unreflected signals from the amplifier 1 and the signals from amplifier 2. It should be noted that the delay time of delay line 3 is very small relative to the delay time of 1H delay lines 1 and 2 so that vertical aperture correction signal has been "combed" at the color frequencies and is thereby contained only in the luminance portions of the video frequency spectrum. In this manner certain high frequency noise in the correction signal is reduced and, therefore, will not show up as low frequency noise in the color signal as a result of heterodyning in the receiver chroma demodulator.

Horizontal aperture correction is accomplished by peaking the higher frequencies within the video bandwidth, which will sharpen the detail of the video signal in a horizontal direction. The first component is the output of amplifier 1. The second component is the signal appearing at the output of amplifier 2 which has been delayed by delay line 3. The third component is the result of a reflection of the component at the terminated receiving end of delay line 3 from the open-circuited sending end.

With the delay time of delay line 3 equal to one-half the period of the subcarrier frequency, the three components will result in zero correction signal at the subcarrier frequency, and the addition of the components will result in maximum peaking of the luminance signal around the subcarrier frequency—except at the previously mentioned periodic null points produced by combing. The components of any frequency appearing at either end and terminated to be reflective at the other, will always be either in phase or 180° out of phase with each other. This characteristic of the delay line which results in a linear phase-versus-frequency response enables the aperture correction signal to have a linear phase-versus-frequency characteristic. The result is symmetrical correction of the video signal for all frequencies within the video bandwidth.

Just as was done for the horizontal and vertical aperture equalizer, the response of the combed aperture equalizer will be obtained for the spectrum of the diagonal stripes. That is, vector addition of the frequency components appearing at the output by means of complex Fourier analysis. The phase relationships of the signals are obtained for Fig. 11.

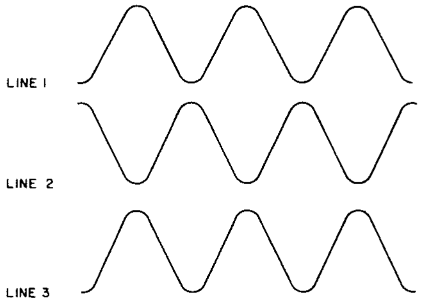


Fig. 10—Phase relationship of subcarrier on adjacent lines.

$$A=e(t) \tag{11}$$

$$B=e(t-H) \tag{12}$$

$$C=e(t-2H) \tag{13}$$

$$e_o=4\,e(t-H-\tau)+e(t)+e(t-2H)-e(t-2\tau)+e(t-2H-2\tau) \tag{14}$$

In a manner similar to that used in Eq. (10) the spectrum is obtained.

The computed result is shown in Fig. 12. Note that unlike Fig. 8, the lines that would be coincident with chroma sidebands are missing! The chroma sidebands of a stationary picture would be exact odd multiples of ½ the line scanning frequency. As the graphs show, the luminance spectrum of the diagonal stripes is more diffuse. For those components that do coincide, the output of the combed equalizer is nil.

The result is horizontal and vertical aperture correction with that portion of the signal that should have low visibility, practically undisturbed.

Evaluation of combing technique

The question may be justifiably raised at this point, about the subjective enhancement of the picture of the combed equalization versus the not

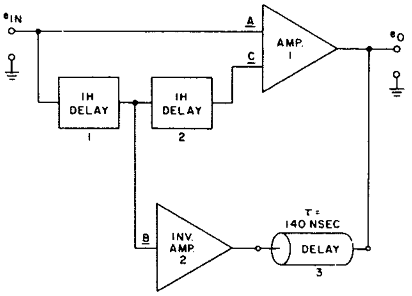


Fig. 11—The combed aperture equalizer.

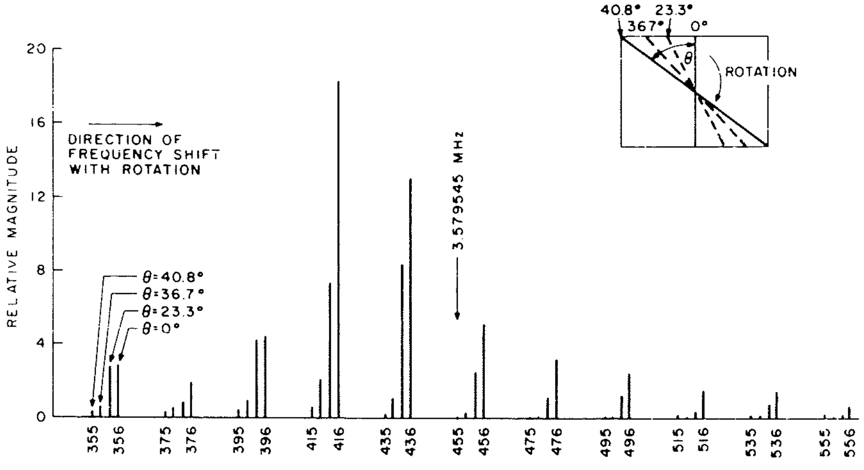


Fig. 12—Spectrum of combed equalizer output for diagonal stripes.

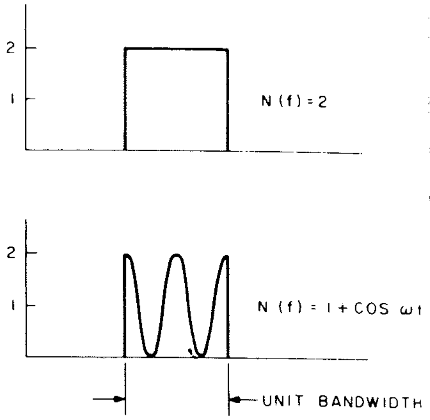


Fig. 13—Comparative shapes of noise responses per unit bandwidth of combed and conventional equalizer.

combed. Our findings are that the picture has as much "snap" when the same peak-to-peak equalization is applied, but is significantly more pleasing due to the reduction of noise and beats when switched from the not-combed to the combed equalization.

In an effort to assign meaningful numbers to the noise reduction due to combing, the noise on the blue cathode of a television monitor kinescope was observed for both conditions. The blue cathode was chosen because it is where the low frequency demodulation products of the noise signal appear. In both cases, the detail signal was generated and processed the same way. In the test setup, by switching to horizontal aperture correction only the combing was eliminated.

The theoretically obtainable improvement in S/N is 4.26dB, since the frequency response of the aperture corrector is changed from continuous to sinusoidally notched. (See to Fig. 13).

A noise waveform is a fluctuating, unpredictable signal which, nevertheless, has a mean-square value which is essentially constant over appropriate averaging times. Since the mean-square value is dependent upon bandwidth, it is convenient to restrict the observation to an arbitrary unit bandwidth and compare the mean-square value of the noise that would be in a continuous spectrum with that in the same bandwidth after it has been sinusoidally "combed". For the rectangle of Fig. 13 the mean-square value is the square of the amplitude divided by 1:

$$P_n = N(f)^2/1 = 4 \qquad (15)$$

If the same bandwidth is combed as shown in the lower part of Fig. 14, the noise power reduces to

$$P_n = \frac{1}{2\pi}\int_0^{2\pi} (1+\cos\omega\, t)^2\, d\,(\omega t) \qquad (16)$$

$$= \frac{1}{2\pi}\Big[\omega t + 2\omega t\, sin\, \omega t + \tfrac{1}{2}\,(\omega t - \omega t \cos \omega t)\Big]\Big|_0^{2\pi}$$

$$= \frac{1}{2\pi}\Big[\frac{3}{2}\,\omega t\Big]\Big|_0^{2\pi} = 1.5$$

Hence, the noise reduction is 4/1.5 = 4.26dB it was determined experimentally that at least 3dB noise reduction in the aperture correcting signal has been obtained.

Conclusion

Combing the detail signal generated for horizontal and vertical aperture correction in color television cameras can significantly reduce the undesirable demodulation products that occur in a receiver due to the presence of the contaminants in the contour signal described.

Appendix—Derivation of Fourier series for the periodic bursts of sinusoids of Fig. 4.

$$X(t) = \sum_{n=0}^{\infty} a_n \frac{\exp\,(jn\,\omega\, t)}{n}$$

$$= \frac{A_0}{2} + \sum_{n=1}^{\infty} (A_n \cos n\,\omega\, t + B_n \sin n\,\omega\, t)$$

where $A_0 = 0$ since there is no DC term

$$A_n = \frac{1}{T}\int_0^T f\,(t)\,\cos n\,\omega\, t\; dt$$

and $f(t) = cos\ \omega_h\ t$

so that

$$A_n = \frac{1}{T}\int_0^{t_c} (\cos \omega_b\, t \sin n\, \omega_h\, t)\, dt$$

$$= \frac{1}{T}\left[\frac{\sin\,(\omega_b + n\,\omega_h)\,t_c}{(\omega_b + n\,\omega_h)} + \frac{\sin\,(\omega_b - n\,\omega_h)\,t_c}{(\omega_b - n\,\omega_h)}\right]$$

and

$$B_n = \frac{1}{T}\int_0^{t_c} (cos\ \omega_b\, t \sin n\, \omega_h\, t)\, dt$$

$$= \frac{1}{T}\left[\frac{1-\cos\,(\omega_b + n\,\omega_h)\,t_c}{(\omega_b + n\,\omega_h)} + \frac{1-\cos\,(\omega_b - n\,\omega_h)\,t_c}{\omega_b - n\omega_h}\right]$$

Rearranging and identifying quantities in terms of the Television system parameters and Fig. 4 we have

$$\omega_b = \frac{2\pi}{t_b}$$

$$n\,\omega_h = \frac{2\pi_h}{t_h} = 2\pi\left(\frac{n}{910}\right)\left(\frac{1}{0.139683}\right)$$

Let $\omega_b + n\,\omega_h = \chi$ and $\omega_b - n\,\omega_b = y$; so that,

$$A_n = \frac{1}{T}\left\{\frac{\sin \chi\, t_c}{\chi} + \frac{\sin y\, t_c}{y}\right\}$$

$$B_n = \frac{1}{T}\left\{\frac{1-\cos \chi t_c}{\chi} + \frac{1 \cos y\, t_c}{y}\right\}$$

A plot of a portion of the spectrum in the vicinity of subcarrier is shown in Fig. 5.

References

1. Fink, Donald G. *Color Television Standards* (McGraw-Hill, 1955).
2. Hazeltine Staff, *Principals of Color Television* (Wiley, 1956).
3. Gibson, W. G. and Schroeder, A. C., "A Vertical Aperture Equalizer For Television" *Journal of the SMPTE* Vol. 69, No. 6 (June 1960).

Laser intrusion alarm techniques

D. G. Herzog

Intrusion detection techniques are gaining importance due to the need for defense of extensive perimeters in Southeast Asia. The laser intrusion-alarm system provides an efficient, reliable, cost-effective method of detection for perimeter defense. RCA Advanced Technology Laboratories has effectively applied injection lasers to this application; this paper describes several of these systems.

In past conflicts, a major objective was to strive continuously to capture more and more territory from the enemy. However, in the present action in Southeast Asia, the maintenance and protection of secured areas is of prime importance. This has placed increased emphasis on intrusion-detection techniques.

The sentry had been the main source of intrusion detection. But he is limited to the area he can cover with his unaided vision and hearing. Intrusion alarm aids such as telescopes and microphones can be used to extend the capabilities of the sentry. However, an intrusion-alarm *aid* only helps the human to make a decision, whereas an intrusion-alarm *system* can be designed to make decisions. In some cases where the intrusion can be pinpointed, immediate automatic defensive action can be taken. An example of this is a pressure-sensitive mine which detects the intrusion, makes the decision, and takes defensive action.

Detection techniques

Intrusion detection techniques generally fall into the following categories:

1) *Eletromagnetic*—classical radar and doppler detection radars;
2) *Acoustic*—microphones and geophones to detect ground vibration;
3) *Mechanical*—pressure transducers and trip wires which break easily to provide electrical signals; and
4) *Optical*—laser break-beams and reconstructed imagery such as TV

Each of these approaches contains a number of the capabilities desired for all intrusion detection systems; these capabilities are:

1) Long range of detection
2) Low power consumption
3) Low false alarm rate
4) All-weather operation
5) Easy, convenient monitoring
6) Detection memory
7) Long life
8) High maintainability
9) Not easily susceptible to countermeasures

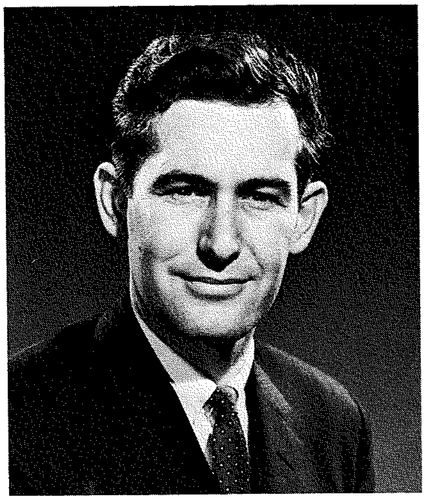
Over the past three years, Advanced Technology Laboratories has increasingly applied injection lasers in break-beam systems for intrusion detection which meet most of the above requirements.

System description

The laser intrusion-alarm system (Fig. 1) consists of four basic components: 1) transmitter, 2) receiver,)3 transmission media, and 4) annunciator. It works similar to the broken-light-beam automatic door openers used in stores. The receiver detects the light beam radiated by the transmitter; as long as the beam is detected, the system is inoperative. When the beam is broken, the system is activated to open the door. In a sense, the light beam is replaced by the laser beam in the intrusion-alarm application. The block diagram of a laser intrusion-alarm system is shown in Fig. 2.

Transmitter

The injection laser is a semiconductor diode made of gallium arsenide (*GaAs*). Light is emitted from the junction of the diode when current is passed in the forward diode direction. Fig. 3 shows the light output characteristics of an RCA TA2829 laser diode as a function of diode current. Where the light-current slope is low, the initial light output (spontaneous



Donald G. Herzog, Ldr.
Laser Group
Advanced Technology Laboratories
Defense Electronic Products
Camden, N.J.

attended Drexel Institute of Technology from 1953 to 1959 under the cooperative program. His cooperative periods were spent at Fort Monmouth Research Laboratories. He received the BSEE in 1959. In 1963 he received the MSEE from Drexel. Mr. Herzog joined RCA in 1959 in the Receiver Group of the Missile and Surface Radar Division at Moorestown. He performed major design work on the BMEWS system, the FPS-16 radar, and MIPER radar receivers. He also performed many study programs in the radar receiver area. In 1963 Mr. Herzog transferred to Advanced Technology Laboratories where he was promoted to Leader of the Laser Group in 1966. Under his direction, injection laser intrusion alarm systems were developed. Rapid advances in this area stemmed from developing unique efficient laser drivers and ultrasensitive optical detectors. In parallel with this effort was the development of advanced full-duplex voice communication systems using lasers. These units were very small and portable with operating ranges of 8 miles. A laser tracker and ranging unit designed under Mr. Herzog's direction for NASA for moon operation can scan dynamically, track with 0.06° accuracy, and range with ½ meter accuracy to beyond 1000 meters. Many different types of laser gated viewing systems were also developed. These units vary from handheld, battery powered to large wide-angle airborne equipment. Another airborne system developed is a laser line scan unit using an Nd laser source. This system can perform imaging and ranging functions. Mr. Herzog is now developing passive detector systems, near and far IR active reconnaissance systems, optical IFF techniques using liquid crystals, and advanced laser modulation techniques. Mr. Herzog is a member of IEEE and Eta Kappa Nu.

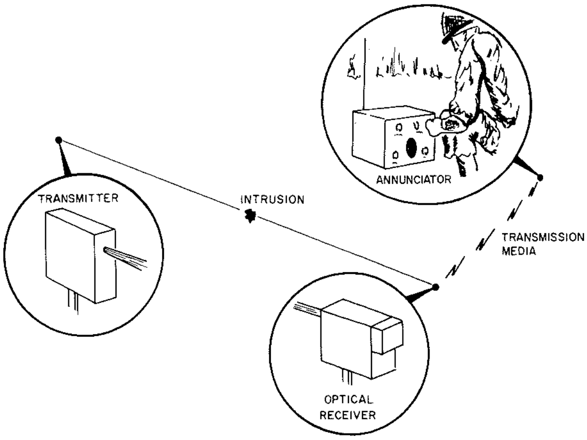


Fig. 1—Laser intrusion-alarm concept. Invisible light beam exists between transmitter and receiver; an intrusion breaks the beam, triggering the receiver to radio an alarm to a remote monitoring location.

Reprint RE-16-1-13
Final manuscript received October 31, 1969

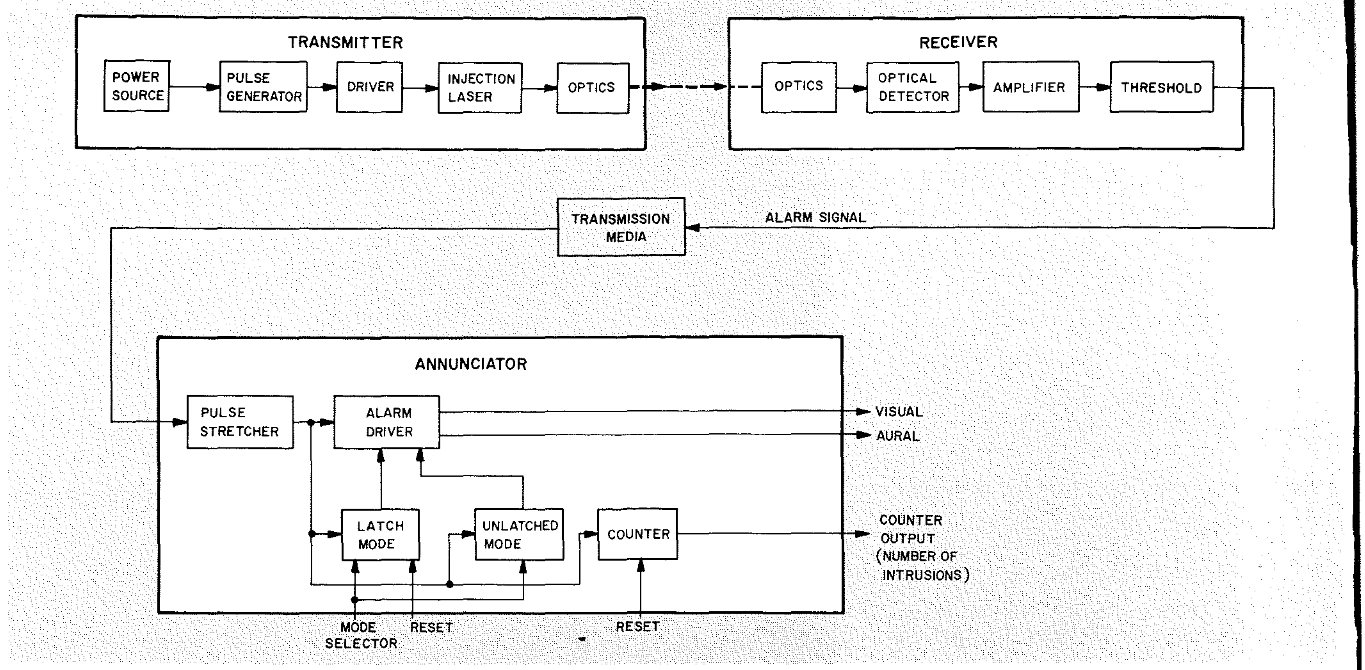


Fig. 2—Laser intrusion alarm system.

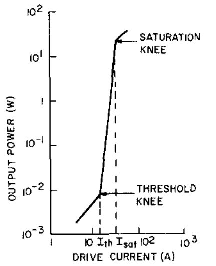


Fig. 3—Light output power vs diode current for RCA TA2829 laser diode.

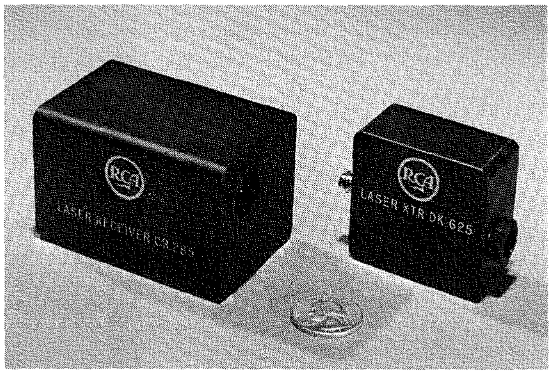


Fig. 4—Mark I intrusion-alarm transmitter and receiver—the first of the miniature high efficiency units. The equipment uses a *GaAs* laser transmitter and a silicon photodiode receiver. The size reduction in the transmitter and receiver shown and in the power supplies and annunciator was a significant step forward in the development of laser intrusion-alarm systems.

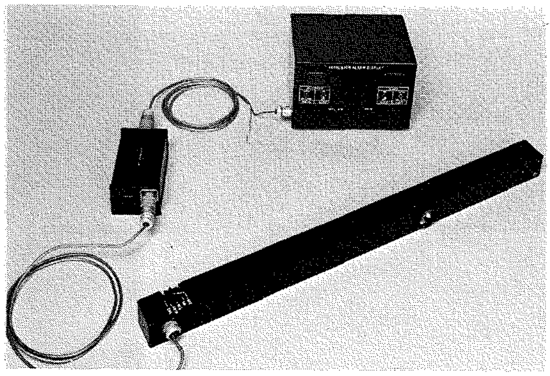


Fig. 5—Fort Monmouth injection laser intrusion-alarm system. The laser transmitter, receiver, battery supply, and self-check features are contained in a single unit. The unit can be operated as a transmitter only, receiver only, or as both when used with a retroreflector. An RF link provides intrusion information to an annunciator.

light emission) is emitted from all points of the diode. Where the slope is steep, light is emitted from only one junction face from a total area of less than 10^{-3} in^2; this is the lasing mode in which several watts of monochromatic light are emitted for a brief period of time.

The injection laser offers several advantages over conventional light sources in the transmitter of the intrusion alarm system:

1) Range performance is improved by orders of magnitude. The detection range is equal in day and night; the range at which a man can be detected is greater than in all other systems.
2) Improvements in size and weight are due to the high radiance of the injection laser. This means that small optics can be used to obtain the good beam directivity (narrow radiation beam) of the transmitter.
3) Power consumption is less because short laser pulses (100 ns) make ultra-low-duty-cycle operation practical. Low power consumption is important for applications in remote locations that require multiple units. Ultra-low-duty-cycle operation results in a total drain of only a few milliwatts/unit. This power drain can be supplied by a moderate-size battery for a shelf-life period. Thus a battery, located (buried) near the transmitter, can provide 1- to 2-year continuous operation; after that period, it could be recharged or replaced.

Figs. 4, 5, 7, 10, 11 and 12 show several injection-laser intrusion-alarm systems developed by the Advanced Technology Laboratories. Fig. 4 shows the prototype of the system in Fig. 5. The injection lasers in these systems were driven by an SCR switch circuit (Fig. 6). A later development model (Fig. 7) improved the driver efficiency by a factor of 15 and considerably reduced the size of the unit. The simplicity of the transmitter circuit, shown in Fig. 8, makes it desirable for military use. Because of the few low-cost components, maintenance is performed on a throwaway basis.

Transmitter operation is as follows: capacitor C_1 charges through constant-current diode CR_1 from battery E_1. When capacitor C_1 charges to the avalanche voltage of four-layer diodes CR_2 and CR_3, CR_2 and CR_3 operate (current avalanche); capacitor C_1 discharges 30 amperes through laser diode CR_4 which emits the light. When capacitor C_1 is discharged to the level of the extinguish voltage of CR_2 and CR_3, the capacitor begins to charge and the process is repeated. Regulation provided by diode CR_1 permits a variation in battery voltage by a factor of four before operation begins to degrade. The PRF is determined by CR_2 and CR_3 since the avalanche voltage is stable (as in a zener diode).

Receiver

A typical receiver circuit is shown in Fig. 9. A silicon photodiode is used as the light detector. The sensitivity of the detector in terms of minimum detectable signal is

$$P_s = \frac{4(KTBF)(SNR)/R_L}{\rho}$$

where P_s is the threshold detection level (W); K is Boltzmann's constant;

T is temperature (°K); B is bandwidth of the system (Hz); F is noise figure of the preamplifier; R_L is the photodiode load resistance (ohms); SNR is the signal-to-noise ratio; and ρ is the responsivity of photodetector (A/W).

Sensitivities (with good SNR's) of better than 100 nW are obtained. This sensitivity is independent of background and sunlight conditions except when the detector is pointing directly at the sun.

Since photodiode CR_1 responds dynamically to light signals as though it were a current source, a very high load resistance is required. An FET preamplifier supplies the required load resistance. Bootstrap feedback capacitor C_1 isolates the effects of the shunt capacitance (due to the photodiode junction capacitance, the gate-to-source capacitance, and the stray capacitance in parallel) from the source of the FET to the photodiode. Integrated amplifier CA3022 provides additional amplification of the signal; a threshold level blocks the noise and only the signal is amplified.

Fig. 10 shows one of RCA's latest development models. It consists of completely self-contained, battery-operated transmitter, receiver, and annunciator units built for rugged operation. The equipment has been drop-tested, jarred, and operated underwater. To provide all-weather capability, normal signal strength is boosted to enable operation in rain, snow, and fog. This increase provides what is known as the optical fade margin.

A combination voice-communications and intrusion-alarm system is shown in Fig. 11. Two laser diodes, producing a minimum peak power of 10 W, are operated at an average pulse repetition rate of 8 kHz in the communications mode. Voice information is pulse-frequency-modulated. In the intrusion-alarm mode, the pulse repetition frequency is 25 p/s. The power supply module shown in Fig. 11, which supplies high voltage to the laser transmitter as well as battery voltage to the remaining circuitry, uses eight rechargeable D-size nickel-cadmium cells. Operating time between complete recharge is eight hours for the intrusion mode and more than two hours for the communications mode with continuous transmitter operation.

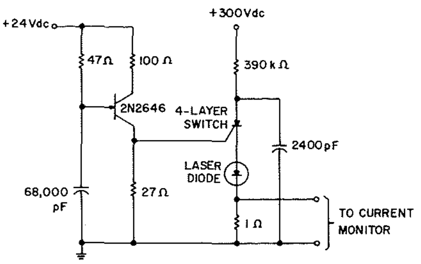


Fig 6—SCR laser driver.

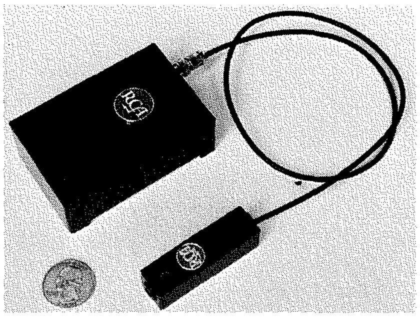


Fig. 7—Mark II injection laser intrusion alarm transmitter.

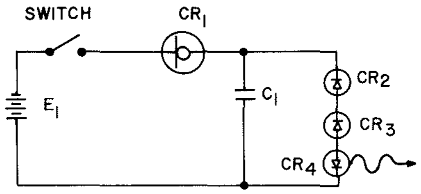


Fig. 8—Transmitter circuit.

Annunciator

Intrusion information can be transmitted from the receiver to the annunciator by either RF link or hard-wire link. Temporary installations would tend to favor the RF link for quick set up while permanent installations would favor the hard-wire link.

The annunciator unit is the display, memory, and system self-check for the system. It may provide selection of either visual or aural alarm outputs and often can monitor several transmitter-receiver units. The system can be operated in one of two modes—unlatched or latched. The unlatched mode gives an alarm signal for each intrusion for as long as the intrusion exists. After the intrusion, the system returns to normal. The latched mode is a memory mode which provides an intrusion indication from the time intrusion is first detected until the system is manually reset at the annunciator. A counter can be added to the annunciator to count the number of intrusions indicated between reset periods.

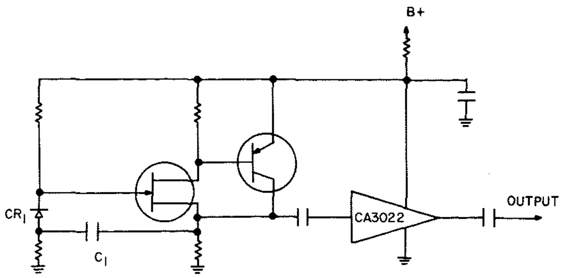


Fig. 9—Typical receiver preamplifier circuit.

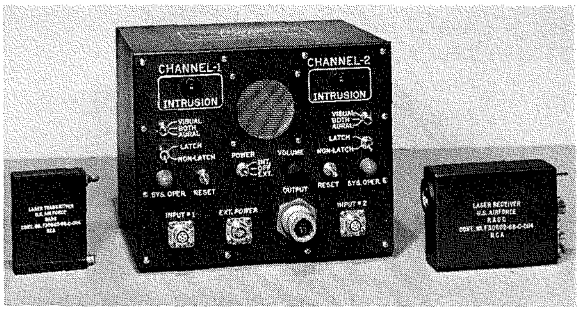


Fig. 10—RADC intrusion-alarm system. The units, all with self-contained rechargeable batteries, are capable of operating continuously for two weeks; with a moderately sized auxiliary battery, operation is possible for greater than one year. The units are of rugged construction and have been operated underwater.

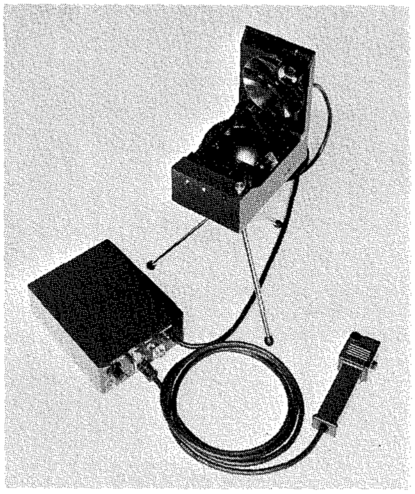


Fig. 11—Advanced voice-channel intrusion-alarm system. This dual function *GaAs* injection-laser system is capable of operating either as a voice communications system or as an intrusion alarm system. The transceiver is shown mounted on the tripod.

Conclusions

The laser intrusion alarm system provides an efficient, reliable method of detection for perimeter defense. A cost-effective system evolves per linear mile of detection capability when development costs are distributed over a large quantity of units, and particularly when installation and maintenance costs are included. This technique provides reliable detection/decision data and can be adapted to effective self-defensive trigger operation, such as by boresighting a rifle to the receiver to fire upon intrusion detection. Field applications may require supplementary detection techniques to provide more complete identification of the intrusion.

Survivability—a new challenge for the engineer

E. Van Keuren

Many military systems must be built to survive exposure to a nuclear blast. This article discusses the various phenomena which may be encountered when a nuclear weapon is detonated, some of the general types of problems with which the design engineer is faced, and some of the design techniques which may help in ensuring survival. The discussion also includes some of the techniques which are used for simulation and testing of nuclear weapon effects, in lieu of an actual nuclear burst.

E. Van Keuren, Ldr.
Systems Engineering
Defense Communications Systems Division
Camden, New Jersey
received the AS in Engineering from University of Bridgeport in 1948 and the BS from Rutgers and MBA from Drexel Institute of Technology in 1963 and 1968, respectively. He joined RCA in 1948 and was assigned shortly thereafter to experimental UHF station KC2XAK. Subsequently he was assigned to what is now the Consumer Electronics Division, first with the Resident Engineering Department in Indianapolis and later as a radio and high fidelity equipment design engineer at Cherry Hill. He has been with the Defense Electronic Products Division since 1961. During this latter period, his primary responsibilities have been in system engineering related to the Minuteman and other programs. Since 1965, his responsibilities have included weapon system survivability/vulnerability analysis and consultation. In this capacity his evaluations have included the Hard Rock Silo Program, the Trajectory Accuracy Prediction System, the Status Authentication System, the Airborne Launch Control Center and TACSAT II.

ANALYSIS OF NUCLEAR WEAPON EFFECTS can be approached from either of two viewpoints:

1) That of the physicist who is primarily concerned with the radiation mechanisms, and hydrodynamic and thermal phenomena which are a part of all nuclear reactions, or
2) That of the engineer who is mainly interested in the electrical and mechanical effects on his design.

This article is directed primarily to the engineer and his problems, with discussion of phenomena held to a minimum.

General design considerations

There are two basic types of nuclear weapons of interest:

1) Fission weapons which produce energy during splitting or fission of the atomic nucleus, and which is the type commonly associated with Hiroshima, and
2) Fusion weapons which are based on the combination or fusion of two hydrogen isotopes—deuterium and tritium—which takes place in the presence of extremely high temperatures.

The fusion weapon is commonly referred to as a hydrogen bomb or, as a result of the high temperatures required to support the reaction, a thermonuclear weapon. Fig. 1 illustrates a typical fission-weapon reaction. In a thermonuclear weapon, a fission source is included to provide the high temperatures required during fusion. Further categorization is possible—as either a *conventional* weapon in which roughly 15% of the energy is in the form of radiation and 85% in the thermal and hydrodynamic phenomena, or an *enhanced-radiation type* of weapon in which significantly higher percentages of radiation are produced.

Reprint RE-16-1-14
Final manuscript received February 17, 1969.

Regardless of the weapon, the same basic phenomena, and their effects, are of concern to the engineer. From a radiation standpoint, these include electromagnetic radiation in the form of gamma rays, x-rays, and neutron particles; the electromagnetic pulse (EMP) which results from atmospheric ionization by the gamma and x-rays is closely related. Other phenomena of particular interest are the extremely high-temperature thermal radiation and the blast wave, which is usually considered in terms of overpressure and peak dynamic pressure. In a surface or near-surface burst, the direct induced motion in the surrounding terrain and the materials excavated by the blast and scattered as debris are significant. Of course, the relative importance of any of these phenomena in a particular design will depend on a variety of factors. These include:

1) The types, sizes, and quantities of weapons which the enemy will be expected to use against the facility;
2) The type of facility (e.g., ground based, aircraft, or missile) and its operating locale (ground level, atmosphere, or exosphere); and
3) The expected relative location and altitude of the detonations.

From the system design standpoint, the engineer may be required to work from the projected threats to develop the detailed nuclear environmental criteria; however at the hardware level, this criteria will usually be provided by the customer in the form of specific doses and dose rates which the equipment must survive.

As a last general comment, the goal in most designs is balanced hardening. In this case, the term hardening refers to designing for resistance to weapon effects, i.e., for survival. To provide a balanced design, each environmental requirement should be treated in a manner that will ensure that the equipment will have relatively equal invulnerability to each of the specified criteria and that it is not overdesigned in some particular area at the expense of others. In the case of the radiation, for example, the dominant effects on the design may be either electrical in nature, due to the ionization and displacement effects which are produced in circuits and components; or predominantly mechanical, due to the stresses which are induced by the extremely rapid rate at which high level radiation energy is deposited. Both of these types of effects are discussed in the following sections.

Radiation effects

The prompt gamma and x-ray pulses produced by a nuclear weapon have extremely rapid risetime and narrow peak pulsewidths: risetimes in the order of a few nanoseconds and peak pulsewidths of less than one hundred nanoseconds. These pulses are in the form of electromagnetic radiation and arrive coincidentally. The neutron par-

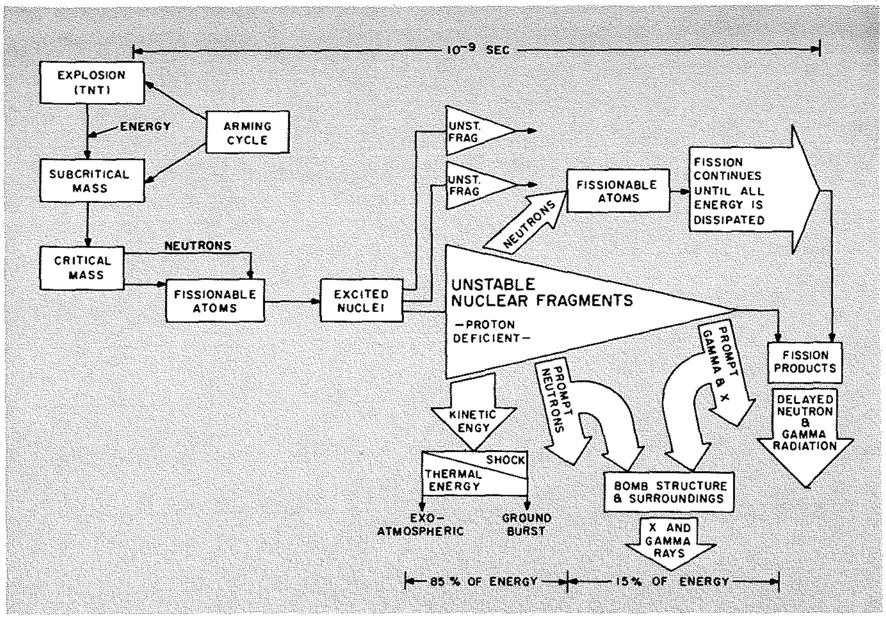


Fig. 1—Fission weapon mechanisms.

ticles travel somewhat slower, arrive a little later, and have a much broader pulse. At extremely high radiation levels, such as are encountered in relatively close proximity to the fireball, structural damage usually dominates over the electrical effects. To a large extent, this damage is due not only to the high levels of radiation that are encountered, but also to the rapid rate at which this energy is deposited and the inability of the structure to dissipate it safely. Types of potential damage include melting of structural metals (particularly exposed devices, such as antenna elements), crumbling of non metallic structures (such as concretes and dielectric materials), and spallation (in which stress waves propagating through the structure cause surface damage and removal of material at surfaces other than those exposed directly to the radiation). Of course, the magnitude of the damage varies with the distance from the blast.

The x-ray problem is particularly significant since most of the energy is deposited in a relatively small volume of material, relatively close to the surface of the structure. Generally, x-rays are not considered a threat within the atmosphere since they are absorbed very rapidly by air, but they can be quite significant at close ranges. At ground level, within approximately one quarter mile of the blast (depending on the weapon) x-rays can melt significant quantities of steel. The problems then are not only to allow for the steel to be removed but also to ensure that the molten metal will not be redeposited in a manner that will cause additional degradation. Problems such as this must be faced in design of survivable antennas for strategic weapon systems, such as in the Minuteman and Hard Rock programs. In some cases, to provide resistance to both the radiation and other phenomena, the probe may consist of a massive steel monopole bolted directly to the supporting structure. The antenna is fed across a gap which is designed into the structure and the melted metal must be prevented from shorting across this gap. Various classified programs are currently underway in the industry which include investigation of survivable dielectrics which can be used as a filler in this type of design.

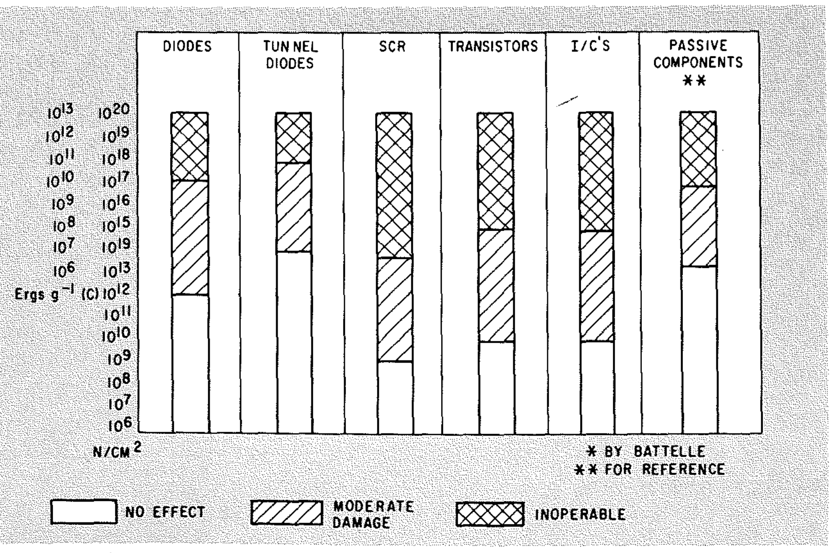


Fig. 2—State of the art assessment of susceptibility to radiation damage in semiconductors.

Within the atmosphere, such as in manned aircraft or in most ground-level electronics facilities, x-ray radiation will be attenuated to insignificance by the air through which it must pass. On the other hand, vehicles such as military satellites and ballistic missiles, operating in or above the exosphere, are potentially vulnerable to x-ray radiation many miles from a blast. From the standpoint of the RCA engineer, this will usually take the form of damage to the high-absorption-coefficient materials used in the construction of semiconductors and other solid-state devices.

As the distance from the blast increases, the mechanical damage due to radiation becomes less, and effects on electrical performance become more significant. In the design of electronic equipment for radiation resistance, four basic phenomena must be considered. Three of these—gamma rays, x-rays, and EMP—arrive essentially simultaneously and tend to reinforce each other, often making the total effect significantly worse than if they occurred independently. Neutrons, however, can arrive up to a few milliseconds later. Table I lists the criteria which are usually specified, along with some typical effects. Fig. 2 shows the radiation doses at which semiconductor damage may be expected to occur.

Gamma radiation

Gamma rays are extremely short-wavelength, high-energy electromagnetic radiation originating from the atomic nuclei. In general, the most serious gamma effects occur in semiconductor devices. The short gamma pulses result in ionization of the material and produce spurious currents which can temporarily disrupt circuit operations. These currents are proportional to the gamma dose rate; the most significant appearing as a reverse bias across the collector-base junction in transistors. At high enough dose rates, more serious effects can result

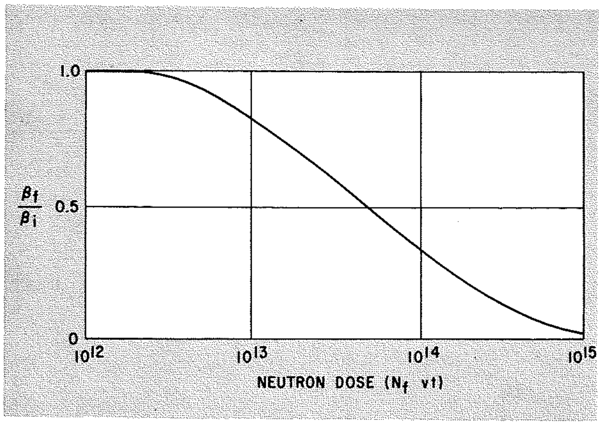


Fig. 3—Typical damage curve.

such as latch up of certain types of integrated circuits and even burn out. High gamma doses also tend to cause permanent surface damage effects and contribute to permanent semiconductor device degradation.

Neutrons

Neutrons are electrically neutral atomic particles that are released during fissioning of the atomic nucleus. These particles produce "permanent" degradation of semiconductor devices by changing the characteristics of the device material through atomic displacement. The most noticeable change is usually beta (β) degradation. A typical damage curve is shown in Fig. 3. The magnitude of the change is proportional to the absorbed dose and, hence, to the mass of semiconductor material that is exposed: larger, higher-power, or lower-frequency devices will undergo much greater degradation for a given dose than lower-power and higher-frequency units. Based on this, it can be seen that one approach to avoiding neutron effects is to use a number of lower-power and/or higher-frequency devices to replace a single large semi-conductor. This approach is particularly applicable to power supply designs where high-power circuits are sometimes unavoidable.

Although neutrons themselves, do not cause ionization, significant secondary gammas (which do cause ionization) are often generated by neutrons being absorbed in the materials surrounding the semiconductors.

Table 1—Radiation damage beyond fireball and blast effects.

Types of radiation
Prompt gamma ($\dot{\gamma}$)
Prompt neutron ($\dot{\eta}$)
Total gamma (γ)
Integrated neutron flux (η)
Electromagnetic pulse (*EMP*)
X-rays (*X*)
Damage mechanisms
Atomic displacement
Ionization
Thermal shock
Chemical effects
High voltage and current effects
Results
Transient interruptions (change of state or output waveform)
Gain changes (Temp or permanent changes in β, H_{FE}, f_T)
Total destruction of devices
Shorting
Melting and debonding (high-Z materials)

X-rays

X-rays are extremely short-wave length, high-energy electromagnetic radiation originating from the orbital electrons adjacent to the atomic nucleus. X-rays can produce ionization effects similar to those resulting from gamma radiation. In addition, the energy spectrum of the x-rays produced by some weapons is such that these rays can be absorbed rapidly enough by high-absorption-coefficient materials to result in destruction of the material. A good example of this might be the vaporization of the bonds used in some semiconductors, and the trend toward use of aluminum, which has a relatively low absorption coefficient, in construction of devices designed for use in certain environments.

In designing for x-ray resistance, a combination of exotic shielding techniques and imaginative circuit design is required. Typically, a multilayer shield, as has been designed for missile-borne transmitters, can be used to provide partial attenuation of the x-rays, with the circuits designed to allow for anticipated degradation and transients resulting from the residual radiation that will penetrate the shield. If the requirement is to resist a single attack, a sacrificial type of shield can be designed. In this case the cheapest possible shield that will provide adequate protection should be used. If a multiple attack is specified, the shielding can be designed to progressively degrade. Usually, the maximum number of bursts is specified, and the shield can be designed accordingly; therefore, a shield which could survive indefinitely would be over designed.

Many tradeoffs are possible; for example, an exception to the above would be a design in which the chassis consisted of one of the shielding materials, in which case it would have to survive. Also, at higher doses, certain classified shielding techniques—more effective than the approach described above—become cost effective.

Electromagnetic pulse

Ionization of the atmosphere during a nuclear blast produces a high-level electromagnetic pulse having characteristics roughly similar to a lightning discharge, except for the rapid rise-time of the EMP, which makes it much more difficult to filter and protect against.

At the minimum distance from a blast at which the most hardened structures can be expected to survive, peak electric fields up to a megavolt/meter and magnetic fields of many kiloampere turns/meter may be encountered. These levels are sufficient to totally disable most cable and radio communication systems unless extreme care is taken in the system design.

The facilities in which electronic equipment is housed are usually designed to provide shielding against the fields outside the facility. However, it is not unusual to find peak fields up to a few kilovolts/meter within them. Because of this, careful attention must be paid to this problem during the actual equipment design and packaging. Fortuitously, the necessary techniques are not unlike those already commonly in use for EMI control.

Blast-wave and thermal-radiation effects

Blast-wave and thermal-radiation environments to be considered by the design engineer run the gamut from pressure pulses of many thousands of pounds-force per square inch (lb-f/in^2) and temperatures of tens of thousands of degrees down to pressures of a few lb-f/in^2 and thermal doses of less than 100 calories/cm^2.[1] The former are usually associated with super-hard structures, such as hardened missile silos, while the latter are more closely related to tactical situations involving field army equipment and vehicles. Assuming a surface burst, the severe environment described above would be encountered relatively close to the crater lip. In

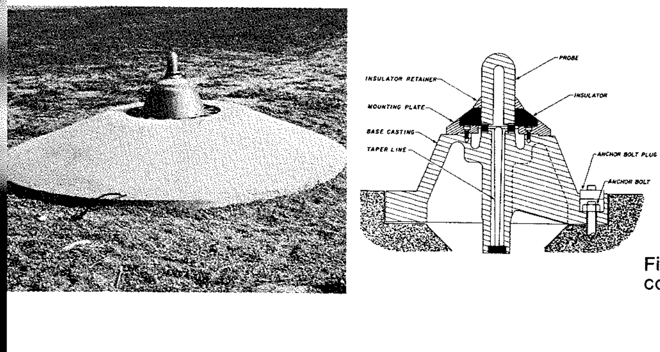


Fig. 4—Hardened Minuteman LF UHF antenna with ablative cover removed.

addition to the direct effects, ground motions of a few feet in competent rock and as much as an order of magnitude greater in some soils should be expected. Debris coverage of several feet and high velocity impact by large boulders also present significant threats.

Severe environmental design considerations

In general, the overpressure impulse can be accommodated by a low profile structure, or one with an extremely high ratio between height and base diameter. The Minuteman hardened antenna (shown in Figure 4) is a good example. Ideally, the upper surface should be flush with the ground, as in the case of a missile silo. In the worst case, the structure to be protected can be surrounded by an outer protecting ring having a similar low profile. As noted previously, the structure may have to be designed to project through several feet of debris (as in the case of an antenna element); therefore, the base area may be extremely large. Even so, the subsurface base may have to extend down several feet to provide adequate support. Extensive rebar strengthening is required, with reinforcement provided in several planes. In soil, the massive base is also required to provide adequate stability against the earth motion which will take place. In rock, the support provided by the structural mass can be supplemented with rock bolts.

Another solution, to the antenna problem is use of an erection/retraction mechanism that permits the antenna to be stored below ground and only erected when required; yet another solution is a multiple antenna complex in which an antenna, once erected, remains up and, if destroyed, is replaced by erection of another one. Both of these approaches are used in Minuteman.

Depending on the frequency band of interest, a variety of other types can be designed. These include buried long-wire dipoles and arrays, a variety of subsurface, cavity-backed and annular-slot types, and some recently developed classified configurations.

Although this discussion has been limited to exposed structures which will bear the direct brunt of the attack, it can be seen that electronic equipments housed within these structures will also undergo abnormally severe mechanical stresses.

Unique requirements are also imposed on cables for communications between hardened facilities. These cables must not only survive overpressures up to thousands of lb-f/in^2 but also the extreme stresses induced by motions in the earth. A particularly serious problem is presented by the shearing effect of large motions between adjacent rock strata. A hardened cable (armored) has been designed for the Hard Rock program. The cable's mechanical strength in tension, compression, and shear (approximately 50,000 lbs.) is provided by the armor. The cable is completely filled with a special type of wax to provide hydrostatic pressure balancing and overpressure immunity. This wax also provides an effective moisture barrier, even if a cable is ruptured, and eliminates the need for a pressurized cable such as often used in other buried installations.

Following, as they do, directly behind the radiation dose, the thermal effects can also be extremely severe. Again, using an antenna element as an example, considerable steel may have been removed by the radiation, which arrived earlier, and a comparable amount may be removed by the thermal pulse. The interaction between the radiation and thermal mechanism is extremely complex; this is particularly true in the boundary-layer region, since radiation-vaporized material may be present at the time the thermal pulse arrives. Disposition of the material which is removed is a problem in both the radiation and thermal cases.

When performed by hand, x-ray energy-deposition calculations are extremely cumbersome because of the broad x-ray spectrum that is produced by certain weapons. This is particularly true when complex shielding configurations must be considered. A variety of energy-deposition programs are available which enable these calculations to be performed by computers. Two of the best recognized and most commonly available are PHOTRAN, a photon transport code, and the PUFF series of hydrodynamic codes.

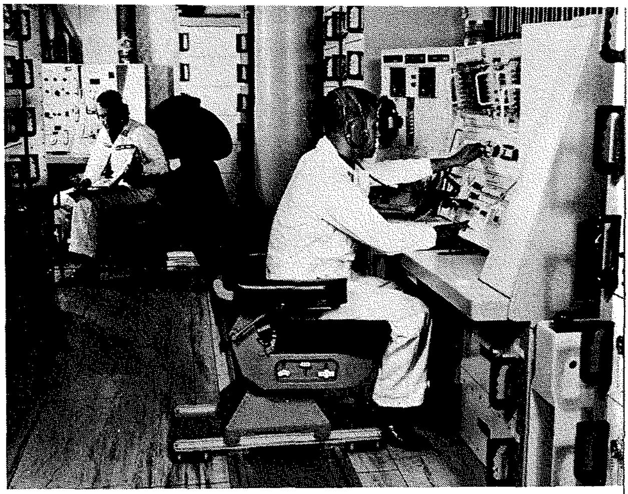


Fig. 5—Interior of Minuteman launch control facility.

Some lesser environments

Two categories of equipment which are subject to blast and thermal effects of a much lesser magnitude than those described previously are manned aircraft and tactical field-army equipment. In the case of the aircraft, overpressure is considered to be the dominant kill mechanism because of the severe mechanical stresses it can introduce. The thermal and radiation criteria are specified at levels which will be encountered at the same distance from the blast as that at which the critical over-pressure contour will be located. At these levels, if reasonable care is used in component selection and equipment design, and if the most vulnerable types of semiconductors (such as large power transistors) are avoided, survival of airborne electronic equipment can reasonably be assured.

In the tactical situation, items of interest include fixed structures, vehicles having varied degrees of hardness, and equipment transported and used by individual soldiers. For the moment, we will consider the users to either be expendable and replaced following the blast or located in protected areas.

In considering relatively soft structures and vehicles, the dynamic pressure as well as the peak overpressure is significant. Criteria for both are

Fig. 6—Airborne launch control center.

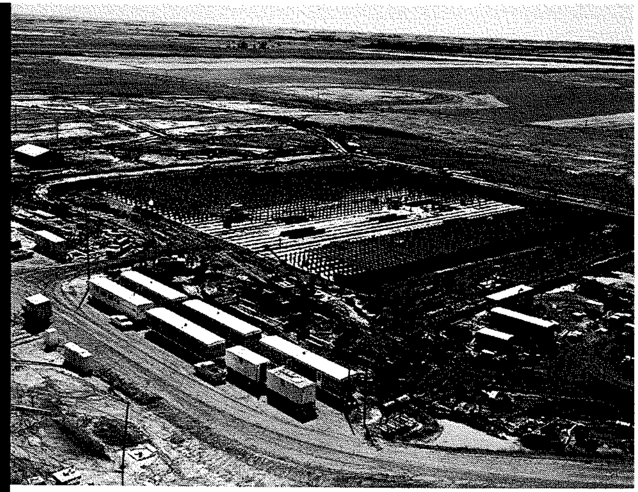


Fig. 7—HEST test site.

usually very mild. Rigidly mounted units will not be affected—provided that the internal structure will withstand the *g* forces that are developed. These do not usually exceed conventional military shock criteria. Loose items are vulnerable to damage from being thrown. Buildings, a house for example, are particularly vulnerable to the dynamic pressure. Immediately following the wavefront, there is a drastic drop in pressure and this combination of pressure followed by suction can literally tear the structure apart. Obviously, relatively fragile structures such as some types of large antenna arrays are also highly vulnerable.

Since the thermal pulse is very short, the effect on temperatures within a military-quality enclosure will be negligible; no more than a few degrees. The primary effect is the charring of the finish and the associated markings. If the equipment is to be used immediately following exposure, the markings must be raised or otherwise distinguishable. Items such as meters should be considered particularly vulnerable and protected by covers which are only opened when a reading is required.

The human factor

Most engineers are relatively familiar with the human factors criteria which are invoked on equipment designs and which cover such areas as operating controls and displays, area and equipment layouts, and equipment handling requirements. A new factor has now been added, the need to protect the operator from the effects of the nuclear environment. In designing a manned system, this requirement can be just as crucial as the design of the electronics equipment. Inhuman as it may seem, in some cases, primary interest may be in only ensuring survival long enough to perform enough functions to satisfy the mission's requirements. In this case, the question is not will he survive, but rather how to ensure that he will survive and retain adequate capability long enough to perform his necessary functions.

Strategic environment

In a manned site designed for the most severe environments (a missile launch-control facility, for example) the occupants are provided with a high degree of protection.

Complete protection from the thermal environment is provided by the capsule structure and by burial. The manned area is shock isolated and the operators, while on alert, are seated in restraining chairs as shown in Fig. 5. The radiation environment is attenuated by the soil surrounding the capsule and the concrete capsule itself to a level in which man can survive for a long period of time.

The control consoles, along with the operators chair, are a part of normal command and control system design. RCA's most recent involvement with a system of this type occurred during development of the command and control system for the Hard Rock Silo program. In addition, the engineer must be aware of the extent of protection provided by the facility itself, so that he can make intelligent judgements with regard to the post-attack capabilities that will be retained by the operators of his system.

Manned Aircraft

Although over-pressure is the limiting item in the case of an aircraft structure, radiation should have the most effect on the occupants.

In a manned aircraft, shielding protection of the pilots and other occupants is usually unfeasible because of the weight premiums that would be imposed. As a minimum, it must be anticipated that they may become severely ill. However, this should not take place until all functions have been performed and possibly the aircraft safely landed. The Airborne Launch Control System, which provides back-up capability for launching of Minuteman missiles in the event that ground communications are destroyed is a good example of a survivable airborne system design in which operator survivability is a major consideration. Fig. 6 is a view of an Airborne Launch Control Center. DCSD provided various items of equipment for this center.

Tactical environment

In a tactical environment, overpressure and thermal effects on personnel will dominate. Although tactical environments are relatively mild, the effect on personnel may be the worst because they have minimum protection. Exposed personnel may be severely burned; however, the shelter afforded by a trench, a vehicle or even a tree or rock will usually provide adequate protection.

Overpressures specified in tactical criteria are unlikely to be directly fatal. The key factor is the bodily injury, such as fractures, which can result from being thrown, and injuries from flying debris. Again, as in the case of the thermal dose, protection is quite easily provided.

Simulation and testing

If all the engineer had to do when he wanted to test the survivability of his design was fire off a nuclear bomb, there might be no need for simulation testing. Needless to say, life is not that simple; therefore, a variety of techniques have been, or are being, developed for simulation of nuclear-weapon effects. Of course, underground nuclear tests are performed from time to time; however, inevitably the demand for access far exceeds the space available. One of the chief difficulties in simulation of individual conditions is the inability to check for combined effects. This is particularly true when analysis shows that a par-

Fig. 8—HEST test detonation.

icular set of conditions may combine synergistically, and design decisions must be made, without the benefit of verification testing, that could have a major cost impact.

Radiation simulation

Neutron and gamma ray testing to the criteria invoked on most electronic equipment is currently feasible. Nuclear reactors that can be operated in the steady-state or pulsed mode provide reasonable fission-spectrum neutron testing. Sources of 14 MeV neutrons, as produced by the fusion reaction are also available—at White Sands, for example. Adequate linear accelerator and flash x-ray sources are available for both prompt gamma and total dose testing. At higher doses and dose rates, there are limitations on the volume that can be uniformly irradiated at one time; however, this is by no means insurmountable. Very few facilities are available that can adequately simulate the effect of high-dose-rate x-ray-energy deposition damage, even over very small areas; the flash x-ray machines at the Air Force Weapons Laboratory and at Physics International can simulate this effect to some extent. The best source for this, however, is still an underground nuclear test.

In the more severe environments, where the concern is with the exposed structures, simulation of radiation damage is still in its infancy. It can be seen that present reactors are unsuitable for neutron-heating tests, since levels which would damage the sample would also effect the reactor. To some extent, x-ray spallation tests in structural materials can be simulated using the largest flash x-ray machines in the electron-beam mode. Limited data on materials such as steel was obtained during early above-ground tests; however, this source is no longer available due to the test ban.

Thermal simulation

A considerable amount of testing has been done in the area of thermal ablation and melting. However, temperatures have been limited to those which can be achieved with an oxymethanol torch—about 5000° F. A fire-ball simulator is now being designed for the Defense Atomic Support Agency (DASA). This will produce temperatures much closer to those of interest. Even with this, sample sizes will be very limited and initial charges will be several thousand dollars/test.

Over-pressure and ground motion facilities

A great deal of work has been done in the area of over-pressure effects and ground-motion simulation. Several high explosive simulation tests (HEST) have been conducted that have achieved overpressures in the thousands of lb-f/in^2. In these tests, the samples are emplaced, a supporting structure is erected, a high explosive charge is laid over the test site, and the whole area is enclosed in a large mound of earth to contain the pressure momentarily. Fig. 7 depicts a typical HEST site with the samples in place and the supporting structure being installed. Fig. 8 was taken shortly after the time of initiation and shows the magnitude of the explosion. Note the increased build up on the left and blast wave moving from left to right. In the ROCK TEST II this spring, buried charges, placed around the test site, were fired in the proper phase with the overhead charge to simulate both the over-pressure and direct induced effects.

Other, smaller types of tests, are also performed. One type is based on spherical charges located either a short distance above ground, tangent with the surface, or with a lower segment below ground level. This type of test provides a wide range of over-pressures, depending on how close the samples are placed to the charge. The direct induced motion varies with the degree of coupling between the sphere and the earth. In a 1968 test, called Praire Flat, samples ranged from hardened structures down to biological samples. Sheep were used in the latter case and suspended in foxholes, to simulate men.

EMP facilities

A wide variety of EMP test facilities are currently available, and new types are in design and construction phases. In both cases, these include both fixed and transportable versions. In the past, two of the key problems have been generation of a rapid risetime pulse comparable to an EMP, and generation of the high pulse amplitudes dictated by the more severe criteria.

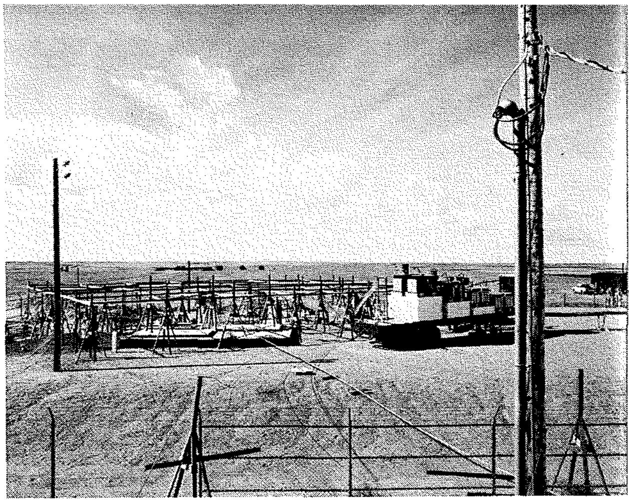


Fig. 9—Minuteman EMP simulator.

The Facility for Research in Electromagnetic Effects (FREME) at Fort Belvoir and the Air Force Weapons Laboratory Electromagnetic Field Calibration and Simulation Facility (ALECS) are the best known, current, government-owned simulators. Martin Marietta's Long Wire Antenna is one of the recently developed contractor facilities.

A transportable system has been in use for several years during Minuteman EMP testing. One configuration is illustrated in Fig. 9. A new system, designated SIEGE, which should provide much higher levels is now under development. Helicopter-borne simulators have also been designed for pulsing of large areas at relatively low levels from an airborne platform.

Conclusion

It can be seen from the breadth of subjects covered in this article that the field of survivability/vulnerability analysis is extremely broad and can impact on many aspects of both system and equipment designs. An attempt has been made to provide a broad-brush treatment, to introduce the RCA engineering fraternity to its many facets. The requirement to produce survivable designs has been growing in intensity for the last several years and it now appears that survivability will soon take its place alongside the other "ilities" with which we are all familiar as a normal part of many military design programs.

Reference

1. Pound-force per square inch (lb-f/in^2) is the new standard abbreviation used in place of pounds per square inch (psi).

Computer-designed printed-circuit board

J. A. Bauer

Design automation techniques can be applied advantageously to the production of complex, multilayer printed-circuit boards. This paper discusses how and when design automation should be used to produce printed-circuit artwork and examines current and future limitations imposed by computer hardware and programming.

IN PRODUCING ARTWORK for multilayer printed-circuit boards, two avenues of approach have proved practical and are being concentrated on within the printed-circuit industry. One is *computer-aided design* where the computer is used as a bookkeeping and drafting tool. Entered data is displayed by way of a cathode-ray tube where it can be controlled by the designer. The other is *design automation,* which makes use of sophisticated computer software programs to make decisions, such as where to place components, how to route wire paths, and how to test the finished board. Both systems have one common requirement: a complete description of the printed-circuit board. Within the computer memory, the size, shape, and detail geography of the board must be laid out. The memory must also include a pattern of allowable interconnection points for the components and connectors and a grid system for the possible paths of interconnecting wires. At this point, it becomes obvious that a set of printed-circuit boards for any one job should have common physical dimensions and placement grid, not only to reduce the task of the packaging and layout designer, but also to reduce the effort in entering this data to the computer. Since this is the practice whether a computer is used or not, the computer presents no limiting factor.

Although both computer-aided design and design automation are tools in printed-circuit design, this article will concentrate on design automation because of its rapid decision-making capability in addition to bookkeeping and, therefore, its faster operation in preparing large-scale artwork for printed-circuit boards.

The computer can't cheat, lie, or steal because it is constrained to operate within its program. It is not capable of inventing new methods of solution to a problem as the program progresses. Therefore, it is desirable that the computer program take into account as many subtle factors as possible to achieve competitive operation with the human designer's layout. For this reason, computer programs are difficult and time consuming to write and are considered to be a major effort.

Design automation

A typical printed-circuit artwork program consists of a memory bookkeeping section, an interconnection checking section, a component placement section, a wire-path routing section, and a magnetic-tape output to a numerically controlled artwork generator. In addition to the artwork program, drill-point location and test programs may also be prepared to drive numerically controlled drills and test machines. Inputs to the system are the board configuration and the interconnection list of the components. A flow diagram of a typical design automation system is shown in Fig. 1.

After the board configuration and the interconnection list have been entered either by means of keypunched cards or other mechanisms, the computer is programmed to check the interconnection list for completeness. If an error has been made in transcribing from the logic diagram or in making the logic diagram, the computer produces an error list which is typed out and fed back to the designer. A typical check run by the computer includes completeness of wiring path: a wiring path must terminate at connections.

John A. Bauer, Mgr.
Advanced Design
Missile and Surface Radar Division
Moorestown, New Jersey
received the BSEE from Virginia Polytechnic Institute in 1947, and subsequently took courses at the U. of Pa., UCLA, and Bell Telephone Laboratories. He is presently responsible for design automation and advanced circuit design within M&SR. In addition he serves as coordinator of all IR&D activities in the Division. Previously, Mr. Bauer was head of the advanced data systems department of the Instrumentation Facility, Bendix Corporation, Pacific Division, where he was responsible for design of military and commercial digital data transmission and data handling systems. As a research Engineer at Franklin Institute Laboratories, between 1948 and 1952, Mr. Bauer participated in electronic design and development of analog computer circuits, FM data transmission, noise signal sources, and photoelectric circuits. He holds several patents in the digital and control fields.

After check of the manually generated data, the computer is programmed to place components so they will be interconnected as simply as possible. The usual placement criterion is to reduce to a minimum the length of connections while taking into account the available channels for interconnections in each direction. For instance, if the board geometry dictates that only two wiring channels are available between components in the *x* direction and four wiring channels are available in the *y* direction, this factor should be considered in preparing the computer program so that component placement is made with more wires available in the *y* direction. Component plasement is done by the placement algorithm.

Reprint RE-16-1-18
Final manuscript received October 17, 1969.

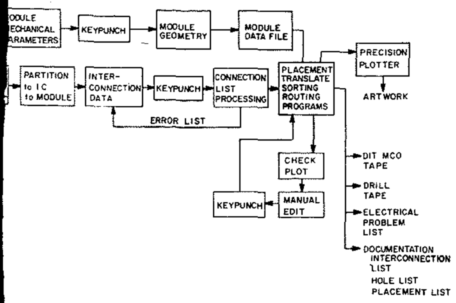


Fig. 1—Flow diagram of an automated printed-circuit artwork system.

The computer rapidly assembles the total wiring length, then re-arranges components and checks wiring lengths again to achieve a minimum total wire length. An additional constraint can be made to eliminate excessively long interconnection paths, particularly for critical signals. Because the computer can make multiple placements and wiring-length calculations very quickly, several thousand alternate placements can be made before the optimum placement is selected.

Routing program

Once an optimum placement is selected, a *routing program* is initiated. In this phase, the computer attempts to interconnect components in accordance with the interconnection list given to it by the logic designer. At this point, it is programmed to operate like a mouse running through a maze from start to end of the interconnect —it must avoid components, wiring pads, and previously laid out wiring paths. However, unlike the mouse in a maze, there are usually many alternate paths available to make an interconnection. The interconnection may stay on one layer of the printed-circuit board, or it may be allowed to go from layer to layer. It may be preferable for it to follow one direction over another to avoid blocking interconnections which will be made later. Also, its possible path may be so long around other components and wires that it would be preferable to reserve the path for a different layer on the board where the path would be shorter. All of these various constraints should be taken into account when setting up the routing program.

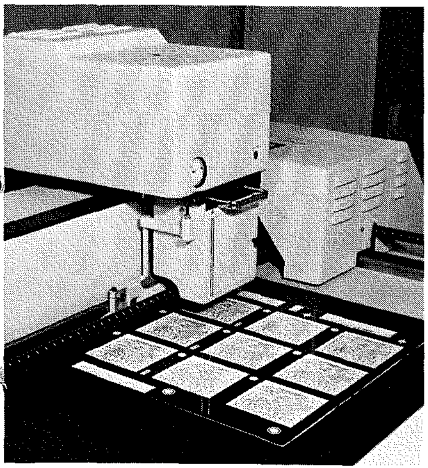


Fig. 2—Numerically controlled artwork generator producing the artwork for a group of nine identical printed-circuit boards.

It has been our experience that as the computer program is made more sophisticated in this area, better performance is achieved, thereby increasing the number of interconnects per layer of artwork. Most of the industry's efforts are concentrated on improving computer programs because the more factors that can be taken into account in the program, the more efficient the artwork can be made.

The current state of the art indicates that human intervention is still desirable to reduce the number of layers in densely packaged printed-circuit boards. However, it is also highly desirable to have all of the information included within the computer so that directions to the numerically controlled artwork generator, drill, and tester can include all data.

A typical example of computer routing for a densely packaged board mounting one-hundred integrated circuits may take two hours of computer time and produce eight layers of signal wiring. With manual intervention, the number of layers may be reduced to six. A prototype multilayer board may be made with the computer program, then changes to the interconnection and additional edited reduction of printed-circuit signal layers may be made for the production boards along with any additional changes determined by prototype test. As many as 22 layers have been successfully interconnected with printed-circuit techniques, indicating the current success of this method.

The programming complexity required by computer layout of multilayer printed-circuit boards indicates that this service requires a large investment. Therefore, it is usually more economical to utilize available programs rather than requiring each engineer to start from scratch to generate computer programs effective enough to prepare artwork.

The engineer and packaging designer should then consider very carefully whether it would be more efficient to manually lay out his densely packed printed-circuit boards or utilize a printed-circuit manufacturing service. One of the items to be taken into account is the number of errors produced by the many steps of manual placement and layout of thousands of interconnects, and the resultant recycling of artwork to correct mistakes compared to the relatively error-free operations of design automation. The designer should also consider the time savings of design automation caused by rapid computer operations.

Making the artwork

Once the placement and interconnection routing have been accomplished, a magnetic tape is prepared by the computer to drive a numericalliy controlled artwork generator. Fig. 2 shows an artwork generator in operation. It is possible to prepare artwork to within 0.0004-inch accuracy with this machine made by the Gerber Scientific Co. Notice that multiple artwork is being prepared on one master so that a group of nine identical printed circuits can be etched at one time. The machines, currently used by RCA, drive a light head which exposes the film master on the table. Two machines are avilable to produce automated artwork for printed-circuit boards, integrated circuits, and for shadow masks for color-TV picture tubes.

An example of computer-generated artwork is shown in Fig. 3, which is a sketch of one of two layers of a multilayer board prepared for checkout before final artwork is made. The typical layouts for a pair of adjacent layers results in artwork in which most of the lines in one layer run at right angles to most of the lines in the next layer. This is an important programmed portion of the computer-generated artwork because a single x (horizontal-axis) connection allowed to cross a layer with most of the connections in the vertical-axis *(y)* direction could block paths of many wires in that layer, thereby limiting the wiring density of the layer pair.

Other more subtle, effects can occur when attempting to program multiple-layer printed-circuit cards. For instance, it is desirable to vary the interconnection path selection depending on which edge of the board is being wired to make maximum use of the board edge. It is also desirable to anticipate the result of using via holes by the computer program since it may be more efficient to reserve them for manual additions.

Considering the above information, the circuit-card designer may feel that designing an efficient automated artwork program is specialized and expensive. This is true. At least several man-years of professional programmer's time are required to prepare the computer software which is competitive with manual layout methods. There is no simple mathematical proof for any of the placement and routing algorithms used. They must be invented and tested by practice with actual printed-circuit boards to gain sufficient experience in predicting performance.

Since the exact number of layers to be produced by the automated program is difficult to predict for densely packed boards, it is desirable to have a manual editing program to take advantage of human inventiveness and visualization which the computer program cannot have built in. As an example of performance currently obtainable, a circuit board with 800 interconnecting wires may be produced automatically in eight layers and, with additional manual editing, could be reduced to six.

Equipment involved

The equipment involved in automated artwork should also be considered. The limiting factor of the computer used to design large multilayer printed-circuits is the memory capacity. Each grid point capable of accepting a wiring path must be entered in memory. A printed-circuit board with dimensions of 6×6 inches and a grid of 50 thousandths of an inch requires at least 30,000 bytes of memory. A board with 25 thousandths of an inch grid requires 120,000 bytes of memory. Alternatively, a 12×12 inch board with 50 thousandths of an inch grid requires 120,000 bytes of memory. This memory capacity is supplied by a medium- to large-scale computer.

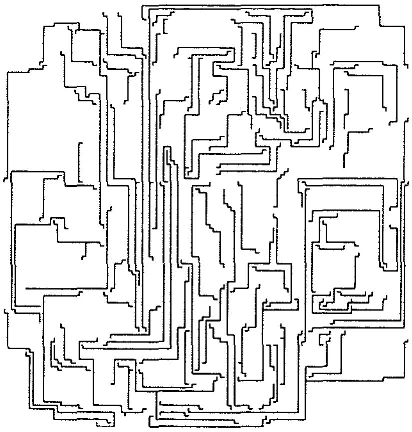


Fig. 3—Example of computer-generated artwork in which most of the lines are in the *Y*, or vertical-axis, direction.

The computer, when properly programmed, is capable of preparing tapes to drive numerically controlled artwork generators. These may be of the high-speed, medium-accuracy cathode-ray-tube type or the slower speed, but highly accurate, electromechanical plot board. These are the two major hardware components required for automated artwork preparation. In addition, each completed circuit board must be tested to assure quality. At the M&SR printed-circuit facility, automated continuity and short-circuit tests are run by the DIT-MCO tester shown in Fig. 4.

Because of the large investment in time and equipment, design automation for multilayer printed-circuit boards will be most effectively used as a service from the printed-circuit manufacturers rather than as separate programs generated by each of the designers. This service reduces artwork production time and cost and is available at locations within RCA.

Automated artwork can be most advantageously applied to more complicated, densely packed integrated-circuit boards requiring multiple layers of interconnection. Single-layer boards are currently laid out more efficiently by manual means. One of the reasons is that as complexity increases so does the chance for making errors in manual artwork. These errors are difficult to catch and only one error in an 800-interconnect board requires modifications of the board.

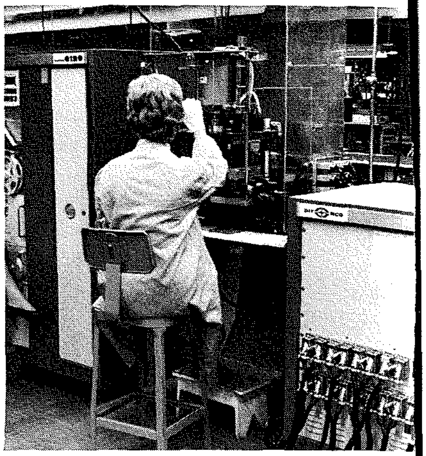


Fig. 4—Using automatic equipment to run continuity and short-circuit tests on completed printed-circuit boards.

Future developments

Automated artwork is one of the items required not only for efficient production of multilayer printed circuits but also for large-scale integrated circuits. An advance in one of these technologies will also benefit the other. The state of the art is rapidly improving because of the newness of the field and the current availability of all the tools, such as computers and plotters.

The limiting factor advancing the state of the art is the inventiveness of programmers preparing software. Certainly, future computers will produce more calculations per dollar and plotters will become faster and more accurate; still, the capability of automatic artwork will depend on the capabilities put in by the programmer.

In addition to solving the placement and routing problems, the programmer will be adding wiring-rule calculations for solving reflection and crosstalk caused by interconnections of high-speed circuits. Moreover, minimum test specifications and a program to define and locate logic errors will also be added in the future.

Programs are available to check the logic by simulation and to prepare waveform and timing checks. When these are integrated into the overall printed-circuit artwork preparation, the engineer will be assured of the proper logic operation in accordance with his design as well as efficient artwork production and test.

Characteristics and selection of small computers

A. L. Linton

A small computer is defined as having the following characteristics: low cost, easily programmed, reliable, small size, and easily interfaced.[1,2] A method of computer selection is described which is accomplished in four phases: systems design, request for quotation, performance scoring, and vendor selection. The performance scoring echnique used involves assignment of relative weights to the various computer and manufacturer characteristics. The characteristics are individually scored and multiplied by their relative weights to obtain a total score for each machine. The data is tabulated, and a cost-versus-performance graph plotted. A machine is selected with the aid of the graph by looking for the computer with the highest performance/cost ratio, or for a machine which exceeds some specified minimum standards while demanding the lowest cost.

A. Lewis Linton
Graphic Systems Division
Dayton, New Jersey*
Mr. Linton received the AAS in Electronics Technology from the Academy of Aeronautics, New York, and the BSE from the Cooper Union School of Engineering. He has taken graduate courses at the University of Southern California and presently is enrolled in a graduate program at Rutgers University. From 1961 until 1967, he was an electronics instructor at the Academy of Aeronautics. In 1967, he joined the staff of the Jet Propulsion Laboratory where he participated in data system design and implementation in conjunction with the Mariner Mars Program. Mr. Linton joined the staff of Graphic Systems Division in 1969 where he participated in analog and digital design. He is a member of the IEEE and The American Society for Engineering Education. He is the author of two published papers and has presented a paper at the 1970 IEEE Convention.

---

*Presently employed at Middlesex County College, Department of Electrical Technology.

THE PROLIFERATION OF SMALL COMPUTERS and small computer manufacturers is quite extensive. The engineer who has to choose a computer for his unique problems is apt to be confused and saturated by the manufacturer's many claims and specifications. To select a reasonably priced computer system, the engineer should use guidelines to aid him in his selection technique.

For the purpose of this paper, a small computer is considered to be a machine with a basic price tag of $4,000 to $40,000.[3] At the present time, there are over 55 machines available from about as many manufacturers. These computers are used for almost every imaginable task including, but certainly not limited to, message switching, process control, stand-alone processors, data acquisition and bio-engineering.[4]

Characteristics

Before it is possible to pick a small machine, it is vital to become intimately familiar with the various characteristics of this class of machines which will allow the selector to purchase the correct one for his application. The characteristics in Table I are those which allow the engineer to make a valid evaluation of the machine, and yet not be swamped with reams of data.[5,6,7]

It may not be necessary to investigate each and every parameter for all applications. The characteristics which are important to one's own task will be determined from the systems-design phase of the selection process.[8,9] It is quite important that the manufacturer's data sheets are carefully interpreted, so that all computers are evaluated on an equal basis.

The criteria concerning the manufacturer's capability (Table II) must also be evaluated since such items as delivery time and documentation may be extremely important to the purchaser.[10,11]

Selection

Once the relevant characteristics have been defined, it will be necessary to employ an analytical technique which will allow for the selection of an *n*-dollar computer without spending an equal amount for the selection process. The analytical technique for computer acquisition is designed to facilitate competitive selection, regardless of the purpose for which the equipment is to be acquired. This system, which uses a weighted-factor selection method, is designed to be flexible, impartial, efficient, and effective. Flexibility is achieved by assigned weights which best suit each individual application.[12]

The four phases of computer selection are

1) Systems design and specification,
2) Request for quotation,
3) Quote evaluation, and
4) Selection.[7]

System design

The system-design phase requires a thorough analysis of the problem and definition of constraints. It is during this phase that the minimum performance criteria and maximum allowable costs are established. The basic characteristics of the *desired* machine are developed, and the *ideal* machine for the job, without consideration of budgetary restrictions, should be determined.

The problem analysis should investigate the overall nature of the task, paying special attention to such items as bit transfer rates to/from memory, data interface capabilities, and efficiency of organization of word length and addressing structure. The number of input/output devices, their data requirements, and signal levels are determined with an allowance for future expansion. The software routines should be analyzed quite extensively and the number of required instruc-

Reprint RE-16-1-4
Final manuscript received February 23, 1970.

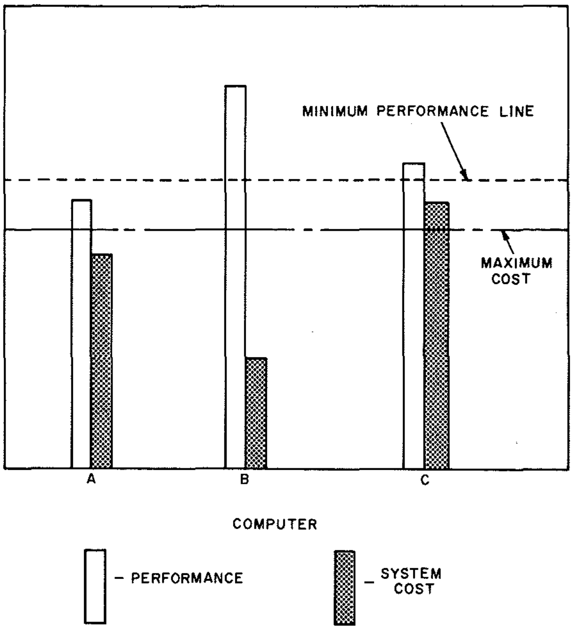


Fig. 1—Performance—system cost characteristics

tions and program run times calculated. This will, in turn, help to estimate the amount of memory required for both program and data storage. A block diagram of the system and data timing diagram should be prepared to establish a total picture of the system.

Request for quotation

The nature of the problem, required minimum specifications, and desired capabilities of the machine should then be supplied to the list of vendors selected as part of the system design phase. Prospective bidders should be fully informed about intended locations and the user's organizational mission and objectives. The minimum standards or conditions with which the vendors must comply should be documented. These restrictions should be held to a minimum and must not be designed to eliminate any vendors from consideration.

The evaluation criteria should be developed with the following objectives in mind:

1) All of the technical requirements stated in the request for quotation (RFQ) must be evaluated.
2) The criteria must allow features which extend beyond the basic RFQ requirements to be evaluated.
3) The criteria must be general enough to encompass widely varying characteristics as proposed by different vendors.
4) The criteria should be worded so that uniform results can be obtained from the evaluators.

Table I—Computer characteristics[1,5,6]

Category	*Parameter*	*Definition*
Class	Word size	Number of bits in CPU word. Basic word length does not includ parity or protect bits.
	Cycle time	Time required for a read or write operation.
Memory	Minimum size	Number of words in basic machine.
	Maximum size	Maximum memory size (words).
	Expansion	Expandable in increments of X words.
	Parity/Protect	Parity bit added to CPU word length to check each memory reference. Size of page protect in words.
	Read-only storage	Minimum and maximum size, module expansion size.
Instructions	Quantity	Number of basic instructions.
	Multiply time	Hardware multiply time in μsec; (SW) indicates subroutine.
	Divide time	Hardware divide time in μsec; (SW) indicates subroutine.
	Indirect address	Number of allowable levels.
	Direct addressing	Page size accessible by absolute specification in a single instruction
Registers	General	Number of general purpose programmable registers. Accumulator index and program counters listed separately.
	Special	Link, overflow, page registers.
	Addressable bits	Total number of addressable bits in programmable registers.
I/O	Rate	Maximum word-transfer rate for basic processor (MHz).
	Channel types	Types of buffered I/O channels for block data transfer. 1) DMA: direct access to memory with cycle stealing. 2) Selector channel with 1 active device for block trans (SEL) 3) Multiplex; several devices active at one time (MPX)
	Number of channels	No. of DMA, SEL and MPX channels in basic machine.
	Cycles stolen/word	Machine cycles lost to the CPU for each word transferred.
	Real time clock	Timer used to generate interrupts.
	Peripherals	Peripherals included in price of basic machine.
	Interfacing	Number of devices (basic and maximum), logic levels, cable constraints, interface characteristics.
Interrupts	Quantity	No. of external interrupts in basic and max. configuration.
	Enable/disable	Group, single or masked arming/disarming (group size).
	Priority	Method of ordering simultaneous interrupts.
	Minimum service time	Time in μsec. from interrupt to first instruction in interrupt routine.
	Pwr. fail./restart	Interrupt generated by power failure; automatic startup.
	Expansion	Modular interrupt expansion.
Software		Compilers (memory size required), assembler, diagnostics, math routines, operating systems, bootstrap loaders.
Features		Sense switches, construction, unusual peripherals available, environmental conditions.
Production	Delivery	Date of 1st delivery, no. of machines in field, delivery time.
	Power & size	Voltage and power required; *H*x*L*x*W* (in.).
Cost		Price of basic machine.

Performance scoring

Prior to receiving the quote from the vendors, the systems designers will have to establish the relative weights of the factors to be included in the evaluation criteria.[7]

The first major decision to be made in the evaluation technique is to determine the ratio of weights between the machine parameters and the vendor's capability. If you are purchasing one or two machines, the machine parameters (Table IV) are very important and the machine/vendor ratio will be higher than if you are purchasing 50 to 100 machines, where such items as vendor documentation and service become critical (Table V). The vendor's reputation will become more important if you have many of his machines spread over a large geographical area. For the one or two machine procurement, it is convenient to assign a weight of three or four to one as the

Table II—Vendor characteristics

Location of vendor
Location and adequacy of field engineering
Documentation
Machine access prior to delivery
Amount of subcontracting
Peripherals available
Machine family (larger and smaller machines)
Location, duration, and type of training
Programming systems support
Backup facilities

Table III—Selection-process definitions

Factor	A measurable computer characteristic.
Weighted sum	Sum of the scores of all the factors.
Equipment capability	Weighted sum of machine characteristics, scored on a 0-to-4 point basis, for each factor.
Vendor capability	Weighted sum of vendor performance parameters, scored on a 0-to-4 point basis.
System performance	Weighted sum of equipment and vendor capabilities.
Engineering costs	Design, fabrication, documentation, training, additional hardware add-ons.
Software costs	Programming costs plus additional peripherals.
System cost	Quoted price + engineering costs + software costs.

Table IV—Typical machine-parameter evaluation

Parameter	*Weight*	*Evaluation criteria*	*Typical score*
Word size	30	4 (24 bits) 2 (16 bits 0 (8 bits).	60
Cycle time	24	4 (less than 1 μsec) 2 (between 1 and 2 μsec) 0 (above 2 μsec).	96
Number of interrupts	20	4 (four or above) 2 (two) 0 (one).	40
Instruction repertoire	16	4 (over 70) 3 (50-70) 2 (30-50) 0 (under 30).	24
Multiply time	14	4 (very fast) 2 (medium speed) 0 (slow software).	0
I/O	10	4 (greater than 3 high speed channels) 2 (one channel) 0 (poor I/O).	40
Power required	2	4 (120v, 60 Hz, 1φ) 2 (208v) 0 (3 phase)	8
Total	116		268

Table V—Typical vendor capability evaluation

Parameter	*Weight*	*Evaluation criteria*	*Typical Score*
Delivery time	10	4 (0-30 days ARO) 2 (30-90 days ARO) 0 (over 90 days).	20
Documentation	6	4 (extensive) 2 (sufficient) 0 (poor).	12
Training	5	4 (programmer & maintenance) 2 (programmer only) 0 (none).	20
Location of field engineering	4	4 (many local offices) 2 (regional office) 0 (home office)	16
Units in field	3	4 (over 50) 2 (between 10 & 50) 0 (less than 10).	6
Manufacturer location	1	4 (local area) 2 (regional area) 0 (remote).	2
Total	29		76

machine/vendor ratio. This means that the sum of the weights for the machine parameters is 3 or 4 times the sum of weights of vendor parameters (e.g., 116/29=4:1).

Since it is difficult to determine the relative weights among a set of parameters, a good starting point would be to assign a weight of one to the least important factor and subjectively increase the weights for the more important factors. After the machine parameter weights have been assigned, and the machine/vendor ratio determined, it is easy to normalize the vendor weights. Before proceeding with the scoring technique, it is vital to realize that certain features are critical. If a zero score is assigned to any of these factors it is necessary to disqualify that particular machine. In the event the vendor has not supplied enough information, further research must be undertaken so the scoring can continue. The machine capability and vendor capability are added to arrive at the total score for each machine. The weighted sum of equipment and vendor performance, defined as the *system performance,* is tabulated in Table VI for each of three hypothetical computers. These values are plotted with the system costs in Fig. 1 to determine the machine or machines which will be satisfactory for the task at hand.

System cost

The system cost (defined in Table III as the sum of the quoted price, engineering costs and software costs) is a little more difficult to obtain. The quoted price, supplied by the manufacturer, for the basic machine and software is the most accurate of the three component costs. This is the price that will appear on the purchase contract and it will probably not vary once the contract has been signed. However, both the engineering costs and the software costs are quite variable and have to be evaluated extremely carefully. While it might be relatively simple to determine the cost of additional peripherals and additional hardware add-ons, the major task that the evaluator faces is the accurate estimation of manpower costs. These manpower costs include software analysis and coding, hardware design, fabrication, documentation, and operating costs. The total system costs of the three hypothetical computers evaluated above are tabulated in Table VII and plotted in Fig. 1.

Selection

After the proposals have been scored and the graph plotted, a computer may be selected by using one of the following criteria:

1) Highest scoring machine with a cost less than some arbitrary maximum:
2) Lowest cost machine which exceeds some minimum performance value; or
3) Machine with the highest performance/cost ratio.

Table VI—System performance

Computer	*A*	*B*	*C*
Equipment capability	244	300	268
Vendor capability	68	88	76
System performance	312	388	344

Table VII—Typical system cost (thousands of dollars).

Computer system	*A*	*B*	*C*
Quoted price	10.3	7.2	12.3
Engineering costs	5.1	4.0	6.3
Software costs	6.8	5.1	7.8
System cost	22.2	16.3	26.4

It is very important that the actual cost of the required system is determined. It is easy to select a machine which has a low initial cost but which has many hidden programming, systems, peripheral and installation costs. The software routines for the major processes are flowcharted so that costs, timing, and memory requirements can be accurately determined. For specialized applications, the engineering costs must also be carefully evaluated. Interfacing a small computer to a specialized system may introduce a number of problems which will increase the costs and complexity of the job. Therefore, the interfacing task will be easier if the computer manufacturer has a large line of modules for sale or has developed a large selection of interface cards such as analog to digital converters, multiplexers, etc.[4]

In conclusion, for the engineer to choose a machine which will result in the best performance/cost ratio for his particular application, he will have to know exactly what he wants that machine to do for him and how much are the *true* systems costs.

References

1. Ollivier, R.T., and Linton, A.L., "Revolt Within the Rack," *EDN,* Vol. 14 (1969).
2. Linton, A.L., "Characteristics and Selection of Small Computers," *1970 IEEE International Convention Digest,* pp. 470-471.
3. Bartik, Jean J., "Minicomputers Turn Classic," *Data Processing,* Vol. 12, No. 1 (1970), pp. 42-50.
4. DeCastro, Edson D., "What Can You Do With a Minicomputer?" *Industrial Research* (Nov. 1969), pp. 46-48.
5. Bhushan, Abhay K., "Selecting a Small Computer for Your Application," *Computer Design* (Sept. 1969), pp. 46-57.
6. Theis, D.J., and Hobbs, L.C., "Mini-Computers for Real-Time Applications," *Datamation,* Vol. 15, No. 3 (1969).
7. Ollivier, Robin T., "A Technique for Selecting Small Computers," *Datamation,* Vol. 16, No. 1 (1970), pp. 141-145.
8. Lapidus, Gerald, "Minicomputer—What All the Noise Is About," *Control Engineering* (Sept. 1968).
9. Lapidus, Gerald, "Minicomputers Revisited," *Control Engineering* (Nov. 1968).
10. Lapidus, Gerald, "Minicomputer Update," *Control Engineering* (May 1969).
11. Cohen, Joel W., "Minicomputers," *Modern Data* (Aug. 1969), pp. 55-63.
12. Rosenthal, Solomon, "Analytical Technique for Automatic Data Processing Equipment Acquisition," *Proceedings — Spring Joint Computer Conference,* Vol. 25 (1964), pp. 359-366.

Ultra-portable color television camera system

M. H. Mesner | F. Lang | D. Binge | F. J. Bingley

A back-pack camera system with communications equipment has been proven effective in colorcasts of the 1968 political conventions and remote sporting events. In choosing the optimum design for such a system, many tradeoff factors were considered. Choices of color coding in the portable camera for best transmission over the RF link were considered. The selection of suitable RF frequencies and bandwidths became a key factor of the preliminary study. The choice of number and size of sensors and the selection of a compatible optical system were also important. The system, as constructed, provided color pictures of acceptable broadcast quality and supported the design decisions.

Max H. Mesner, Mgr.
Advanced Sensors
Astro-Electronics Division
Princeton, N.J.
received the BSEE from the University of Missouri in 1940, after which he joined the RCA Research Laboratories. Mr. Mesner's research and development activity included radar indicators and pulse modulators, storage tubes and circuitry for both airborne and ground radar recording, and tube development for memories for digital computers. From 1949 until 1958, he contributed to the development of color TV receiver encoders, special color cameras, and line-screen kinescopes and receivers using linescreen techniques. He joined AED in March 1958, where he was responsible for the TV systems used in TIROS and directed the development of a number of miniaturized TV cameras. More recently, he has directed research and development on spaceborne TV systems capable of very-high-resolution. Mr. Mesner is a Fellow of the IEEE, a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu, and a member of the Society of Photographic Instrumentation Engineers. He holds 14 U.S. patents and has been a frequent contributor to technical publications.

THE POLITICAL CONVENTIONS IN 1968 provided the impetus to develop a lightweight portable color TV camera system. Since the conventions, the advantages of such equipment in broadcasting sporting and other field events has been clearly demonstrated. The system consisted of two major subsystems: 1) color TV camera facilities at the pickup point sufficiently light in weight to be carried by one man, and 2) an RF link or cable-connected base station within about a ½ mile of the pickup point. The principal problem was, of course, to design the system so that the portable part could be carried and operated comfortably by one man without sacrificing performance or reliability. The approach taken in designing such "man-pack" type color TV facilities for NBC forms the subject for this paper.

System description

Fig. 1 depicts the man-pack facilities—the camera proper, a combination viewfinder and control unit, and a back-pack containing the power supply, RF transmitter, control receiver, sync generator, and associated control circuits. The base station (not shown) comprises two racks to provide all the control and monitoring facilities required to process the signals from the man-pack facility and to generate an NTSC standard output signal. As shown in Fig. 2, the system design allows the interconnection between the man-pack unit and the base station by cable or RF link.

The base station includes the equipment for normal studio control of the composite video signal such as "painting" and iris adjustment. It also includes monitoring, synchronization, and switching equipment for operating three portable cameras simultaneously. The base station is packaged for field operation.

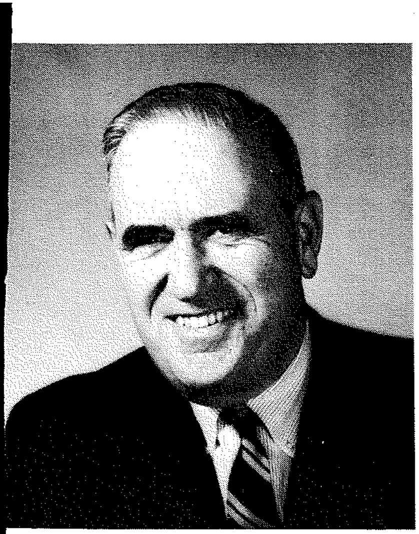
The portable camera senses three separate color signals: green, red, and blue. It uses three, hybrid, 1-inch vidicons similar to the RCA type 8134 (electromagnetically deflected, electrostatically focused), designated C23074G, C23074R, and C23074B, respectively. The camera optics consist of a zoom lens with a 4:1 zoom range and a dichroic prism. Camera operation is based on an alternate red-blue (R/B) scan technique: this decreases the vertical red-blue resolution but improves the signal-to-noise ratio and simplifies encoding of the three vidicon signals for RF transmission. The RF link employs a 13-GHz solid-state transmitter. The RF channel bandwidth is 25 MHz and the modulation bandwidth is 8 MHz. The composite video signal consists of 4 MHz of green video and 2.5-MHz red-blue video signal, which is transmitted as a vestigial sideband on a 5.45-MHz subcarrier.

The camera is designed to operate in three different modes: portable mode, portable-remote RF mode, and cable mode. In the fully portable mode, the video output signal is transmitted via a 13-GHz RF link to the base station. In the portable-remote RF mode, as shown in Fig. 2, a 50-ft. cable is connected between a transceiver adapter (which replaces the transceiver on the camera back pack) and the transceiver; this mode permits RF transmission from the camera to the base station "around corners." In the cable mode, 500-ft cable sections are connected between the camera and the base station; the cables replace the RF link and also supply power to the portable equipment. A transceiver adapter replaces the transceiver, and a battery adapter replaces the battery. Synchronization of the portable system to a master synchronization source may be accomplished as well as slaving one portable system to another.

Operator instructions are maintained through a separate audio channel between the portable-camera operator, the base-station operator, and the 13.5-GHz-antenna operator. This channel

---

Reprint RE-16-1-17
An earlier version of this paper was published in the *Journal of the SMPTE*, Volume 78, Number 11, November 1969.



F. J. Bingley, Mgr.
Sensor Technology
Astro-Electronics Division
Princeton, N.J.
received the BSc in Mathematics with honors in 1926 and the BSc in Physics with honors in 1927, both from the University of London. Since he began his engineering career in 1927, Mr. Bingley has had extensive TV engineering design and development experience, encompassing TV receivers, transmitters, optics, data recording, and tape camera techniques. Mr. Bingley joined the Astro-Electronics Division in 1962, and has been engaged in developmental work on high-resolution TV systems including photo-dielectric tape and return beam vidicon, and on color TV systems for both space and broadcast applications. He is a Fellow of the IEEE and the SMPTE, and a member of the Franklin Institute; and he was the recipient of the 1956 Zworykin Television Award of the IRE for his contributions in the application of colorimetric science to television. He has been granted twenty-nine patents, all in the television field.

Derek S. Binge
Advanced Sensors
Astro-Electronics Division
Princeton, N.J.
received a diploma in Mechanical Engineering from Westminster Technical Institute in London, England, in 1950. In 1956, he received an HNC in Mechanical Engineering from the Borough Polytechnic Institute. He joined AED in 1963, as a mechanical engineer in the Space Sensor Group. His past duties have included the mechanical and packaging design for the Ranger TV cameras and the responsibility for integration support and optical alignment of the Ranger camera system. He has been associated with the design, fabrication, and testing of the TIROS, Nimbus, and ATS camera systems. Mr. Binge has also been responsible for the engineering and environmental testing of space-qualified lenses designed for the Apollo Portable TV camera. Mr. Binge contributed to the design and development of multi-spectral television camera systems and was responsible for the mechanical and optical design of ultra-lightweight color television cameras for commercial and space applications. Mr. Binge's most recent responsibility has been the design of the mirror scanning mechanism and housing design for the RCA dual-channel very-high-resolution scanning radiometer.

Frank B. Lang
Advanced Sensors
Astro-Electronics Division
Princeton, N.J.
received the BEE from Renesslaer Polytechnic Institute in 1962. He joined RCA as a Design and Development Trainee with assignments at Moorestown; Indianapolis; Cambridge, Ohio; and Camden. He was assigned to Studio Equipment Engineering in Camden and in 1963 was transferred to Lancaster, Pa., where he was a factory engineer in vidicon production. Later in 1963 he joined AED where he has designed TV camera circuitry for TIROS, TIGRIS, ATS, and several classified programs. Mr. Lang also designed deflection and shading correction circuitry for the ultra-portable color TV camera system that was built for NBC. In 1968, while on loan to CESD he designed deflection and color processing circuity for a single vidicon color TV camera system. Mr. Lang was a member of the team that received the 1968 David Sarnoff Outstanding Team Award in Engineering for the single vidicon color camera. Recently he was lead engineer on a project that designed a color camera intended for use on the lunar surface. Mr. Lang is a member of the SMPTE and the IEEE.

---

is in continuous operation and does not require switching.

Number of camera tubes

Weight considerations led to the choice of hybrid vidicons since these tubes do not require magnetic focus coils, which add considerable weight. The only camera tubes which were considered to be capable of permitting the design of a camera within the weight limits were 1-inch hybrid vidicons or ½-inch magnetic vidicons.

Consideration was then given to the optimum number of camera tubes to be used in the camera. Evaluation weighed the merits of using more than three tubes and less than three tubes. The former required that one or more of the following conditions be met:

1) Provide additional transmission channels;
2) Suffer an additional weight penalty; or
3) Transmit a composite signal.

The use of less than three camera tubes, on the other hand, would result in some or all of the following disadvantages being incurred:

1) Camera target-area sharing;
2) Complex camera optics; and
3) Complex camera tubes.

Camera target-area sharing implies that a given target area of the camera tube must be shared two or three ways to permit more than one of the color-separation signals to be obtained from a single tube. One means of effecting this, for example, is a striped filter built into the inside of the camera faceplate, or placed in an image plane in a relay optical system.[1] However, at the time the camera was designed the striped-filter system had not been completely developed. And for that reason, the system was not considered.

Examination of the other design constraints of both methods resulted in the conclusion that the camera should be provided with three camera tubes. An outline drawing of the three-tube camera configuration is shown in Fig. 3.

Camera-tube considerations

The decision to use three camera tubes led to the attractive possibility of the use of a prism-type beam-splitter. Such a device, when coupled with a zoom lens, can provide a very compact optical system having an adequate range of focal length. Its use necessarily implies equal-size images at the three outputs. While it would have been possible (in view of the lesser resolution required in red and blue) to contemplate the use of smaller camera tubes for detection of

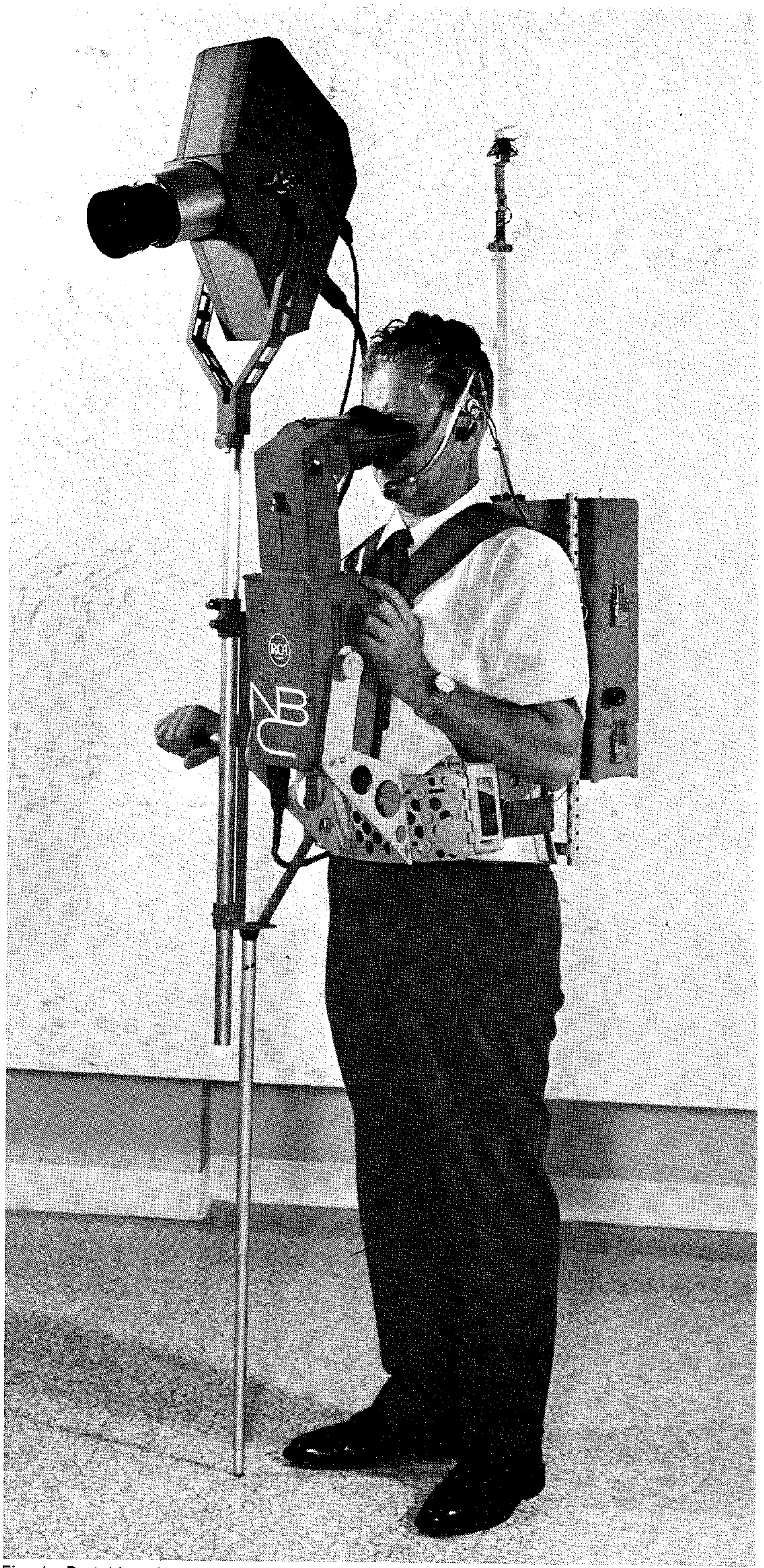


Fig. 1—Portable color television camera (prototype model).

red and blue than for detection o green, this would result in a more complex optical system. It would have been necessary to re-image the red and blue at less magnification; this would involve a relay lens and field lens for each, or a fiber-optics demagnifier associated with fiber-optic faceplates. The extra bulk of the relay-lens system would have eliminated the advantage of the smaller tubes; the fiber-optics demagnifier presented procurement problems for commercial equipment. It was concluded that the three camera tubes should be of equal format size.

The matter of what size of camera tube to use was then considered. The ½-inch vidicon was a possibility, but the weight and size advantage over the 1-inch hybrid vidicon was not very great.

In general, it became apparent that the tubes selected should be standard and readily available, since the development of special camera tubes is slow and costly, and replacement can present real problems to maintaining operating schedules. Therefore, the 1-inch vidicon was selected.

Transmitted camera signals

The fact that only three channels were available set practical limits on the choice of transmitting either the set of tristimulants Y, R, B, or R, G, B. The two contending sets of signals to be transmitted would be:

a) Y, R, B Signals

$$E''_Y = KY^{1/\gamma} = K\,[0.30\,R + 0.59\,G + 0.11\,B]^{1/\gamma}$$
$$E'_R = KR^{1/\gamma}$$
$$E'_B = KB^{1/\gamma}$$

b) R, G, B Signals

$$E'_G = KR^{1/\gamma}$$
$$E'_G = KG^{1/\gamma}$$
$$E'_B = KB^{1/\gamma}$$

where the symbol E''_Y has been used to distinguish it from $E'_Y = K\,[0.30R^{1/\gamma} + 0.59G^{1/\gamma} + 0.11B^{1/\gamma}]$ with which it is not identical, except near the white point. The problem with the set of tristimulants, designated a) above, is that it is impossible to obtain the value of E'_G by linear matrixing. In effect, the gamma correction must be removed from each of the three signals by an inverse nonlinear process before linear matrixing can give the true value of G.

Once this value is obtained, by this means, it must be subjected to gamma

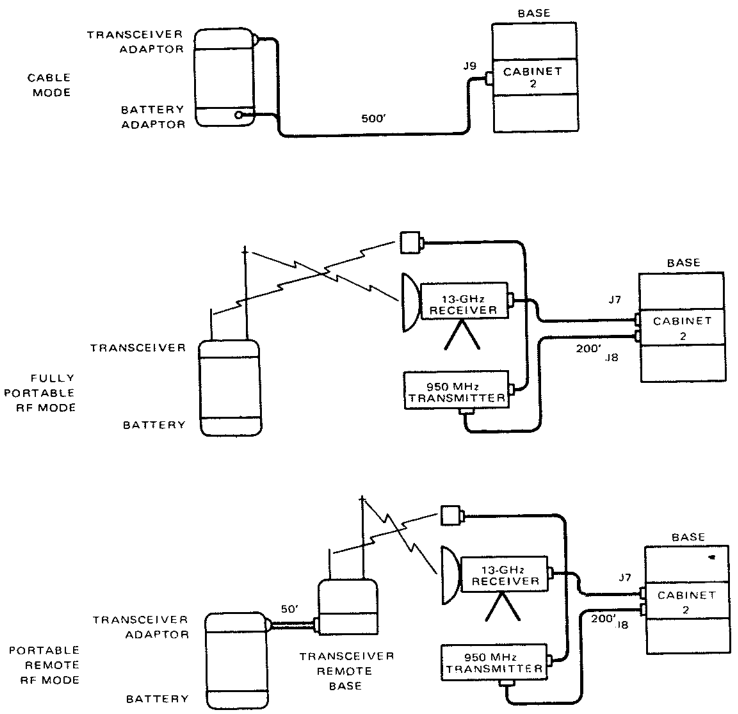


Fig. 2—Equipment operating modes.

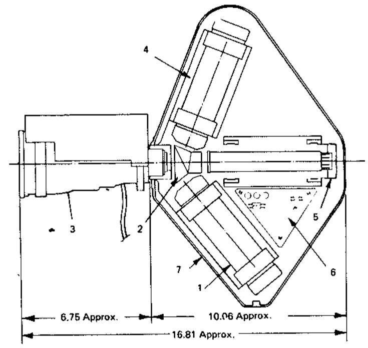


Fig. 3 Outline of the 3-tube camera configuration: 1) vidicon yoke shield assembly; 2)prism beamsplitter; 3) 25 to 110mm Canon 6/20; 4) optical faceplate; 5) shield cap; 6) electronic circuit boards; 7) sensor case.

correction to obtain $E_G=KG^{1/\gamma}$. The complexity of this approach is apparent; but if it is avoided and matrixing of the nonlinear signals (which is satisfactory in the neighborhood of the white point) is performed, intolerable color distortion results. This color distortion takes the form of a substantial shift toward the green, particularly of colors whose chromaticities lie near the blue-red side of the primary triangle. This effect is illustrated in Fig. 4, taken from a paper by Hirsch.[2]

The arrows in Fig. 4 indicate the amount of shift of green caused by the YRB-type camera. The tail of the arrow represents the chromaticity of the color as presented to the camera; the head of the arrow shows the chromaticity of the reproduction. The number adjacent to the arrow represents the number of just perceptible color differences contained within the length of the arrow. Since the CIE[5] diagram is not uniform in chromaticity intervals throughout its area, it is the number rather than the physical length of the arrow which is significant in displaying the extent of the green shift.

There is another disadvantage in the use of YRB, which is present even if the linearizing-before-matrixing operation is accomplished. The disadvantage arises because of the $\bar{y}$ taking (or spectral filter characteristic) overlaps $\bar{r}$ substantially; so that a dichroic surface, which attempts to separate them, causes a reduction of the effective sensitivity of the red camera. This is illustrated in Figs. 5 through 9. Fig. 5 shows a set of taking characteristics (negative lobes eliminated) typical of the RCA TK41 image-orthicon camera; Fig. 6 shows a blue-reflecting dichroic and Fig. 7 shows a red-reflecting dichroic. Fig. 8 shows how the blue-reflecting dichroic can separate between the $\bar{b}$ and the $\bar{g}$ taking characteristic. Fig. 9 shows the conditions obtained when effecting a split between $\bar{g}$ and $\bar{r}$; the dashed curve of Fig. 9 shows the dichroic which matches the long-wave end of $\bar{g}$; while the solid dichroic curve matches the long-wave end of $\bar{y}$. It cuts severely into $\bar{r}$ and would cut the red sensitivity to one-half of its normal value or less.

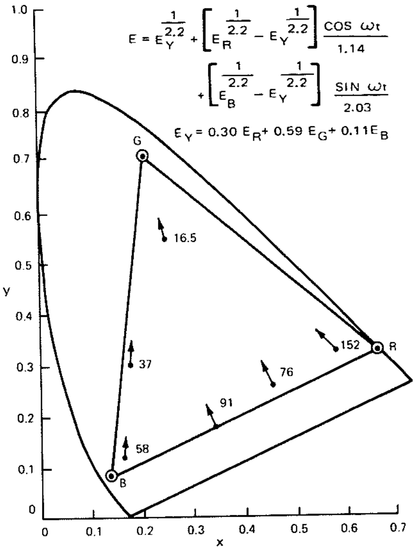


Fig. 4—Typical color shifts for camera with one luminance tube and two chrominance tubes.

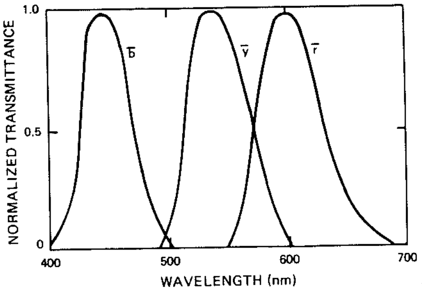


Fig. 5—Taking characteristics typical of the TK-41 image-orthicon color camera.

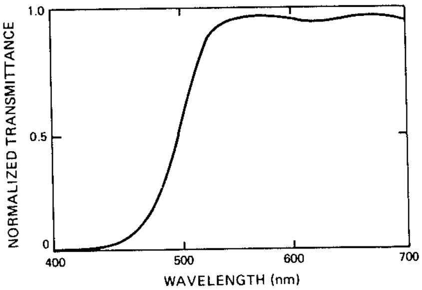


Fig. 6—Typical dichroic (blue reflecting).

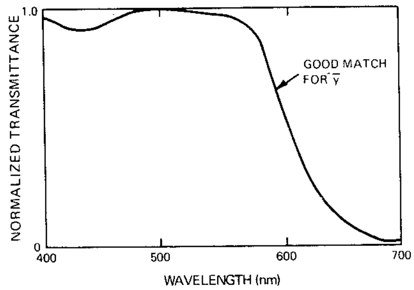


Fig. 7—Typical dichroic (red reflecting).

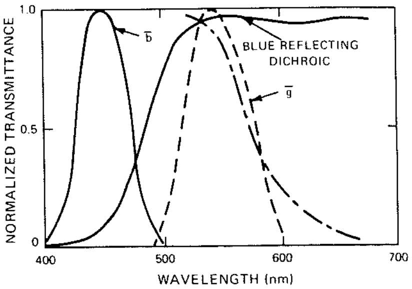


Fig. 8—Effect of dichroic cut upon blue separation.

As a result of the above analysis, it was decided that the transmission of the tristimulants *R, G, B* was preferable. It was recognized that an advantage exists for luminance (*Y*) transmission because it makes camera registration less critical; but by making use of the principle of “green highs,”[3,4] many of the advantages of the noncritical registration characteristic of the single luminance tube can be realized. The price of inversing the gamma to permit accurate matrixing, followed by re-gamma correction, seems to be excessive in relation to the advantages obtained. When the “green highs” system is used, there is some loss of resolution experienced when detail appears in red. To alleviate this condition, additional bandwidth can be provided for the red signal (2.5 MHz). In addition, red objects do generate signal in the green channel, though not as much as in a luminance channel. Fig. 10 is appropriate here; it shows the locus of colors representing rectangular wavebands (i.e., extending with uniform power density over a given range of wavelengths). The loci for 40- and 100-nm wavebands are shown in full, together with significant points on the loci for 60- and 80-nm wavebands. The equal energy white point is, of course, the limiting contour for a 300-nm waveband. The bandwidth of the red channel will be preserved up to the input to the matrix which forms the luminance signal (with a similar bandwidth for the blue channel at this point), so that the luminance resolution for the red component will be 2.5 MHz (corresponding to 310 lines horizontal resolution).

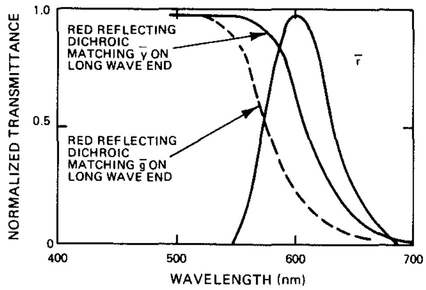


Fig. 9—Effect of dichroic cut upon red separation.

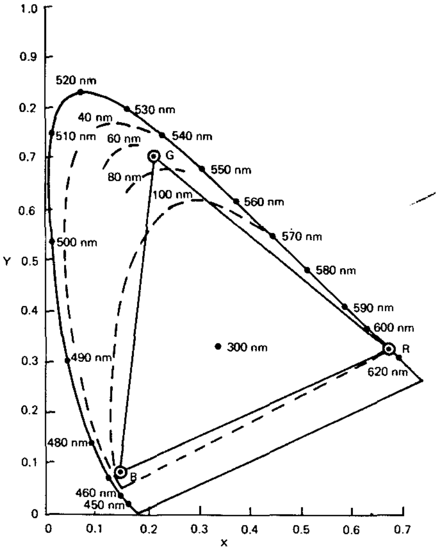


Fig. 10—Locus of rectangular wavebands.

As seen in Fig. 10, the loci of wavebands narrower than 80 nm are outside the primary triangle, except near the red primary, so that they cannot be reproduced accurately. Most reflecting objects are, fortunately, of relatively wide waveband (particularly near red, due to the straightness of the spectral locus there), so that very wide wavebands (100 nm or more) can represent quite saturated colors. Thus, a red object having a waveband from, say, 580 to 680 nm will place appreciable signal in the green channel (as can be seen from Fig. 5). The signal in the green channel will be enhanced by the effective peaking used in transmitting in the “green highs” mode.

Camera optics

The heart of the optical system is the method used to split the light into three primary color components. The two basic methods of beam splitting considered were dichroic mirrors and the dichroic prism block. To weigh the advantages and disadvantages of these beam-splitting devices the performance of the basic optical elements had to be evaluated as it affected the requirements described above, and the effect of environmental conditions on the performance had to be considered.

Some of the problems which can be expected when dichroic reflecting surfaces deposited on plane parallel glass plates are used for beam splitting are:

1) Astigmatism,
2) Polarization and color gradation,
3) Ghost images,
4) Degradation of multifilms,
5) Necessity for relay and field lenses,
6) Thermal distortion, and
7) Mechanical instability due to vibration.

The dichroic prism block is not subject to these problems. The prism however, is more difficult to manufacture than the dichroic mirror; but the difficulties have been overcome successfully.

Some advantages of the dichroic prism block over the dichroic mirror are:

1) Longer available path length, due to the refractive index of glass;
2) Sealed-in dichroic multifilms, not subject to contamination;
3) Smaller and lighter system package;
4) Mechanical and thermal stability;
5) Greater optical efficiency; and
6) Smaller angle of incidence.

During the study, several prism concepts were evaluated. The configuration shown in Fig. 11 was chosen as the only one which is compatible with the requirement for good color definition and simplicity, and which requires the minimum design and development effort to meet the system specification. The alternative prism configurations would have required considerable development to produce acceptable colorimetry.

In the selected configuration, the angle of the central ray incident on the red reflecting surface was made as small as possible (13° in glass) to make the separation of red from green as efficient as possible. The angle of incidence onto the blue reflector is 25°. An air gap is provided between the first and second prism to internally reflect the red component. The back focal length required to use this configuration is 35 mm, in air, assuming the prism is designed for the 1-inch vidicon format. The spectral characteristics achieved with this prism configuration are shown in Fig. 12.

Video-link considerations

Generally, conventional studio-type color cameras are cable-connected to a console or base station and transmit wideband red, green, and blue video information over this cable link. The portable color camera was designed to operate in either of two modes. In the primary mode, the output signal is RF linked from the portable unit to the base station. The secondary mode employs a cable connection in place of the link, which imposes strict limitations on video bandwidths. With the maximum bandwidth of 25 MHz available, the modulation bandwidth cannot exceed approximately 8 MHz. Commercial TV signals require approximately 4 to 4.5 MHz of bandwidth, uch that if wide-bandwidth red, reen, and blue video signals were to e transmitted, a minimum modulaion bandwidth of 12 MHz plus guard ands would be required. Thus, in the ortable color camera, certain compromises had to be made to retain a atisfactory picture within the 8-MHz bandwidth constraint. A satisfactory picture requires a luminance resolution of approximately 4 MHz and adequate signal-to-noise ratio.

Numerous system approaches were available for the video link. One system employs the method of simultaneously transmitting the three color signals. However, a major disadvantage here is that a much wider bandwidth is required.

Another approach consists of transmitting green information, with the red and blue signals transmitted in quadrature on a separate subcarrier. The disadvantage of this system is the requirement of phase-locking the receiver to the red-blue subcarrier, and this phase-locking can result in serious problems from multipath transmission.

A third system, and the selected one, consists of transmitting green information, with alternate lines of red and blue information transmitted on a separate subcarrier (Fig. 13). This system has the advantage of satisfactory red, green, and blue horizontal resolution. Also, no subcarrier-locking in the receiver is required with this system. An important advantage of this system is the better apportionment of available transmitter deviation; for when three signals must be accommodated (the monochrome and two subcarriers), the available range of deviation previously reserved for the third signal can be shared between them, leading to an improvement in signal-to-noise ratio.

The system selected also provides improved signal-to-noise ratio in the red and blue camera channels. This advantage results from scanning every other line in the red and blue sensors —thus allowing the vidicon beam to be blanked off during alternate scan lines in the red and blue vidicons. The vidicons receive continuous illumination resulting in a photon-induced charge on the vidicon target. In a continuous mode of operation, this charge would be read out once every 1/30 second. Instead, with the blanking of alternate lines, a given scanning line on the red or blue tube is discharged by the scanning beam every 1/15 second. Thus, the area of the tube corresponding to a given scan line has twice the time to acquire charge from the effect of image exposure, and when it is read by the scanning beam it will generate twice the video signal. The resulting signal-to-noise ratio for the alternate red-blue system is twice that of a continuous-scan mode, since the signal is being read into a preamplifier with the same bandwidth that would be used for continuous scanning but with twice the signal input.

The principal disadvantages of the system selected are reduced vertical resolution in the red and blue channels and the requirement for a one-scan-line delay line in the base station. The loss of vertical resolution in this mode is not serious, nor probably even noticeable under most conditions. Wide-bandwidth green information is transmitted continuously. In a scene with white and black information, the luminance signal would consist of approximately 60% of the green information, 30% of the red, and 10% of the blue. For scenes with vertical resolution above approximately 200 TV lines, the vertical resolution of the luminance signal would be deficient in the red and blue but the maximum worst-case would only degrade the resulting vertical resolution by 40%.

Conclusions

Operational experience with the portable color TV camera, gained during the political conventions and numerous sporting events since then, supports the conclusion that the analysis presented in this paper provided a sound technical basis for the design of the overall system. Under reasonable lighting conditions, the pictures produced by the camera have proven to be of acceptable broadcast quality.

Yet another application has been developed for the ultra-portable TV camera. AED has designed a counterpart for space-type applications, such as operation on the surface of the moon or planets, or within an operating spacecraft. Since the design constraints are different, and the motion within the scene is relatively slow, a

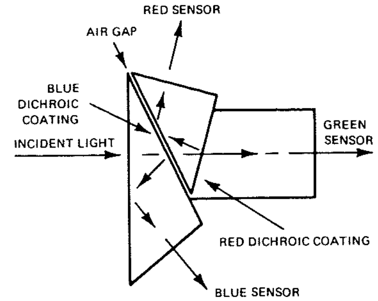


Fig. 11—Selected prism configuration.

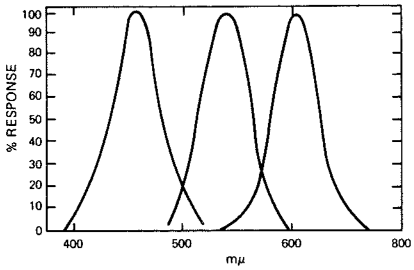


Fig 12—Measured spectral response.

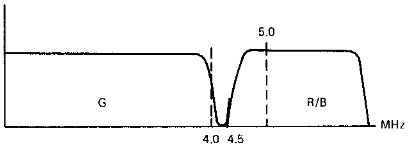


Fig. 13—Frequency spectrum for video link system.

color wheel was used. This camera utilizes a recent RCA development in camera tubes, the silicon intersifier target (SIT). The new silicon diode pickup tube makes possible a lighter, more rugged camera having much greater sensitivity; the new camera weighs 10.2 lbs. as compared to 17.0 lbs. for the previous design. Also, the camera may be safely pointed directly at the sun. The greatly increased sensitivity permits the use of adequately balanced color filters, a zoom lens, and a wide-range automatic light control.

In addition, the camera output may be converted from field-sequential to simultaneous output by using a magnetic disc recorder. Recoding these signals to NTSC standards makes it practical to distribute signal outputs on the conventional color broadcast network.

References

1. Wagner, T. M., "New one-tube color-camera for live or film use," Reprint RE-15-6-20; RCA ENGINEER, Vol. 15, No. 6 (Apr-May, 1970) p. 74.
2. Hirsch, C. J., unpublished communication to the authors.
3. Kell, R. D., et al., "An experimental simultaneous color television system," *Proc. IRE*, Vol. 35, No. 9, Sept. 1947; p. 861.
4. RCA Laboratories Div., Princeton, N.J., "A six megacycle compatible high definition color television system," *RCA Review*, Vol. 10, No. 4, (Dec. 1949) p. 504.
5. The CIE is the *Commission International de l'Eclairage* (also called International Commission on Illumination, or ICE).

Automatic light control for TV film cameras

K. D. Erhardt | K. W. Jorgensen

Film materials prepared for TV presentation vary considerably in both density and contrast. This variation must be compensated for during transmission to achieve the best picture at the home receiver. Manual control of projector light has been used for many years to accomplish part of this compensation. This paper describes a new Automatic Light Control (ALC) system using a control device which directly and conveniently replaces the manual light control potentiometer. The system uses light dependent resistive elements as the control device.

FOR MANY YEARS, manual control methods have been used to compensate for variation in the light and dark densities of motion picture and slide film materials prepared for television. But now, automatic means are becoming available to reduce the need for manual attention. One of the means of achieving the best pictures from a television camera is to adjust the light arriving from the scene so that the lightest areas in the scene remain at the same value of peak beam current. This can be done by placing a variable light attenuator in the light path and holding other factors constant. A paper on this subject prepared by Mr. H. H. Martin, Consultant in Video Engineering to the General Electric Company, was presented at the March 1966 convention of the NAB.

This paper offers an alternative approach to the problem, one particularly adaptable to equipment which was originally built with manual light control. The description begins with the basic system for light control and progresses through the intermediary steps leading to the final design of the ALC system for four-channel operation.

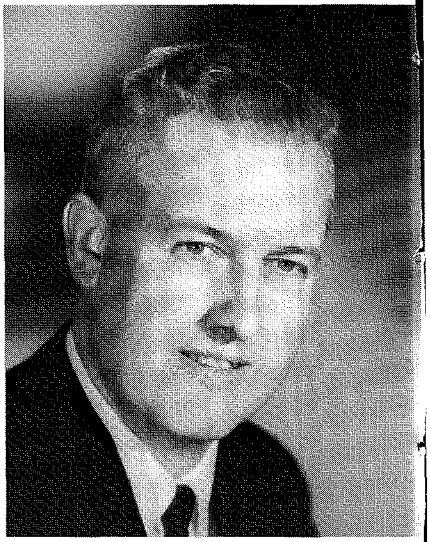
Existing manual light control system

The basic TV film chain consists of a film or slide projector, which projects a light image into a television camera. In a color film chain, the intensity of light transmitted through the film to the camera is usually controlled by a device inserted in the light path between the light source and the camera. Fig. 1 shows a system where the device is a neutral density disc the position of which is determined by a remotely controlled servo motor.

A neutral density disc (Fig. 2) consists of a disc of glass onto which neutral density material is deposited. (Neutral density material attenuates all colors of light equally.) This material is distributed around the glass surface in gradually increasing amounts. The deposit on the disc is very dense at one extreme of rotation (equivalent to a 2.0 Wratten Filter) and is clear at the other extreme. When a neutral density disc is placed in the light path of a projector, the amount of light passing through the disc depends upon the rotational position of the disc. The position of the disc is controlled, in a manual system, by a remote light control located at the video control console. The control is adjusted to provide the correct camera output as monitored on an oscilloscope.

Fig. 3 shows the servo system circuitry for manual light control. The servo motor which rotates the neutral density disc is driven by a remotely controlled servo amplifier. The shaft of a follow-pot indicates, to the servo amplifier, the exact position of rotation of the neutral density disc.

When the remote light control and the follow pot are at the same mechanical position of rotation, no signal is developed across the input transformer of the servo amplifier. Adjusting the remote light control to a new position results in the development of a difference signal. This signal is amplified and fed to the servo motor. The servo motor shaft rotates just enough and in the right direction to cause the follow pot to cancel the input signal to the servo amplifier. Thus, the final position of the neutral density disc mounted on the servo motor shaft, is determined by the remote light control.



Kenneth D. Erhardt, Mgr.
Film Technical Operations
National Broadcasting Company
Burbank, California
earned the Bachelor of Science in Electronics and Radio Engineering at California State Polytechnic College in 1950. Since then he has completed post-graduate studies in Computers and Electronics at U.C.L.A. Mr. Erhardt joined NBC Radio in San Francisco in 1950 and transferred later the same year to the NBC Television Network in New York. From 1951 to 1953 he took part in field testing the RCA/NTSC color television system. From 1953 to 1954 he worked in the NBC development laboratory in New York on color film pickup devices. In 1954 he was transferred to Burbank to aid the opening of NBC's Burbank color facility. From 1963 to 1966 he worked with NBC and Control Data Corporation engineers in developing, installing, and placing into operation the computer controlled automatic switching system at NBC, Burbank. Mr. Erhardt is a member of SMPTE and at present is serving a second term in the Board of Managers of the Hollywood Chapter and has for seven years been a member of the Color Committee.

Preparation for automation

The first step toward automating this system is to replace the manual light control with a light-dependent resistor

---

Reprint RE-16-1-16
Final manuscript received April 21, 1969.

Kenneth W. Jorgensen
Maintenance Engineering
National Broadcasting Company
Burbank, California

completed courses in electronic design engineering at DeForest Training, Incorporated, completed an Atomic Energy course at Wright Jr. College (Chicago), and attended U.C.L.A. for advance color instruction. He joined NBC in 1948, as a Television Transmitter Engineer and participated in the installation of NBC's first TV transmitter in Chicago. In 1951, Mr. Jorgensen was one of the first engineers associated with the design, construction and checkout of NBC's Burbank facilities. One of his first patent disclosures, in connection with color equipment, concerned an automatic carrier balance system. He developed an electronic process to analyze electrophoretic patterns used in hospitals for diagnostic purposes. He designed a lap-dissolve amplifier for TV broadcasting which is used in NBC and RCA switching systems. Among his recent developments are a color title insertion unit; a chroma key unit with no adjustments; a super-lock system which does not require the use of sync generators; and a relay-operated audio fader system—all of which are currently used at NBC.

(LDR). An LDR consists of a light source and a photosensitive element in a light-tight case. Varying the voltage to the light source causes a change in resistance of the photosensitive element. Thus an LDR can be used as a remotely controlled, variable resistor.

Fig. 4 shows how two LDR's can be used to operate as a remote controlled potentiometer. When the "swinger" of the remote control is fully clockwise, all the DC voltage is applied to light source B and no voltage is applied to A. Under this condition, the resistance of the photosensitive element B is low (about 100 ohms) and A is high (about 10 megohms). The reverse is true when the swinger of the remote control is fully counterclockwise. When the remote control swinger is at midpoint, equal voltage is applied to each light source and the two photosensitive elements have approximately the same resistance (about 500 ohms each). Thus terminals X, Y, and Z can be used to operate as a remotely controlled potentiometer, with terminal Y as the swinger and terminals X and Z as the ends.

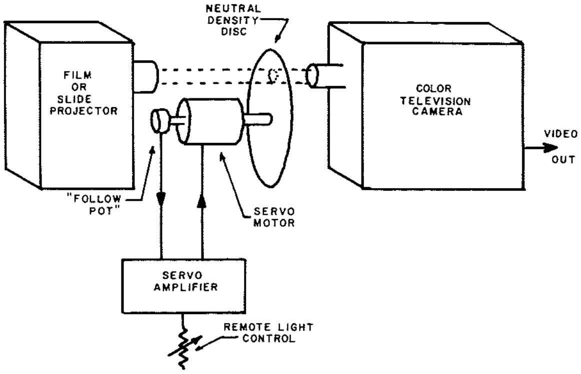


Fig. 1—Remote control for neutral density disc.

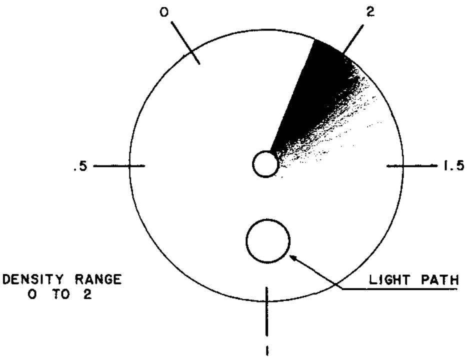


Fig. 2—Neutral density disc.

To operate this remote-controlled potentiometer with a control voltage, a control amplifier is used (Fig. 5). The control amplifier consists of two transistors connected in a complementary configuration. When the control voltage is zero, transistor 1 is off and transistor 2 is conducting heavily. Under this condition, nearly all of the supply voltage is developed across light source A and very little voltage is developed across light source B. The resistance between terminals X and Y is low and between Y and Z is high. The reverse is true when the control voltage is four volts. When the control voltage is two volts, the voltages across the two light sources are equal to each other and the swinger terminal Y is mid-point. As the control voltage is gradually varied from zero to

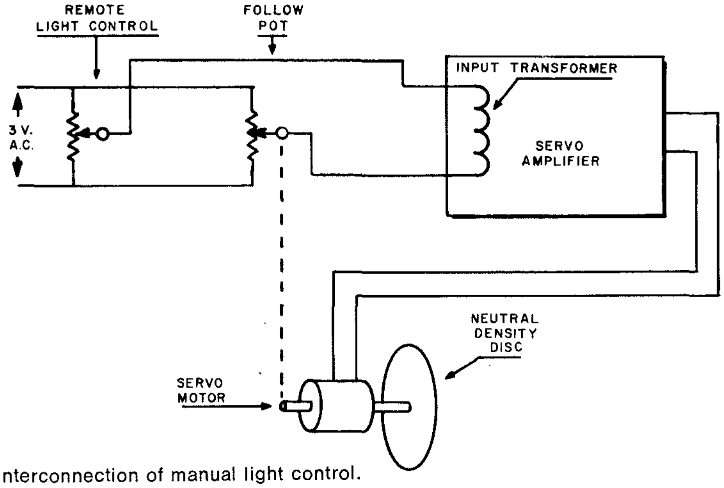


Fig. 3—Interconnection of manual light control.

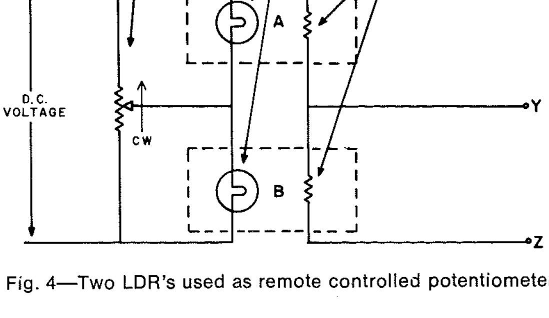


Fig. 4—Two LDR's used as remote controlled potentiometer.

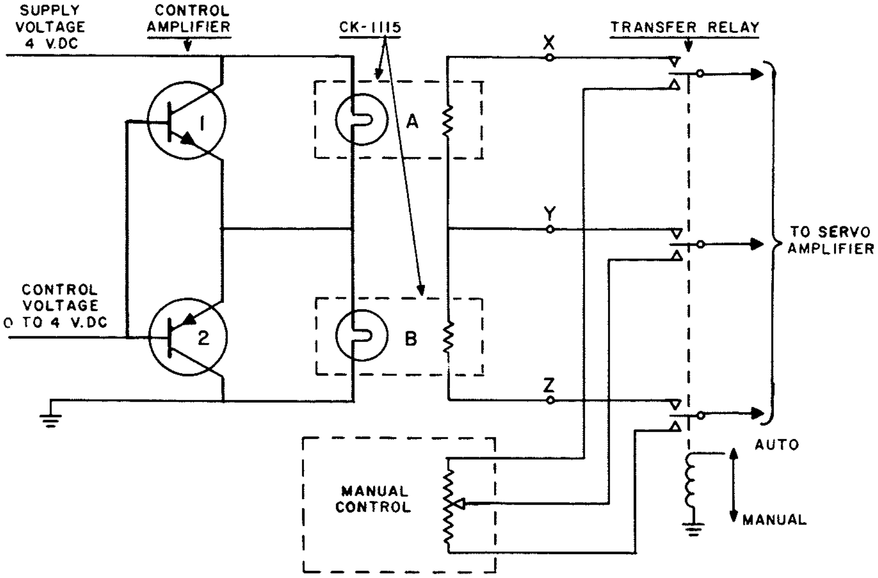


Fig. 5—Automatic and manual control with transfer relay.

four volts, the swinger terminal Y appears to move smoothly from X to Z.

To transfer from manual to automatic control a relay is used. When in this mode, the voltage-controlled potentiometer directly replaces the manual control. Raytheon CK-1115 Raysistors are used in this circuit as the LDR's. This Raysistor was selected because of convenient packaging (TO-5 Case), the resistance range available (100 ohms to 10 megohms), and the low control voltage required (4 volts).

Completing the automatic system

To make the light-control-system action automatic, the camera output signal must be sampled and compared to some reference to generate the control signal for the control amplifier (Fig. 6).

The output signal of a camera can be used to develope a control voltage which corresponds to the peak white information in the picture. Then, the control voltage can be used to drive a pair of Raysistors which will function as a remote light control for the servo amplifier.

The position of the neutral density disc and thus the amount of light reaching the camera, as modified by the density of the film being viewed, will be a function of the video output signal of the camera. This completes a control loop from the camera output, through the ALC system, and back to the neutral density disc, which allows the camera chain to be operated automatically. The operation is such that the lightest element in the scene is continuously compared to the reference and the neutral density disc is turned to maintain the value originally setup.

The ALC unit

In the basic ALC unit illustrated in Fig. 7, a sample of the output video from the camera is amplified, clamped, peak detected, and filtered in a conventional way to produce a control voltage. The control voltage is amplified and fed to a control amplifier. The control amplifier Raysistors, manual control, and transfer relay circuits are exactly the same as described with Fig. 5.

The peak detector samples the white peaks of the incoming video and the filter charges to the peak white level. By controlling the clamp reference, the ALC level control adjusts the voltage to which the filter charges on white peaks. When the picture white information increases in amplitude, the filter charges to a higher voltage. This causes the Raysistors to operate in a way which rotates the neutral density disc to a denser position. Thus, the peak white signal out of the camera is held to the desired level.

This ALC system operates such that when the film goes to black, the neutral density disc rotates to its least dense position. Then, when the film returns to normal level, the amount of light presented to the camera is too high. The picture will bloom momentarily until the neutral density disc rotates to its correct operating position. This problem is important because it occurs every time a film chain is rolled and a leader goes through ahead of the program picture material. The leader is black for the last 2 seconds, just about the right interval for the disc to go its position of least density. However, this undesirable m mentary blooming problem can b eliminated by adding a preset facilit to the basic ALC unit.

Preset control

The preset control facility (Fig. 8 consists of a preset detector, prese control amplifier, and disconnect di ode. The preset detector notes th presence of video from the video an plifier and holds the preset contro amplifier at cutoff. When the film goe to black, no video is present at th video amplifier output, and the prese detector allows the preset control an plifier to conduct. When the prese control amplifier conducts, the diod disconnects the DC amplifier from th ALC control amplifier. The preset con trol amplifier via the ALC contro amplifier, causes the neutral densit disc to rotate to a mid-range positio and remain there until the film leve returns to normal. A preset voltage i also fed to the filter to keep it charge during the black period for a smoot transition back to normal level.

This ALC system, as described, wil accommodate a monochrome film chain or the monochannel of a four channel color film chain. It will main tain the peak white picture informa tion at proper level. However, certai color picture material, such as slides may not contain any white informa tion. With such a slide, the outpu amplitude of a color channel in a four channel color camera chain may b higher than that of the monochrome channel. Therefore, the output level of all four channels must be independently sampled in order to adjust the light for correct output level of the chain. Otherwise, one or more channels may be overloaded while the monochrome channel is correct.

Four channel operation

As shown in Fig. 9, three separate ALC detector units are added for the color channels of a four-channel film chain, one each for red, blue, and green. These units are identical to the monochrome ALC unit except that they do not have the preset facility, ALC con trol amplifier, or Raysistors. Each of the four units has a disconnect diode: the one with the highest control voltage will control the light level, and the other three will be disconnected by the

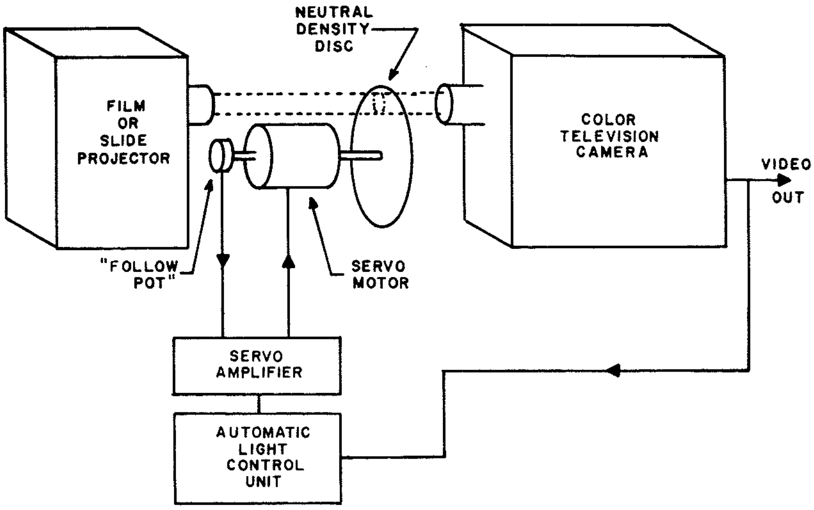


Fig. 6—Control loop for automatic light control system.

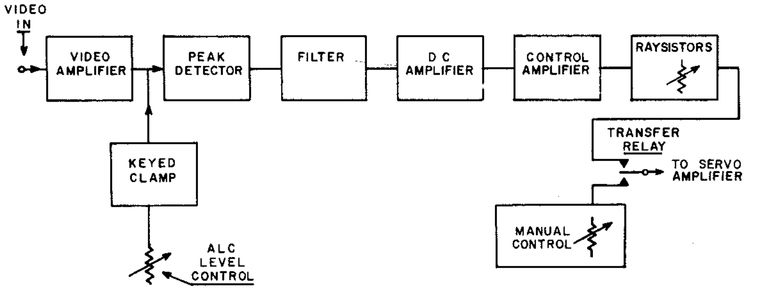


Fig. 7—Block diagram of basic ALC unit.

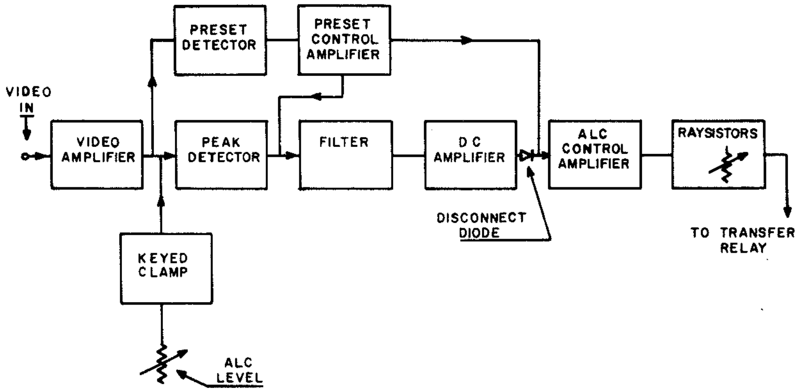


Fig. 8—Block diagram of basic ALC unit with preset control.

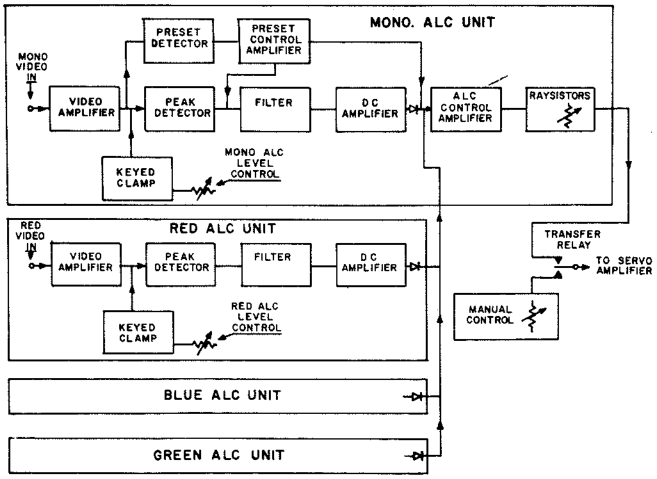


Fig. 9—Block diagram of ALC units in four-channel film chain.

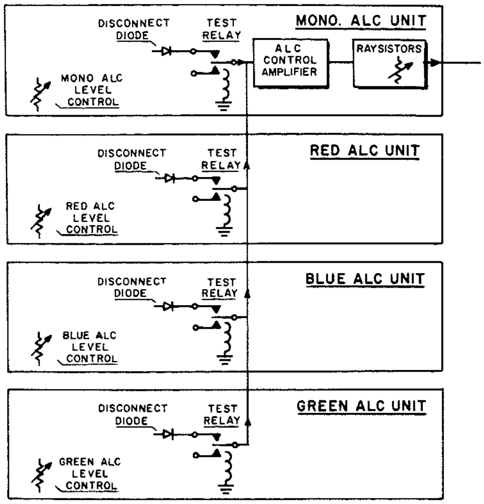


Fig. 10—Partial block diagram of ALC units in four-channel film chain.

diodes. Thus, depending on the program material, either the monochrome ALC unit or one of the color units will control the light level. The transfer of control from one unit to another is smooth and automatic once the ALC system is setup.

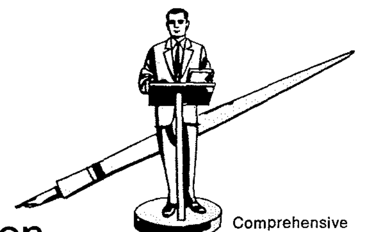
Setup procedure

To facilitate the ALC setup procedure, test relays are used (Fig. 10). Each ALC unit has a test relay which allows its control circuit to operate independently of the other three. When a test relay is energized, the control circuit of that unit is disconnected from the ALC control amplifier. The ALC level control of each unit must be adjusted with the control circuits of the other three units disconnected. For example, when adjusting the monochrome ALC level control, the test relay in the monochrome unit must be de-energized and the test relays of red, blue, and green units must be energized.

Using a monochrome picture source such as a test pattern or target, each ALC level control in turn is adjusted for proper level at the output of the chain. After this adjustment is made, all four test relays are de-energized and the light level will be controlled automatically.

Conclusion

The ALC system described has been in constant use at the NBC color film facilities in Burbank for approximately one year and at NBC in New York for about four months. It has proved to be a practical system which operates well and is simple to setup.



Pen and Podium

Comprehensive subject-author index to Recent RCA technical papers

Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal in which it appears from your library, or write or call the author for a reprint. For information on unpublished verbal presentations, write or call the author. (The author's RCA Division appears parenthetically after his name in the subject-index entry.) For additional assistance in locating RCA technical literature, contact: **RCA Staff Technical Publications, Bldg. 2-8, RCA, Camden, N.J. (Ext. PC-4018).**

This index is prepared from listings provided bimonthly by RCA Division Technical Publcations Administrators and Editorial Representatives—who should be contacted concerning errors or omissons (see inside back cover).

Subject index categories are based upon the Thesaurus of Engineering Terms, Engineers Joint Council, N.Y., 1st Ed., May 1964.

Subject Index

Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. An author may have more than one paper for each subject category.

ACOUSTICS

THERMAL AGITATION Noise, Microphone—H. F. Olson (Labs., Pr) Acoustical Society of America, Atlantic City, N.J.; 4/24/70

AIRCRAFT INSTRUMENTS

SOLID-STATE POWER CONTROLLERS for Aircraft Electrical Power Systems—R. D. Gold, F. S. Kamp (EC, Som) SAE Transportation Meeting, New York; 4/20-23/70; *SAE Meeting Preprint;* 4/70

AMPLIFICATION

OPERATIONAL TRANSCONDUCTANCE AMPLIFIER—A New Circuit Dimension—C. F. Wheatley (EC, Som) EEE Seminar on Integrated Circuits, Paris, France; 3/31-4/3/70

ANTENNAS

ITOS Deployable Antenna Array—J. Kara (AED, Pr) SAMSO Symposium, El Segundo, Calif.; 4/9-10/70

CHECKOUT

TEST DATA, What to do with—F. W. Wehrfritz (EC, Som) American Society for Quality Control Meeting, Allentown-Bethlehem Section, Pa.; 3/5/70

TIME SHARING TEST SYSTEMS with Centrally Controlled Test Stations—E. D. Wyant (ASD, Burl) NEPCON-West, Anaheim, Calif.; 2/11/70

CIRCUIT ANALYSIS

DELAY MODULATION—M. Hecht (AED, Pr) and A. A. Guida (Labs., Pr) *Proceedings of the IEEE;* 7/69 and 1/70

NONLINEARITY EFFECTS in Receiver Circuits, Designing for the Reduction of—R. L. Ernst, W. Y. Pan (DSCD, Som) 1970 IEEE International Convention, New York, N.Y.; 3/25/70; *Digest*

POWER HYBRID CIRCUITS, Design and Application of—H. R. Meisel (EC, Som) New York Chapter of Society of Hybrid Microelectronics; 3/3/70

CIRCUITS, INTEGRATED

ARRAY DESIGN, Integrated Circuits in—W. Patton, D. Staiman (MSR, Mrstn) New York Hilton; 3/23-26/70

COLOR TV to LIC's, The Transition of—R. A. Santilli (EC, Som) IEEE International Convention, New York, N.Y.; 3/23-26/70; IEEE Convention Digest; 3/70

DIGITAL FILTER Building Blocks for LSI Technologies—W. A. Clapp (ATL, Cam) IEEE Convention and Exhibition, New York, N.Y.; 3/23-26/70

IMPROVED INSULATORS for Microelectronics—K. H. Zaininger (Labs, Pr) IBM, East Fishkill Facility, New York; 3/12/70

IMPROVED INSULATORS for Microelectronic Applications—K. H. Zaininger (Labs., Pr) International Conference on Advanced Microelectronics, Paris, France; 4/6-10/70

INTEGRATED-CIRCUIT TECHNOLOGY, The Anatomy of—H. Johnson (Labs., Pr) *IEEE Spectrum,* Vol. 7, No. 2; 2/70

LUMPED-CONSTANT MIC—R. E. Kleppinger (EC, Som) Symposium on Microwave Integrated-Circuit Technology, NASA-Goddard Research Center; 3/10/70; *Symposium Proceedings;* 3/70

MICROELECTRONIC INTERCONNECTION PROCESSES, Promises and Problems of—A. S. Rose (EC, Som) IEEE International Convention, New York, N.Y.; 3/23-26/70; *IEEE Convention Digest;* 3/70

MONOLITHIC INTEGRATED CIRCUITS, The ABC's of—M. V. Hoover (EC, Som) IEEE Section Meeting, Peoria, Ill.; 4/23/70

PROCESSOR ARRAY, COS/MOS Parallel—A. Alaspa, A. Dingwall (ASD, Burl) International Solid State Circuits Conference, Phila., Pa.; 2/19/70; *ISSCC Digest*

CIRCUITS, PACKAGED

POWER DEVICE PACKAGING—S. Silverstein (EC, Som) Computer Element Committee of IEEE Packing—S. Silverstein (EC, Som) Computer Element Committee of IEEE Packing Group, New York, N.Y.; 3/5/70

SEMICONDUCTOR PACKAGING in the 70's—V. J. Lukach (EC, Som) Brooklyn Polytechnic Institute Packaging Conf., New York; 3/16/70

COMMUNICATIONS COMPONENTS

OSCILLATOR, Microstrip High-Power, High Efficiency Avalanche-Diode—S. G. Liu (Labs., Pr) *IEEE Trans. on Microwave Theory and Techniques,* Vol. MMT-17, No. 12; 12/69

TRANSFERRED-ELECTRON OSCILLATORS, High-Power L- and S-Band—B. E. Berson, R. E. Enstrom, J. F. Reynolds (EC, Pr) *RCA Review;* 3/70

TRANSFERRED-ELECTRON OSCILLATORS and Amplifiers, GaAs—F. Sterzer (EC, Pr) IEEE International Convention, New York, N.Y.; 3/23-26/70; *IEEE Convention Digest;* 3/70

COMPUTER APPLICATIONS

RCA PATENT OPERATIONS, A Computer System for—M. S. Winters (Labs., Pr) Licensing Executives Society, Inc., Eastern Regional Meeting, N.Y., N.Y.; 4/20/70

COMPUTER COMPONENTS

PROCESSOR ARRAY, COS/MOS Parallel—A. Alaspa, A. Dingwall (ASD, Burl) International Solid State Circuits Conference, Phila., Pa.; 2/19/70; *ISSCC Digest*

COMPUTER STORAGE

HOLOGRAM STORAGE AND RETRIEVAL in Photochromic Strontium Titanate Crystals—J. J. Amodei, D. R. Bosomworth (Labs., Pr) *Applied Optics,* Vol. 8, No. 12; 12/69

HOLOGRAPHIC OPTICAL MEMORIES, A Photodetector Array for—J. M. Assour, R. D. Lohman (Labs., Pr) *RCA Review,* Vol. 30, No. 4; 12/69

HOLOGRAPHY and the Promise of Optical Memories—J. A. Rajchman (Labs., Pr) Computer Science Forum, Columbia University, New York; 4/8/70

OPTICAL MEMORIES, Present and Future of—W. F. Kosonocky (Labs., Pr) Electrical Engineering Department, Princeton University; 4/7/70

COMPUTER SYSTEMS

SMALL COMPUTERS, Characteristics and Selection of—A. L. Linton (GSD, Dayton) 1970 IEEE Convention; 3/70; *Conference Digest*

CONTROL SYSTEMS

AUTOMATION of Materials Research, A Step Toward—J. J. Hanak (Labs., Pr) Scandinavian Sputtering Conference and School, Copenhagen, Denmark; 4/20-22/70

DYNAMICS CONTROL for Operational Spacecraft—W. Lindorfer (AED, Pr) 3rd IFAS Symposium, Toulouse, France; 3/4/70

NUMERICAL CONTROL—S. T. Villanyi (EC, Lanc) University of Toronto Seminar in Industrial Engineering; 3/16/70

SOLID-STATE POWER CONTROLLERS for Aircraft Electrical Power Systems—R. D. Gold, F. S. Kamp (EC, Som) Transportation Meeting, New York; 4/20-23/70; *SAE Meeting Preprint;* 4/70

DISPLAYS

FACSIMILE ART, Advancements in the—K. H. Fishbeck, D. A. Ross (Labs., Pr) IEEE Convention, New York Coliseum, N.Y.; 3/23-26/70

TELEVISION DISPLAY, A Reflex Electro-Optic Light Valve—D. H. Pritchard (Labs., Pr) *RCA Review,* Vol. 30, No. 4; 12/69

DOCUMENTATION

ENGINEERING DATA RETRIEVAL, The Utilization of Computer Output Microfilm for—G. S. Black (MSR, Mrstn) MIS Technical Committee, Phila., Pa.; 11/25/69

IDEAS INTO PRINT, Speeding—D. Meyerhofer (Labs., Pr) *Laser Focus,* Vol. 6, No. 2; 2/70

NEW PRODUCT RELEASES, How to Prepare Good—H. K. Mintz (ASD, Burl) *Industrial Marketing;* 2/70

PATENTS Pay for Engineers—The Engineer's Point of View—J. A. van Raalte (Labs., Pr) IEEE Convention, New York Coliseum, N.Y.; 3/23-26/70

WRITING Better Memos—H. K. Mintz (ASD, Burl) *Chemical Engineering;* 1/26/70

ELECTROMAGNETIC WAVES

ELECTROMAGNETIC REFLECTION from an Extended Turbulent Medium—Cumulative Forward-Scatter Single Back-Scatter Approximation—D. A. de Wolf (Labs., Pr) Spring URSI Meeting, Washington, D.C.; 4/16/70

EMPLOYMENT OPPORTUNITIES for Electrical Engineers in the Electronics Industry, Specialty—F. Klawsnik (MSR, Mrstn) New York University; 2/24/70

HYBRID TECHNOLOGY, Training Engineers in—H. Fenster (DME, Som) Winter Meeting of Keystone Chapter of ISHM, Sheraton Inn, Ft. Washington, Pa.; 2/18/70

IMAGE DISSECTION AND CONVERSION at Nonvisible Wavelengths—B. J. Levin, N. H. Farhat (ATL, Cam) *Applied Optics,* Vol. 9, No. 3; 3/70

RAMAN SCATTERING in $SrTiO_3$, Effect of Uniaxial Stress on—W. J. Burke, R. J. Pressley (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

SEMICONDUCTOR IMAGE CONVERTER, Millimeter Wave Image Conversion, Using a—B. J. Levin (ATL, Cam) *Proceedings of IEEE,* Vol. 59; 3/70

ENVIRONMENTAL ENGINEERING

HEAT PIPE, A New Thermodynamic Device—G. Y Eastman (EC, Lanc) Armstrong Research Laboratory, Lancaster, Pa.; 4/10/70

FILTERS, ELECTRIC

DIGITAL FILTER Building Blocks for LSI Technologies—W. A. Clapp (ATL, Cam) IEEE Convention and Exhibition, New York., N.Y.; 3/23-26/70

DIGITAL FILTER COEFFICIENTS, Sensitivity Factors for—M. S. Corrington (ATL, Cam) *Proceedings* of the Seminar on Digital Filtering, the State of the Art, IEEE Publications; 1/70

GEOPHYSICS

SEA SURFACE TEMPERATURE, Microwave and Infrared Radiometer Measurements of—C. Braun, D. Mercer, D. G. Shipley, K. J. Torok (AED, Pr) 1970 IEEE International Geoscience Electronics Symposium, Washington, D.C.; 4/14-17/70

GRAPHIC ARTS

ELECTRONIC PUBLICATION System, VideoComp—A. H. Coleman, H. W. Stewart (GSD, Dayton) STWP and Ventura College presentation; 4/4/70

ELECTROPHOTOGRAPHY to Computer Printout, Application of—D. A. Ross (Labs., Pr) IEEE Convention, New York Coliseum, N.Y.; 3/23-26/70

HOLOGRAM STORAGE AND RETRIEVAL in Photochromic Strontium Titanate Crystals—J. J. Amodei, D. R. Bosomworth (Labs., Pr) *Applied Optics,* Vol. 8, No. 12; 12/69

HOLOGRAPHY

HOLOGRAPHIC MOVIES for TV—W. J. Hannan (Labs., Pr) SMPTE Conference, Chicago, Ill.; 4/30/70

HOLOGRAPHIC OPTICAL MEMORIES, A Photodetector Array for—J. M. Assour, R. D. Lohman (Labs., Pr) *RCA Review,* Vol. 30, No. 4; 12/69

MAGNETIC HOLOGRAPHY, Reconstruction Effects in—R. S. Mezrich (Labs., Pr) INTERMAG Conference, Statler Hilton, Washington, D.C.; 4/21-24/70

OPTICAL MEMORIES, Holography and the Promise of—J. A. Rajchman (Labs., Pr) Computer Science Forum, Columbia University, New York; 4/8/70

VIDEO PLAYBACK SYSTEM, A Holographic—W. J. Hannan (Labs., Pr) IEEE Convention, New York Coliseum, N.Y.; 3/23-26/70

LABORATORY TECHNIQUES

ELECTRON MICROSCOPY, Applications of Transmission and Scanning—M. D. Coutts (Labs., Pr) Case Western Reserve University, Cleveland, Ohio; 3/19/70

SCANNING ELECTRON MICROSCOPE—M. D. Coutts (Labs., Pr) Summit Association of Scientists, Summit, N.J.; 2/19/70

SCANNING ELECTRON MICROSCOPY—M. D. Coutts (Labs., Pr) Seminar, Physics Department, Newark College of Engineering, Newark, N.J.; 2/18/70

SCANNING ELECTRON MICROSCOPY of Normal and Abnormal Articular Cartilage and Synovica—M. D. Coutts (Labs., Pr) Panel Discussion, American Academy of Orthopaedic Surgeon's Meeting, New Orleans, Louisiana; 1/22/70

LASERS

ATMOSPHERE PHASE JITTER Measurements for a HeNe Phase Locked Laser—A. L. Waksberg, J. I. Wood (LTD, Montreal) *Applied Optics,* Vol. 9, No. 2; 2/70

COMPOSITE MATERIALS for Superconducting and Semiconducting Applications—R. E. Enstrom (Labs., Pr) Lehigh University Seminar, Bethlehem, Pa.; 3/10/70

INDIUM ANTIMONIDE with Closely Spaced Coplanar Contacts, Coherent Emission from—G. A. Swartz (Labs., Pr) *Journal of Applied Physics,* Vol. 40, No. 13; 12/69

INJECTION LASER RELIABILITY: Theory and Experiment—H. Kressel, H. Lockwood, M. Ettenberg, H. Nelson (Labs., Pr) IEEE Reliability Physics Symposium, Las Vegas, Nevada; 4/7-9/70

OBSTACLE DETECTOR for High Speed Guideways, Laser—B. R. Clay, E. Kornstein, N. A. Luce, F. Bernstein (ASD, Burl) *Laser Journal,* Vol. 2, No. 2; 3-4/70

LOGIC THEORY

SORTING ALGORITHMS, An Algebra with Application to—S. Levy (Labs., Pr) Rutgers University, New Brunswick, N.J.; 2/27/70

MANAGEMENT

PERFORMANCE MEASUREMENT Study, Program—W. Waddington (MSR, Mrstn) ASPR Institute Seminar Performance Measurement Systems, Washington, D.C.; 4/7/70

PROJECTION, Casting Up a—G. K. Dye (Labs., Pr) *Management Accounting;* 2/70

SYSTEMS FUNCTION, Advanced Planning for the—F. P. Congdon (ASD, Burl) 11th Annual Southwest Systems Conf., Phoenix, Arizona; 3/13/70

MANUFACTURING

MICROELECTRONIC INTERCONNECTION PROCESSES, Promises and Problems of—A. S. Rose (EC, Som) IEEE International Convention, New York, N.Y.; 3/23-26/70; *IEEE Convention Digest;* 3/70

PRINTED-CIRCUIT FABRICATION, An All-Station Monitoring System for—H. Schellack (DCSD, Cam) *Electronic Packaging and Production,* Vol. 10, No. 2; 2/70

PURCHASE MATERIAL, True Cost of—G. J. Branin (MSR, Mrstn) ASQC Meeting, Downingtown, Pa.; 3/10/70

MATHEMATICS

FACTORS of Repunits—S. Yates (MS Mrstn) *Journal of Recreational Math matics;* 4/70

MAXIMUM A POSTERIORI ESTIMAT Solving the Equation for the—A. Guida (Labs., Pr) *Proceedings of th IEEE;* 5/9

MECHANICAL DEVICES

HEAT PIPE, A New Thermodynamic De vice—G. Y. Eastman (EC, Lanc) Arr strong Research Laboratory, Lancaste Pa.; 4/10/70

INTERNAL COMBUSTION ENGINE, A Index to Characterize the Overall Fu Economy of an—T. Szirtes (LTD, Mont *1969 Proc. of the American Society o Mechanical Engineers;* 3/70

PLASMA PHYSICS

PLASMAS INJECTED INTO SOLIDS; An alytic Study of the Diffusion Correction—R. B. Schilling, M. A. Lampert (EC, P *Journal of Applied Physics;* 3/70

PROPERTIES, ATOMIC

HOLES IN ANTHRACENE, Volume-Gen eration and Hall Mobility of—J. Dresne (Labs., Pr) American Physical Societ Meeting, Dallas, Texas; 3/23-26/70

PROPERTIES, MOLECULAR

CADMIUM SULPHIDE on Gallium Arse nide Substrates, The Epitaxial Growth o—B. J. Curtis, H. Brunner (Labs., Pr) *Journal of Crystal Growth,* Vol. 6, No. 3 3-4/70

CHOLESTERIC LIQUID CRYSTALS, Cap illary Viscometry of—W. Helfrich (Labs. Pr) Chapter of the book, *Liquid Crystals and Ordered Fluids,* Plenum Press; 1970

CRYSTAL GROWTH of Semiconducting Materials for the Electronics Industry—J. P. Dismukes (Labs., Pr) Graduate Seminar, Dept. of Ceramic Engineering, University of Illinois; 4/16/70 and Rice University, Houston, Texas; 4/17/70

GREEN ELECTROLUMINESCENT DIODES from Vapor Phase Epitaxial GaP, The Preparation and Properties of—B. J. Curtis, A. E. Widmer (Labs., Pr) Meeting on Electroluminescent Diodes at the IEEE, London, England; 3/4/70

LATTICE VIBRATIONS in GeTe, Soft Mode Behavior of—E. F. Steigmeier, G. Harbeke (Labs., Zurich) Spring Meeting of the German Physical Society, Greudenstadt, Germany; 4/6-11/70

LINEAR DICHROISM in Y-Doped CaF_2—D. L. Staebler (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

LIQUID CRYSTALS IV., Electro-Optic Effects in p-Alkoxybenzylidene-p-Aminoalkylphenones and Related Compounds—J. A. Castellano, M. T. McCaffrey (Labs., Pr) Chapter of the book, *Liquid Crystals and Ordered Fluids,* Plenum Press; 1970

LIQUID PHASE EPITAXY on Zinc Telluride—R. Widmer, D. P. Bortfeld, H. P. Kleinknecht (Labs., Pr) *Journal of Crystal Growth,* Vol. 6, No. 3; 3-4/70

LUMINESCENT SEMICONDUCTOR CRYSTALS Under Pressure, Techniques for Melt-Growth of—A. G. Fischer (Labs., Pr) *Journal of the Electrochemical Society,* Vol. 117, No. 2; 2/70

MIXED LIQUID-CRYSTAL SYSTEM, Some Experiments on Electric-Field-Induced Structural Changes in a—G. H. Heilmeier, L. A. Zanoni, J. E. Goldmacher (Labs., Pr) Chapter of the book, *Liquid Crystals and Ordered Fluids,* Plenum Press; 1970

NEMATIC LIQUID CRYSTALS, Dynamic Scattering and Related Electro-Optic Effects in—G. H. Heilmeier (Labs., Pr) Seminar, Eastman Kodak Research Laboratory, Rochester, N.Y.; 3/9/70

NEMATIC LIQUID CRYSTALS, Dynamic Scattering and Related Electro-Optic Effects in—G. H. Heilmeier (Labs., Pr) Seminar, University of Massachusetts, Amherst, Mass.; 3/2/70

NEMATIC LIQUID CRYSTALS and Their Applications, Electro-Optic Effects in—G. H. Heilmeier (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

NEMATIC LIQUID CRYSTALS, Further Studies of the Dynamic Scattering Mode in—G. H. Heilmeier, L. A. Zanoni, L. A. Barton (Labs., Pr) *IEEE Trans. on Electron Devices,* Vol. ED-17, No. 1; 1/70

NEMATIC LIQUID CRYSTALS, Orientational Oscillations in—G. H. Heilmeier, W. Helfrich (Labs., Pr) *Applied Physics Letters,* Vol. 6, No. 4; 2/15/70

PHASE TRANSITIONS OF LIQUID CRYSTALS, Effect of Electric Fields on the Temperature—W. Helfrich (Labs., Pr) *Physical Review Letters,* Vol. 24, No. 5 2/2/70

LYCRYSTALLINE LAYERS of ZnSiP$_2$ an Open-Flow System, The Prepara- n and Growth on—B. J. Curtis, P. Wild bs., Pr) *Materials Research Bulletin,* . 5, No. 2; 1970

NGLE-CRYSTAL FILMS of CdCr$_2$S$_4$, tical Properties of—S. B. Berger, L. strom (Labs., Pr) *Physical Review Let- s,* Vol. 23, No. 26; 12/29/69

NGLE CRYSTAL GROWTH and Some operties of HgCr$_{2-x}$ In$_x$Se$_4$ Solid Solu- ons—T. Takahashi, K. Minematsu, K. iyatani (Labs., Tokyo) The Spring Meet- g of the Physical Society of Japan; 4/70

RANSITION-METAL-DOPED SrTiO$_3$ RYSTALS, Nonlinear Coloration Effects —J. J. Amodei (Labs., Pr) *The Physical eview,* Vol. 188, No. 3; 12/15/69

ROPERTIES, SURFACE

URFACE STATE ANALYSIS, Determina- on of Surface Atom Geometry from— D. Levine, S. Freeman (Labs., Pr) Phy- cal Electronics Conference, Milwaukee, isconsin; 3/29-31/70

ROPERTIES, ACOUSTIC

COUSTIC WAVES in Solids, Amplifica- on of—M. C. Steele (Labs., Pr) Contin- um Mechanics Seminar, Princeton Uni- rsity; 4/29/70

QUID HELIUM BELOW 0.6K, Sound bsorption in—R. K. Wehner, R. Klein abs., Pr) *Physical Review Letters,* Vol. , No. 24; 12/15/69

ROPERTIES, CHEMICAL

NTERFACE PROPERTIES OF Si-(SiO$_2$)- l$_2$O$_3$ Structures—M. T. Duffy, A. G. Re- esz (Labs., Pr) *Journal of the Electro- hemical Society,* Vol. 117, No. 3; 3/70

ROPERTIES, ELECTRICAL

NERGY LEVELS of Ce^{2+} in CaF$_2$— R. C. lig, Z. J. Kiss, J. P. Brown, D. S. Mc- lure (Labs., Pr) *Physical Review,* Vol. 186, No. 2; 10/10/69

ENERGY LEVELS of the F$_A$ Center— R. C. Alig (Labs., Pr) American Physical Society Meeting, Washington, D.C.; 4/27- 30/70

HOT ELECTRON DISTRIBUTION in GaAs rom Photoluminescence Measurements, Derivation of the—P. D. Southgate, D. S. Hall, A. B. Dreeben (Labs., Pr) American hysical Society Meeting, Dallas, Texas; /23-26/70

RADIATIVE RECOMBINATION AND EQUILIBRIUM between Near-Band-Edge Tail States in n-Type GaAs—P. D. South- gate (Labs., Pr) *Journal of Applied Phys- cs,* Vol. 40, No. 13; 12/69

RARE EARTH F-CENTER Complexes in CaF$_2$, EPR of—E. S. Sabisky, C. H. Ander- son (Labs., Pr) American Physical Soci- ety Meeting, Dallas, Texas; 3/23-26/70

RECOMBINATION RATE CONSTANTS rom Time-Dependent Bulk Electrolumi- nescent Spectra in Compensated GaAs, The Derivation of—P. D. Southgate (Labs., Pr) *Journal of the Physics and Chemistry of Solids,* Vol. 31; 1970

SEMICONDUCTING CdF$_2$: Cyclotron Res- onance and Far-Infrared Properties, Polaron Effects in—D. R. Bosomworth (Labs., Pr) *The Physical Review,* Vol. 188, No. 3; 12/15/69

SEMICONDUCTOR PROPERTIES of PbTe, PbSe, PbS, and PbO, A Review of the—R. Dalven (EC, Pr) *Infrared Physics;* 3/70

TRANSITION IN THE SPINEL CdIn$_2$S$_4$, An Apparent Landau-Type Second Order —W. Czaja (Labs., Pr) *Physik der kondensierten Materie,* Vol. 10; 1970

PROPERTIES, OPTICAL

HOT ELECTRON DISTRIBUTION in GaAs rom Photoluminescence Measurements, Derivation of the—P. D. Southgate, D. S. Hall, A. B. Dreeben (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

INFRARED PHOTOEMISSION from Silicon—R. U. Martinelli (EC, Pr) *Applied Physics Letters;* 4/1/70

LUMINESCENT PROPERTIES of Energy Band Tail States—D. Refield, J. P. Wittke (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

OPTICAL ABSORPTION EDGE of SrTiO$_3$ —D. Refield, W. Burke (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

PHONON INTERFACE in Liquid Helium Films—C. H. Anderson, E. S. Sabisky (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

PHONON INTERFERENCE in Thin Films of Liquid Helium—C. H. Anderson, E. S. Sabisky (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23/70

PHONON-PHONON INTERACTIONS and Ultrasonic Attenuation in He II—R. K. wehner, R. Klein (Labs., Pr) *Helvitica Physica Acta,* Vol. 42, No. 7/8; 1969

PHOTOCHROMIC CaF$_2$—R. C. Alig (Labs., Pr) Hofstra University, Hempstead, Long Island, N.Y.; 4/20/70

PHOTOCHROMIC CaF$_2$—R. C. Alig (Labs., Pr) The J. Franck Institute, University of Chicago; 3/17/70

PHOTOCHROMIC CENTERS in CaF$_2$—R. C. Alig (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

PHOTOEMISSION of Holes and Electrons from Aluminum into Aluminum Oxide—A. M. Goodman (Labs., Pr) American Physical Society Meeting, Dallas, Texas; 3/23-26/70

RECOMBINATION RATE CONSTANTS from Time-Dependent Bulk Electroluminescent Spectra in Compensated GaAs, The Derivation of—P. D. Southgate (Labs., Pr) *Journal of the Physics and Chemistry of Solids,* Vol. 31; 1970

RADAR

INSTRUMENTATION RADARS to Obtain Accurate Real-Time Tracking Data, Calibration of—D. J. Dempsey (MSR, Mrstn) AIAA Meeting—Princeton Conference on Guidance Control and Flight Mechanics; 8/21/69

LM RENDEZVOUS RADARS for Project Apollo—J. D. Johnson (ASD, Burl) abstract published in *The Reflector,* Vol. 18, No. 8; 4/70

RADIATION DETECTION

MICROWAVE AND INFRARED RADIOMETER Measurements of Sea Surface Temperature—C. Braun, D. Mercer, D. G. Shipley, K. J. Torok (AED, Pr) 1970 IEEE International Geoscience Electronics Symposium, Washington, D.C.; 4/14-17/70

NIGHT-SURVEILLANCE SYSTEMS for Law Enforcement—R. G. Stoudenheimer, R. D. Faulkner (EC, Lanc) Symposium on Law-Enforcement Science and Technology, Chicago, Ill.; 3/31-4/2/70 and Conference on Electronic Crime Countermeasures, Kentucky; 4/16-18/70; *Proceedings*

PHOTOCONDUCTIVE DETECTORS at 10.6 Microns with R. F. Biasing, Performance of HgGe and Hg$_{1-x}$Cd$_x$Te—M. Markulec (AED, Pr) National Infrared Information Symposium (IRIS); *Proceedings of the IRIS,* Colorado Springs, Colo.; 5/5-7/70

UPCONVERSION: A New Technique for Infrared to Visible Conversion—A. H. Firester (Labs., Pr) IEEE Convention, New York Coliseum, N.Y.; 3/23-26/70

RELIABILITY

INJECTION LASER RELIABILITY: Theory and Experiment—H. Kressel, H. Lockwood, M. Ettenberg, H. Nelson (Labs., Pr) IEEE Reliability Physics Symposium, Las Vegas, Nevada; 4/7-9/70

MNOS MEMORY TRANSISTORS, The Effects of SiO$_2$ Thickness Variation on the Operation of Direct-Tunneling Mode—E. C. Ross, A. M. Goodman, M. T. Duffy (Labs., Pr) 1970 Reliability Physics Symposium, Las Vegas, Nevada; 4/7-9/70

QUALITY MINDED Work Force, Developing a—E. S. Shecter (MSR, Mrstn) *Handbook of Modern Manufacturing Management Chapter* in Book; 4/70

RELIABILITY CONCEPTS for Space Programs—F. J. Gardiner (ASD, Burl) *TREND,* Vol. 9, No. 11; 3/70

SYSTEM RELIABILITY OBJECTIVE, What Must be Done to Meet a—B. Tiger (DCSD, Cam) American Society for Quality Control, Asheville, N.C.; 2/10/70

TEST DATA, What to do with—F. W. Wehrfritz (EC, Som) American Society for Quality Control Meeting, Allentown-Bethlehem Section, Pa.; 3/5/70

WNBC RADIO INSTALLATION—O. S. Paganuzzi (NBC, N.Y.) National Assoc. of Broadcasters, Chicago, Illinois; 4/7/70

SOLID-STATE DEVICES

EPITAXIAL GROWTH of ScN, A New High Bandgap Semiconductor—J. P. Dismukes, R. E. Novak, J. J. Tietjen (Labs., Pr) 8th Rate Earth Research Conference, Reno, Nevada; 4/19-22/70

HIGH-POWER UHF/MICROWAVE TRANSISTORS, Recent Developments in—H. C. Lee (EC, Som) IEEE Group on Microwave Theory and Techniques, Washington, D.C.; 4/14/70

MICROWAVE POWER TRANSISTORS— H. C. Lee (EC, Som) IEEE Southwest Conference, Dallas, Texas; 4/23/70; Conference *Proceedings;* 4/70

MNOS MEMORY TRANSISTORS, The Effects of SiO$_2$ Thickness Variation on the Operation of Direct-Tunneling Mode —E. C. Ross, A. M. Goodman, M. T. Duffy (Labs., Pr) 1970 Reliability Physics Symposium, Las Vegas, Nevada; 4/7-9/70

MOS TECHNOLOGY, The Use of Improved Insulators in—K. H. Zaininger (Labs., Pr) Science center, North American Rockwell, Thousand Oaks, Calif.; 3/4/70

TELEVISION BROADCASTING

TV TAPE for Automation of Station Breaks—B. L. Dickens, L. V. Hedlund (CES, Cam) NAB, Chicago, Ill.; 4/7/70

SPACECRAFT

APOLLO, RCA Participation in—D. B. Dobson (ASD, Burl) Electric League of Indianapolis, Ind.; 2/12/70

DYNAMICS CONTROL for Operational Spacecraft—W. Lindorfer (AED, Pr) 3rd IFAC Symposium Toulouse, France; 3/4/70

EARTH RESOURCES SATELLITE DATA, Multi-Discipline Applications for—C. R. Smith, P. Wood, (AED, Pr) AIAA Symposium on Earth Resources, Annapolis, Md.; 3/3/70

SUPERCONDUCTIVITY

COMPOSITE MATERIALS for Superconducting and Semiconducting Applications—R. E. Enstrom (Labs., Pr) Lehigh University Seminar, Bethlehem, Pa.; 3/10/70

TELEVISION BROADCASTING

INCREASING TV COVERAGE through Precise Frequency Control—W. L. Behrend (CES, Mds. Lds) NAB, Chicago, Ill; 4/8/70

SUPER 8 MM for News Film—S. Bajak (NBC, N.Y.) National Assoc. of Broadcaster, Chicago, Illinois; 4/7/70

SUPERCONDUCTING TRANSITION TEMPERATURE of the Transition Metals, The Effect of Grain Size on the—J. J. Hanak, J. I. Gittleman, J. P. Pellican, S. Bozowski (Labs., Pr) *Physics Letters,* Vol. 30A, No. 3; 10/6/69

TELEVISION EQUIPMENT

HIGH-DEFINITION RETURN-BEAM VIDICON CAMERA, Electron Optics and Signal Readout of—O. H. Schade, Sr. (EC, Hr) *RCA Review;* 3/70

HIGH-RESOLUTION TELEVISION SYSTEMS, Advances in—O. H. Schade, Sr. (EC, Hr) Optical Society of America Meeting, Phila., Pa.; 4/7-10/70

HORIZONTAL DEFLECTION for High-Definition Television Systems, Linear Solid-State—O. H. Schade, Jr. (EC, Som) *RCA Review;* 3/70

LOW LIGHT LEVEL Television—R. J. Gildea (ASD, Burl) Worcester Polytechnic Institute, IEEE Student Chapter, Worcester, Mass.; 3/3/70

VERTICAL DEFLECTION For High-Definition Television Systems, Stable Solid-State—O. H. Schade, Jr. (EC, Som) RCA Review; 3/70

TELEVISION RECEIVERS

COLOR TV to LIC's, The Transition of— R. A. Santilli (EC, Som) IEEE International Convention, New York, N.Y.; 3/23-26/70; *IEEE Convention Digest;* 3/70

COLOR TELEVISION Principles and Servicing—R. J. Butler (NBC, N.Y.) IEEE Communication Technology Group, New York, N.Y.; 4/8/70

TRANSMISSION LINES

COPLANAR WAVEGUIDE: A surface Strip Transmission Line Suitable for Nonreciprocal Gyromagnetic Device Applications—C. P. Wen (Labs., Pr) *IEEE Trans. on Microwave Theory and Techniques,* Vol. MTT-17, No. 12; 12/69

COPLANAR WAVEGUIDES, Attenuation Characteristics of—C. P. Wen (Labs., Pr) *Proceedings of the IEEE,* Vol. 58, No. 1; 1/70

FERRITE WAVEGUIDE CIRCULATOR, A Latching Ring-and-Post—T. E. Walsh, W. W. Siekanowicz, R. W. Paglione (EC, Pr) *IEEE Trans. on Microwave Theory and Techniques;* 4/70

MILLIMETER THROUGH WAVEGUIDE SYSTEM with Nonreciprocal Elements, Integrated-Circuit Metalized Plastic Symmetrical—C. P. Wen (Labs., Pr) *RCA Review,* Vol. 30, No. 4; 12/69

TUBES, ELECTRON

GaP(Cs)-DYNODE Photomultipliers, Recent Developments in—H. R. Krall, D. E. Persyk, F. A. Helvy (EC, Lanc) Semiconductor and Scintillation Counter Symposium, Washington, D.C.; 3/11/70

IMAGE ISOCON—A Versatile, High-Quality Camera Tube—E. M. Musselman (EC, Lanc) SPSE Symposium on Electronic maging Systems, Palo Alto, Calif.; 4/13-15/70

VACUUM

CHEMISTRY in High Vacuum—J. J. Moscony (EC, Lanc) Millersville State College, Pa.; 3/9/70

GENERAL TECHNOLOGY

CONCEPT ENGINEERING, Interdisciplinary Aspects of Engineering: The Environment of—H. Wetzstein (ASD, Burl) *EEE Trans. on Aerospace & Electronic Systems;* 3/70

MECHANICAL ENGINEER in the Electronics Industry, The Role of the—J. M. Herzlinger (ASD, Burl) Northeastern University Student Chapter of ASME; 2/10/70

Author Index

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

ADVANCED TECHNOLOGY LABORATORIES

Clapp, W. A. circuits, integrated
Clapp, W. A. filters, electric
Corrington, M. S. filters, electric
Farhat, N. H. electromagnetic waves
Levin, B. J. electromagnetic waves
Levin, B. J. electromagnetic waves

ASTRO-ELECTRONIC DIVISION

Braun, C. geophysics
Braun, C. radiation detection
Guida, A. A. circuit analysis
Hecht, M. circuit analysis
Kara, J. antennas
Lindorfer, W. control systems
Lindorfer, W. spacecraft
Markulec, M. radiation detection
Mercer, D. geophysics
Mercer, D. radiation detection
Shipley, D. G. geophysics
Shipley, D. G. radiation detection
Smith, C. R. geophysics
Smith, C. R. spacecraft
Torok, K. J. geophysics
Torok, K. J. radiation detection
Wood, P. geophysics
Wood, P. spacecraft

AEROSPACE SYSTEMS DIVISION

Alaspa, A. circuits, integrated
Alaspa, A. computer components
Bernstein, F. lasers
Clay, B. R. lasers
Congdon, F. P. management
Dingwall, A. circuits, integrated
Dingwall, A. computer components
Dobson, D. B. spacecraft
Gardiner, F. J. reliability
Gildea, R. J. television equipment
Herzlinger, J. M. general technology
Johnson, J. D. radar
Kornstein, E. lasers
Luce, N. A. lasers
Mintz, H. K. documentation
Mintz, H. K. documentation
Wetzstein, H. general technology
Wyent, E. D. checkout

COMMERCIAL ELECTRONIC SYSTEMS

Behrend, W. L. television broadcasting
Dickens, B. L. television broadcasting
Hedlund, L. V. television broadcasting

DEFENSE COMMUNICATIONS SYSTEMS DIVISION

Ernst, R. L. circuit analysis
Pan, W. Y. circuit analysis
Schellack, H. manufacturing
Tiger, B. reliability

DEFENSE MICROELECTRONICS DIVISION

Fenster, H. education

ELECTRONIC COMPONENTS

Berson, B. E. communications components
Dalven, R. properties, electrical
Eastman, G. Y. environmental engineering
Eastman, G. Y. mechanical devices
Enstrom, R. E. communications components
Faulkner, R. D. radiation detection
Gold, R. D. aircraft instruments
Gold, R. D. control systems
Helvy, F. A. tubes, electron
Hoover, M. V. circuits, integrated
Kamp, F. S. aircraft instruments
Kamp, F. S. control systems
Kleppinger, R. E. circuits, integrated
Krall, H. R. tubes, electron
Lampert, M. A. plasma physics
Lee, H. C. solid-state devices
Lee, H. C. solid-state devices
Lukach, V. J. circuits, Packaged
Martinelli, R. U. properties, optical
Meisel, H. R. circuit analysis
Moscony, J. J. vacuum
Musselman, E. M. tubes, electron
Paglione, R. W. transmission lines
Persyk, D. E. tubes, electron
Reynolds, J. F. communications components
Rose, A. S. circuits, integrated
Rose, A. S. manufacturing
Santilli, R. A. circuits, integrated
Santilli, R. A. television receivers
Schade, Sr., O. H. television equipment
Schade, Sr., O. H. television equipment
Schade, Sr., O. H. television equipment
Schade, Sr., O. H. television equipment
Schilling, R. B. plasma physics
Siekanowicz, W. W. transmission lines
Silverstein, S. circuits, packaged
Sterzer, F. communications components
Stoudenheimer, R. G. radiation detection
Villanyi, S. T. control systems
Walsh, T. E. transmission lines
Wehrfritz, F. W. checkout
Wehrfritz, F. W. reliability
Wheatley, C. F. amplification

GRAPHIC SYSTEMS DIVISION

Coleman, A. H. graphic arts
Linton A. L. computer systems
Stewart, H. W. graphic arts

LIMITED, MONTREAL

Szirtes, T. mechanical devices
Waksberg, A. L. lasers
Wood, J. I. lasers

MISSILE AND SURFACE RADAR DIVISION

Black, G. S. documentation
Branin, G. J. manufacturing
Dempsey, D. J. radar
Klawsnik, F. education
Patton, W. circuits, integrated
Shecter, E. S. reliability
Staiman, D. circuits, integrated
Waddington, W. management
Yates, S. mathematics

NATIONAL BROADCASTING COMPANY

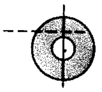
Bajak, S. television broadcasting
Butler, R. J. television receivers
Paganuzzi, O. S. reliability

LABORATORIES

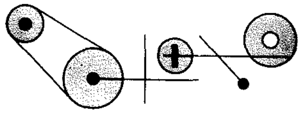
Alig, R. C. electrical
Alig, R. C. properties, optical
Alig, R. C. properties, optical
Alig, R. C. properties, optical
Amodei, J. J. computer storage
Amodei, J. J. graphic arts
Amodei, J. J. properties, molecular
Anderson, C. H. properties, electrical
Anderson, C. H. properties, optical
Anderson, C. H. properties, optical
Assour, J. M. computer storage
Assour, J. M. holography
Berger, S. B. properties, molecular
Bortfeld, D. P. properties, molecular
Bosomworth, D. R. computer storage
Bosomworth, D. R. graphic arts
Bosomworth, D. R. properties, electrical
Bozowski, S. superconductivity
Brown, J. P. properties, electrical
Brunner, H. properties, molecular
Burke, W. J. electromagnetic waves
Burke, W. properties, optical
Castellano, J. A. properties, molecular
Coutts, M. D. laboratory techniques
Coutts, M. D. laboratory techniques
Coutts, M. D. laboratory techniques
Coutts, M. D. laboratory techniques
Curtis, B. J. properties, molecular
Curtis, B. J. properties, molecular
Curtis, B. J. properties, molecular
Czaja, W. properties, electrical
deWolf, D. A. electromagnetic waves
Dismukes, J. P. properties, molecular
Dismukes, J. P. solid-state devices
Dreeben, A. B. properties, electrical
Dreeben, A. B. properties, optical
Dresner, J. properties, atomic
Duffy, M. T. properties, chemical
Duffy, M. T. reliability
Duffy, M. T. solid-state devices
Dye, G. K. management
Ekstrom, L. properties, molecular
Enstrom, R. E. lasers
Enstrom, R. E. superconductivity
Ettenberg, M. lasers
Ettenberg, M. reliability
Firester, A. H. radiation detection
Fischbeck, K. H. displays
Fischer, A. G. properties, molecular
Freeman, S. properties, surface
Gittlemen, J. I. superconductivity
Goldmacher, J. E. properties, molecular
Goodman, A. M. properties, optical
Goodman, A. M. reliability
Goodman, A. M. solid-state devices
Guida, A. A. mathematics
Hall, D. S. properties, electrical
Hall, D. S. properties, optical
Hanak, J. J. superconductivity
Hanak, J. J. control systems
Hannan, W. J. holography
Hannan, W. J. holography
Heilmeier, G. H. properties, molecular
Heilmeier, G. H. properties, molecular
Heilmeier, G. H. properties, molecular
Heilmeier, G. H. properties, molecular
Heilmeier, G. H. properties, molecular
Heilmeier, G. H. properties, molecular

Helfrich, W. properties, molecular
Helfrich, W. properties, molecular
Helfrich, W. properties, molecular
Johnson, H. circuits, integrated
Kiss, Z. J. properties, electrical
Klein, R. circuit analysis
Klein, R. properties, acoustic
Klein, R. properties, optical
Kleinknecht, H. P. properties, molecular
Kosonocky, W. F. computer storage
Kressel, H. lasers
Kressel, H. reliability
Levy, S. logic theory
Levy, S. logic elements
Liu, S. G. communications components
Lockwood, H. lasers
Lockwood, H. reliability
Lohman, R. D. computer storage
Lohman, R. D. holography
McCaffrey, M. T. properties, molecular
McClure, D. S. properties, electrical
Meyerhofer, D. documentation
Mezrich, R. S. holography
Minematsu, K. properties, molecular
Miyanti, K. properties, molecular
Nelson, H. lasers
Nelson, H. reliability
Novak, R. E. solid-state devices
Olson, H. F. acoustics
Pellican, J. P. superconductivity
Pressley, R. J. electromagnetic waves
Pritchard, D. H. displays
Rajchman, J. A. computer storage
Rajchman, J. A. holography
Refield, D. properties, optical
Refield, D. properties, optical
Revesz, A. G. properties, chemical
Ross, D. A. displays
Ross, D. A. graphic arts
Ross, E. C. reliability
Ross, E. C. solid-state devices
Sabisky, E. S. properties, electrical
Sabisky, E. S. properties, optical
Sabisky, E. S. properties, optical
Southgate, P. D. properties, electrical
Southgate, P. D. properties, optical
Southgate, P. D. properties, electrical
Southgate, P. D. properties, electrical
Southgate, P. D. properties, optical
Staebler, D. L. properties, molecular
Steele, M. C. properties, acoustic
Steigmeier, E. F. properties, molecular
Swartz, G. A. lasers
Tietjen, J. J. solid-state devices
vanRaalte, J. A. documentation
Wehner, R. K. circuit analysis
Wehner, R. K. properties, acoustic
Wehner, R. K. properties, optical
Wen, C. P. transmission lines
Wen, C. P. transmission lines
Wen, C. P. transmission lines
Widmer, A. E. properties, molecular
Widmer, R. properties, molecular
Wild, P. properties, molecular
Winters, M. S. computer applications
Wittke, J. P. properties, optical
Zaininger, K. H. circuits, integrated
Zaininger, K. H. circuits, integrated
Zaininger, K. H. solid-state devices
Zanoni, L. A. properties, molecular

Patents Granted



to RCA Engineers



As reported by RCA Domestic Patents, Princeton

Defense Communications Systems Division

Analog Feedback Implementation of Gaussian Modulated Signals—A. Newton (DCSD, Camden) U.S. Pat. 3,502,987; March 24, 1970; Assigned to U.S. Government

Varying-Bandwidth Frequency-Shift Keying Receiver—J. Klapper (DCSD, Camden) U.S. Pat. 3,510,779; May 5, 1970

Drum Construction for Helical Scan Tape Recorder—Furman Donald Kell (DCSD) Camden) U.S. Pat. 3,510,604; May 5, 1970

Switching Circuit—Frederick Orie Bartholomew (DCSD, Camden) U.S. Pat. 3,509,362; April 28, 1970; Assigned to U.S. Government

Code Converter—Sidney Wald and Leroy Henry Werner (DCSD, Camden) U.S. Pat. 3,505,667; April 7, 1970; Assigned to U.S. Government

Astro Electronics Division

Thermoelectric Generator Suitable for use at Elevated Temperatures in a Vacuum—Seymour Heywood and Rudolph Reinhold Laesig, (AED, Hightstown) U.S. Pat. 3,510,363; May 5, 1970; Assigned to U.S. Government

Helical Coaxial Resonator RF Filter—Myron Walter Maxwell (AED, Hightstown) U.S. Pat. 3,437,959; April 8, 1969; Assigned to U.S. Government

Retrodirective Phased Array Antenna for a Spacecraft—John Donald Kiesling (AED, Hightstown) U.S. Pat. 3,500,411; March 10, 1970

Aerospace Systems Division

Digital Logic Apparatus—Joseph Elliott Annis (ASD, Burlington, Mass.) U.S. Pat. 3,500,062; March 10, 1970

Centrifugal Force Controlled Transducer—Abraham Lichowsky (ASD, Van Nuys, Calif.) U.S. Pat. 3,505,744; April 14, 1970

Electronic Components

Methods of Etching Semiconductive Devices Having Lead-Containing Elements—Charles Samuel Jackson (EC, Somerville, N.J.) U.S. Pat. 3,505,132; April 7, 1970

Integrated Circuit Planar Transistor—Andrew Gordon Francis Dingwall (EC, Somerville, N.J.) U.S. Pat. 3,510,736; May 5, 1970

Load Sensing and Compensating Control Circuits—Austin Joseph Mortimer (EC, Mountaintop, Pa.) U.S. Pat. 3,510,743; May 5, 1970

Impedance Control Using Transferred Electron Diodes—Fred Sterzer (EC, Princeton, N.J.) U.S. Pat. 3,510,805; May 5, 1970

Method of Dicing Semiconductor Wafers—Joseph Michael Bielen and Gilbert Victor Morris (EC, Mountaintop, Pa.) U.S. Pat. 3,507,426; April 21, 1970

Method of Fabricating Photomasks—Joseph Lawrence McLaughlin (EC, Somerville, N.J.) U.S. Pat. 3,507,592; April 21, 1970

Thyristor Controlled Voltage Regulating Circuit—Thomas Charles McNulty (EC, Mountaintop, Pa.) U.S. Pat. 3,509,450; April 28, 1970

Encapsulated Optical Semiconductor Device—George Andrew Kupsky (EC, Somerville, N.J.) U.S. Pat. 3,512,027; May 12, 1970

High Voltage Transient Protection for an Insulated-Gate Field-Effect Transistor—Heshmat Khajezadeh and Lewis Alfred Jacobus, Jr. (EC, Somerville, N.J.) U.S. Pat. 3,512,058; May 12, 1970

Transistor Electrical Circuit with Collector Voltage Stabilization—Jack Avins (EC, Somerville, N.J.) U.S. Pat. 3,512,098; May 12, 1970

Color Display Tube Whose Blue Emitter is a Silver-Activated Zinc Sulphide Containing Only One of Magnesium, Calcium, Strontium and Barium—Franklin Glenn Bushey (EC, Marion, Ind.) U.S. Pat. 3,497,749; February 24, 1970

Switching Type Voltage and Current Regulator and Load Therefor—Peter Schiff (EC, Somerville, N.J.) U.S. Pat. 3,500,127; March 10, 1970

Random-Access Memory Organization—Francis David Cassidy (EC, Needham, Mass.) U.S. Pat. 3,500,360; March 10, 1970

Process for Preparing Phosphor—Martin Robert Royce (EC, Lancaster, Pa.) Soren Milton and Perry Neil Yocom (Labs., Princeton, N.J.) U.S. Pat. 3,502,590; March 24, 1970

Method for Glass to Glass Sealing Utilizing Softened and Rigid Circumferential Segments—Herbert Claire Werner (EC, Lancaster, Pa.) U.S. Pat. 3,503,727; March 31, 1970

Transistor with Distributed Resistor Between Emitter Lead and Emitter Region—Edward O'Easten Johnson and William Merle Webster (EC, Somerville, N.J.) U.S. Pat. 3,504,239; March 31, 1970

Industrial and Automation Systems

Speed Control for Automotive Vehicles—Daniel Aaron Wisner (CES, Plymouth, Mich.) U.S. Pat. 3,511,329; May 12, 1970

True Presence Vehicle Detector Including Means to Distinguish between Slow Ambient Changes and Changes due to the Presence of a Vehicle—Eugene Joseph Marcinkiewicz (CES, Plymouth), Mich.) U.S. Pat. 3,500,310; March 10, 1970

Laboratories

Optical Data Selection and Display—Philip Joseph Donald (Labs., Princeton, N.J.) U.S. Pat. 3,504,609; April 7, 1970

Method of Making a Laminated Ferrite Memory—Chandler Wentworth (Labs., Princeton, N.J.) U.S. Pat. 3,505,139; April 7, 1970

Video Circuits for Color Television Receivers—Roland Norman Rhodes and Albert Macovski (Labs., Princeton, N.J.) U.S. Pat. 3,510,573; May 5, 1970

Gain Controlled Transistor Amplifier with Constant Bandwidth Operation over the AGC Control Range—Yoshihiro Okuno (Labs., Japan, Tokyo) U.S. Pat. 3,510,580; May 5, 1970

Combination of a Container for a Liquid and Means for Dispersing the Liquid—Marvin Allan Leedom (Labs., Princeton, N.J.) U.S. Pat. 3,507,252; April 21, 1970

Sync Slipper—Robert Fincher Sanford (Labs., Princeton, N.J.) U.S. Pat. 3,507,986; April 21, 1970

Logic Circuity—Robert Owen Winder (Labs., Princeton, N.J.) U.S. Pat. 3,508,076; April 21, 1970

High Efficiency Light Polarization System—Joseph Wilder and Walter Joseph Gorkiewicz (Labs., Princeton, N.J.) U.S. Pat. 3,508,809; April 28, 1970

Motionless Hologram Imaging—Hendrik Jurgen Gerritsen and David Leslie Greenaway (Labs., Princeton, N.J.) U.S. Pat. 3,511,553; May 12, 1970

Nematic Liquid Crystal Mixtures for use in a Light Valve—Joel Edward Goldmacher and George Harry Heilmeier (Labs., Princeton, N.J.) U.S. Pat 3,499,702; March 10, 1970

Electromechanical Switch—Abraham Harel (Labs., Princeton, N.J.) U.S. Pat. 3,500,010; March 10, 1970; Assigned to U.S. Government

Unitary Q-Switch Laser Device—Peter Valere Goedertier Labs., Princeton, N.J.) U.S. Pat. 3,500,234; March 10, 1970; Assigned to U.S. Government

Variable Frequency Oscillator with Constant Amplitude Output—Richard Earl Werner (Labs., Princeton, N.J.) U.S. Pat. 3,500,246; March 10, 1970

Selective Etching of Chromium-Silica Laminates—Ralph David DiStefano (Labs., Princeton, N.J.) U.S. Pat. 3,502,555; March 24, 1970

Method and Apparatus for Detecting Light by Capacitance Change Using Semiconductor Material with Depletion Layer—Stuart Stanley Perlman and Bernard Goldstein (Labs., Princeton, N.J.) U.S. Pat. 3,502,884; March 24, 1970

Display Apparatus—George William Taylor (Labs., Princeton, N.J.) U.S. Pat. 3,503,551; March 31, 1970

Reduction of Turn-on Delay in Liquid Crystal Cell—Frank Jerome Marlowe (Labs., Princeton, N.J.) U.S. Pat. 3,503,672; March 31, 1970

Reduction of Turn-on Delay in Liquid Crystal Cell—George Harry Heilmeier and Louis Anthony Zanoni (Labs., Princeton, N.J.) U.S. Pat. 3,503,673; March 31, 1970

Solid State Clock—Steven Robert Hofstein (Labs., Princeton, N.J.) U.S. Pat. 3,505,804; April 14, 1970

Binary Arithmetic Circuits Employing Threshold Gates in which Both the Sum and Carry are Obtained in One Gate Delay Interval—Robert Owen Winder (Labs., Princeton, N.J.) U.S. Pat. 3,506,817; April 14, 1970

Networks of Elements for Implementing Threshold Functions—Robert Owen Winder (Labs., Princeton, N.J.) U.S. Pat. 3,506,845; April 14, 1970

Process for Preparing Phosphor—Martin Robert Royce (EC, Lancaster, Pa.) Soren Milton Thomsen and Perry Neil Yocom (Labs., Princeton, N.J.) U.S. Pat. 3,502,590; March 24, 1970

Consumer Electronics Division

Tape Reeling Search System with Transistor Search Amplifier—Dallas Roy Andrews (CED, Indianapolis, Ind.) U.S. Pat. 3,505,485; April 7, 1970

Transistorized Automatic-Gain-Controlled Amplifier—James Courtland Marsh, Jr. (CED, Indianapolis, Ind.) U.S. Pat. 3,510,579; May 5, 1970

Protection Circuits for Kinescopes—Edward Wesley Curtis (CED, Indianapolis, Ind.) U.S. Pat. 3,510,722; May 5, 1970

Ultra-High Frequency Transistor Oscillator—David John Carlson (CED, Indianapolis, Ind.) U.S. Pat. 3,510,802; May 5, 1970

Brightness Control Circuit—George Edward Anderson (CED, Indianapolis, Ind.) U.S. Pat. 3,502,807; March 24, 1970

Transistor Deflection Circuits—Roland Norman Rhodes and John Brewer Beck (CED, Indianapolis, Ind.) U.S. Pat. 3,502,935; March 24, 1970

Simplified Horizontal Dynamic Convergence Circuit—John Kenneth Allen (CED, Indianapolis, Ind.) U.S. Pat. 3,500,113; March 10, 1970

Information Systems

Counter Circuits—Anatole Turecki (CSD, W. Palm Beach, Fla.) U.S. Pat. 3,508,033; April 21, 1970

Signal Envelope Discriminator and Gating Circuit—Raymond Louis Giordano (CSD, Camden, N.J.) U.S. Pat. 3,505,537; April 7, 1970

Electronic Timer—Alfred Soon-Nam Sheng and Emile Hebert (CSD, Camden, N.J.) U.S. Pat. 3,505,541; April 7, 1970

Memory Line Selection Matrix for Application of Read and Write Pulses—Peter Ko-Chen Hsieh and Donald Hall Montgomery (CSD, Camden, N.J.) U.S. Pat. 3,500,359; March 10, 1970

Constant Tension—Constant Speed Drive by Means of a Tandem Motor Connection—George Victor Jacoby (CSD, Camden, N.J.) U.S. Pat. 3,501,682; March 17, 1970

Graphic Systems Division

Photocomposing Apparatus—James Francis Delany (GSD, Princeton, N.J.) U.S. Pat. 3,509,803; May 5, 1970

Deflection Corrector Circuit for Cathode Ray Tube—Richard Joseph Klensch (GSD, Princeton, N.J.) U.S. Pat. 3,512,039; May 12, 1970

Commercial Electronic Systems

Optical Multiplexing Apparatus—Charles Joseph Mangiaracina and Charles Boyd Meyer (CES, Camden, N.J.) U.S. Pat. 3,510,657; May 5, 1970

Slide Projector Including Two Light Paths and One Slide Magazine—William Francis Fisher (CES, Camden, N.J.) U.S. Pat. 3,501,231; March 17, 1970

Slide Projector Including Two Light Pa and One Slide Magazine—Arnel Edmu Jackson (CES, Camden, N.J.) U.S. 3,501,232; March 17, 1970

Television Camera Power Supply—Lu John Bazin (CES, Camden, N.J.) U.S. 3,510,578; May 5, 1970

RCA Service Company

Test Tape with Preselected Skew—Ro ert Levin (Sv. Co., Cherry Hill, N.J.) U Pat. 3,508,231; April 21, 1970

Stepper Drive Device—Neil Worrall Bu well; John David Callaghan and Frank Roosevelt DiMeo (P&A, Deptford, N. U.S. Pat. 3,501,969; March 24, 1970

Missile and Surface Radar Division

Double Photoresist Processing—Willia Adolph Gottfried (MSR, Moorestow N.J.) U.S. Pat. 3,506,441; April 14, 1970

Optical Time Delay Program Recorder- G. W. Hunka and J. J. Rudnick (MS Moorestown, N.J.) U.S. Pat. 3,500,43 March 10, 1970; Assigned to U.S. Go ernment

Linear Flux Control Circuit—Dougl Alan Johnson; Robert Joseph Tomsic a Hunter Crary Goodrich (MSR, Moore town, N.J.) U.S. Pat. 3,510,675; May 1970

Defense Engineering

Current Steering Networks Providing th Exclusive OR Function—Michael Coope man (ATL, Camden, N.J.) U.S. Pat. 3,510 681; May 5, 1970

Scanning Laser Obstruction Detectio System Utilizing A Retroreflective Stri—Charles William Reno and Richar James Tarzaiski (ATL, Camden, N.J U.S. Pat. 3,500,063; March 10, 1970

Emitter Coupled Logic Biasing Circui—Joseph John DiGiacomo (ATL, Cam den, N.J.) U.S. Pat. 3,501,647; March 17 1970

Square Wave Generator Comprising Back-to-Back Series-Connected Charge Storage Diodes—Michael Cooperman (ATL, Camden, N.J.) U.S. Pat. 3,504,199 March 31, 1970

Multivibrators Employing Transistors of **Opposite Conductivity Types**—Adolph Karl Rapp (DME, Somerville, N.J.) U.S Pat. 3,509,379; April 28, 1970

Slide Selector Contact Switch with O thogonal U-Shaped Spring Detent—Joseph Bonacquisti (ATL, Camden, N.J.) U.S. Pat. 3,502,824; March 24, 1970

RCA Limited

Recording Apparatus with Plural Independent Record-Reproduce Devices—William Ronald Atkins (Ltd., Montreal, Canada) U.S. Pat. 3,497,223; February 2 1970

National Broadcasting Company, Inc. Record Division

Tape Basket—George Van Taylor (Record Div., Indianapolis, Ind.) U.S. Pat. 3,508,696; April 28, 1970

Magnetic Tape Reel—Robert Daniel Browning (Record Div., Indianapolis Ind.) U.S. Pat. 3,508,719; April 28, 1970

ngineering News and Highlights

. W. Widmann in new post

Frank W. Widmann has been appointed Manager, Engineering Professional Development. Mr. Widmann will report to A. Robert Trudel, Director, Corporate Engineering Services. In his new capacity, Mr. Widmann will assist Mr. Trudel in he overall management of Corporate Engineering Services, with emphasis on intensified development of the professional ngineering capability of the Corporation nd the utilization of that capability to chieve profitable business growth.

He will be responsible for the development, integration, and implementation of engineering and engineering management professional development programs involving communication, education, professional recognition, technical excellence, and modern engineering techniques. He will collaborate with other responsible activities concerning employee relations and all other areas affecting engineering and engineering management.

Mr. Widmann has twenty-four years of experience in the commercial, military, and space electronics business. Prior to his new position, he was Manager, Combat Electronic System Programs, Missile and Surface Radar Division, Moorestown, N.J. Mr. Widmann received the BS in Electrical Engineering from Drexel Institute of Technology in 1943. He also attended the University of Pennsylvania for post-graduate work in electrical engineering. Mr. Widmann holds membership in various technical, professional, and business societies. Among these are: Eta Kappa Nu, Tau Beta Pi, and IEEE (senior member). He is a registered professional engineer, State of New Jersey.

Chief Engineers discuss role in building future earnings

At the Corporate Engineering Conference, convened at West Palm Beach, Florida, during May, the predominant theme was the role of engineers and their management in improving the earnings posture of RCA in future years. Over 130 participated, including key members of top management, Chief Engineers, and others closely involved with the investment of Company technical resources for future earnings. The 3-day conference was sponsored by Corporate Research and Engineering, under the direction of **Dr. James Hillier,** Executive Vice President.

The conference provided a unique opportunity for key engineering managers from various RCA locations to exchange ideas about the utilization of their technical resources, in particular the essential contributions of their engineers toward RCA's steady business progress.

Keynoting the conference, **Mr. Chase Morsey, Jr.** underscored the leadership role of top management in providing for the Company's future strength. There was strong agreement among the speakers that good communications among planning, marketing, and technical people, combined with careful teamwork, are essential to success and must be given high priority attention. According to Dr. Hillier, a "high degree of technological selectivity will be needed to ensure that the *right kind* of inventions (not just inventions) are provided to match technology to the marketplace."

Technical sessions during the 3-day conference were moderated by **A. R. Trudel,** Director, Corporate Engineering Services; topics presented at the meeting are given below:

Projecting Profits: The Corporate Role	**C. Morsey, Jr.**
Selectivity in Engineering for the Future	**J. Hillier**
Planning for the Decade of the 1970's	**G. C. Evanoff**
Financial Review of RCA	**J. W. Caffry**
Future Trends in Research	**W. M. Webster**
Information Systems	**J. R. Bradburn**
Report on RCA's Computer Systems Division	**L. E. Donegan, Jr.**
Computer Systems Technology—Yesterday, Today, and Tomorrow	**H. N. Morris**
Highlights of MPD	**S. P. Marcy**
Qualitative Analysis of Graphic Images	**G. O. Walter**
The RCA Holographic System	**H. Ball**
Holographic Motion Pictures	**W. J. Hannan**
Consumer Electronic Aspects of SelectaVision	**R. W. Rhodes**
SelectaVision Cartridge Replication	**A. L. Stancel**
Vidicons and Lasers for SelectaVision	**R. E. Simon**
Current Engineering Personnel Considerations	**H. Krieger, Jr.**
Microsonics—The Wave of the Future	**J. Vollmer**

Heilmeier appointed White House Fellow

Dr. George H. Heilmeier, Head, Device Concepts Research, Consumer Electronics Research Laboratory, RCA Laboratories, is one of seventeen Americans appointed White House Fellows by President Nixon. The Fellows, who serve for a year as special assistants to the President's staff and Cabinet members, will begin their duties in September.

Dr. Heilmeier, who joined RCA Laboratories in 1958, was named the "Outstanding Young Electrical Engineer in the USA" by Eta Kappa Nu in 1969. Also in 1969, he was one of the recipients of the David Sarnoff Outstanding Team Award in Science for his work on liquid crystals. The White House Fellows program was set up six years ago to provide promising young leaders from business, universities and professions a first-hand opportunity to work with the top level of the Federal Government.

Leverenz elected to National Academy of Engineering

H. W. Leverenz, Staff Vice President, Patents and Licensing, and Chairman of the RCA Educational Aid Committee, has been elected a member of the National Academy of Engineering. Including newly elected members, the Academy is now composed of 329 engineers who have made "superior contributions to engineering." Other RCA members of the NAE are Dr. George H. Brown, Dr. Elmer W. Engstrom, Dr. James Hillier, Dr. Jan A. Rajchman and Dr. Vladimir K. Zworykin.

E. M. Hinsdale appointed Staff Engineer

Edward M. Hinsdale has been appointed to the RCA Corporate Engineering Staff by **Dr. James Hillier,** Executive Vice President, Research and Engineering. As Staff Engineer, Engineering, Mr. Hinsdale's initial assignment is to provide liaison between the engineering activities of the Consumer Electronics Division in Indianapolis and the office of Howard Rosenthal, Director, Engineering Research and Engineering, Princeton, N.J. Prior to his promotion, Mr. Hinsdale was Manager, Advanced Development, for the Consumer Electronics Division.

ATL honors authors, inventors and speakers

Advanced Technology Laboratories honored forty-five members of its technical staff at a special banquet at the Cherry Hill Inn. Each of the men honored had either authored a paper, given a formal talk, or had been granted a patent during 1969.

In his opening remarks, **Dr. James Vollmer**, Manager of Advanced Technology Laboratories, stressed the importance of this kind of activity, both to the individual and to RCA. **Dr. Harry Woll,** Chief Engineer, in his congratulatory statement to the group further emphasized the correlation between the professional activity of an individual and his contribution to RCA.

The guest speaker for the event was **Irving Kessler**, Executive Vice President, Defense and Commercial Systems. Mr. Kessler said that every organization keeps looking for the kind of man who is at the upper end of the curve of gaussian distribution. He emphasized that organizations can be only as good as their people. He then pointed out that DEP will continue to endorse those measures and actions which help promote an environment in which talent flourishes.

Author's reception at M&SR

Recently, thirty-nine authors from Missile & Surface Radar Division were honored with a reception in the plant dining room. This annual affair provides recognition for engineers and other personnel who presented or published technical talks, papers, or articles. Guests included **Dr. H. J. Woll**, Chief Defense Engineer; **A. R. Trudel**, Director, Corporate Engineering Services; **W. O. Hadlock**, Manager, RCA Technical Publications and Editor, *RCA Engineer;* **P. A. Piro**, Division Vice-President and General Manager, M&SR; **Dr. T. T. Reboul**, Defense Engineering Staff; **T. G. Greene**, Technical Publications Administrator, M&SR; **D. M. Cottler**, Chief Engineer, M&SR; **F. W. Widmann**, Manager, Engineering Professional Development; **D. Shore**, Manager, DEP Plans & Systems Development. The authors were enthusiastic in their praise of the hors d'oeuvres prepared by M&SR chef **Zack Stoner. D. M. Cottler,** Chief Engineer—M&SR who acted as host threw out a challenge to M&SR authors, "double the number of papers by M&SR authors and we'll schedule these enjoyable receptions twice a year".

Professional Activities

Central Engineering

The Aerospace Industries Association (AIA) has appointed **S. K. Magee** of DEP Central Engineering as Chairman of the Standardization Management Policy Group (SMPG). This key policy group provides counsel to the AIA Aerospace Technical Council on standardization matters and provides the AIA interface with other national and international standardization organizations. The SMPG is currently working with the Department of Defense in the proposed establishment of a DoD-Industry Standardization Management Advisory Committee to improve the overall visibility and management of parts standardization within DoD and improved utilization of standardization resources within Government and Industry.

Defense Electronic Products

Edwin S. Shecter, Manager, Defense Quality Assurance, and **Pat MacCrabie,** Personnel Assistant at AED, were guest speakers at three seminars handled under the auspices of the Defense Contract Administration Services Region, Dallas, Texas. Presentations were made in Dallas, Houston, and Tulsa on three consecutive days.

A. W. "Tony" Slapkowski, Manager of Field Liaison for RCA Defense Electronic Products' Product Assurance activity, was elected President of the South Jersey Radio Association for 1970.

Advanced Technology Laboratories

Murlan S. Corrington, Leader, Computer Applications, Computer Systems Research and Applications, has been reappointed as Chairman of the Constitution and Bylaws Committee of the National IEEE Group on Circuit Theory. He wrote the original Constitution and Bylaws for this group, and recently completed an extensive revision of them.

Aerospace Systems Division

David B. Dobson has been elected chairman of the Publications Committee for the Northeastern Electronic Research and Engineering Meeting (NEREM).

David B. Dobson has been appointed to serve on the IEEE Committee on Electronic Methods of Printing. This is a special committee of the IEEE formed on the recommendation of the Board of Directors to study methods of importance in the publication program of the Institute.

James Colt, Manager of Product Evaluation, is President of the Boston Chapter of the Institute of Environmental Science and was host at the organization's 16th Annual Meeting and Equipment Exposition.

Astro-Electronics Division

G. Barna was technical program chairman and toastmaster for AIAA Earth Observations and Information Systems Conference—USNA, Annapolis, Md.

W. Poch successfully completed a Fallout Shelter Analysis Course at Rutgers University, Livingston Campus (this qualifies AED for inclusion in DoD National Directory of Architecture and Engineering Firms).

B. Sheffield was National Chairman of the Eta Kappa Nu Award Organization Committee which helped to select the Outstanding Young Electrical Engineer for the year in the United States.

H. Gurk was session chairman for t AIAA Earth Resources Observation ar Information Systems Meeting at Anna olis, Md.

V. R. Monshaw is the General Chairma for the 1970 Annual Symposium on R liability in Los Angeles, California.

J. Dzomba was elected President of th Delaware Valley Section of Society Plastics Engineers.

RCA Limited

Dr. F. G. R. Warren, Associate Direct of Research, RCA Limited, Montrea P. Q., Canada was appointed to the 1 member Associate Committee on Instru tional Technology established by th National Research Council of Canad The committee will study, coordinate, an promote research concerned with th application of technological developmen in instruction.

Defense Communication Systems Division

D. J. Parker, Chief Engineer, DCSD, wa elected 1970 Chairman of the Philade phia IEEE Engineering Management Pro fessional Group.

Defense Microelectronics

H. Fenster was elected Secretary of th Keystone Branch of International Societ for Hybrid Microelectronics.

Commercial Electronic Systems Division

Dr. J. H. Reisner, was recently elected Fellow of the American Physical Society This was in recognition of his contribu tions to electron optics, electron bea instrumentation, and in particular th electron microscope. Dr. Reisner wa Leader of the Scientific Instruments En gineering Group from 1951 to the tim of the sale of the Scientific Instruments business in July 1969.

Staff Announcements

Corporate Staff

Robert W. Sarnoff, Chairman of the Board, President and Chief Executive Officer announced that the Board of Directors of RCA Corporation has electe **W. C. Hittinger** a Vice President of the Corporation. The Solid State operations of Electronic Components and the Integrated Circuit Technology Center of Research and Engineering will be combined into a newly constituted Solid State Division. Mr. Hittinger will become Vice President and General Manager of th new Solid State Division.

Robert W. Sarnoff has announced that the Board of Directors has elected **H. T. Brunn** a Vice President of the Corporation, Consumer Affairs.

Operations Staff

. Morsey, Jr., Executive Vice President, Operations Staff, has appointed **T. J. McDermott** as Staff Vice President, SelectaVision Special Projects and **R. C. itting** as Staff Vice President, SelectaVision Development.

. A. Fadler, Vice President, Manufacturing Services and Materials has appointed **A. A. Bence** as Staff Vice President, Manufacturing.

Corporate Engineering Services

. Robert Trudel, Director, Corporate Engineering Services, has appointed **F. V. Widmann** as Manager, Engineering Professional Development and **R. E. Simonds** as Director, RCA Frequency Bureau.

Research and Engineering

F. D. Rosi, Staff Vice President, Materials and Device Research has announced the organization of Materials and Device Research as follows: **G. D. Cody,** Director, Solid State Research Laboratory; **W. J. Merz,** Director, Laboratories RCA, Ltd., Zurich; **P. Rappaport,** Director, Process and Materials Applied Research Laboratory; **J. J. Tietjen,** Director, Materials Research Laboratory; **L. R. Weisberg,** Director, Semi-conductor Device Research Laboratory.

J. J. Tietjen, Director, Materials Research Laboratory has announced the organization of the Materials Research Laboratory as follows: **A. R. Moore,** Head, Insulator Research; **D. Richman,** Head, Semiconductor Research; **P. N. Yocom,** Head, Luminescence Research; **S. Larach,** Fellow, Technical Staff.

G. D. Cody, Director, Solid State Research Laboratory has announced the organization of the Solid State Research Laboratory as follows: **B. Abeles,** Head, General Research; **D. O. North,** Fellow, Technical Staff; **E. G. Ramberg,** Fellow, Technical Staff; **A. Rose,** Fellow, Technical Staff; **P. K. Baltzer,** Director, RCA Research Laboratories, Inc., Tokyo; **R. W. Cohen,** Head, Magnetism and Superconductivity Research; **I. Gorog,** Head, Optical Electronics Research; **R. Williams,** Head, Quantum Electronics Research; **K. G. Hernqvist,** Fellow, Technical Staff.

H. Rosenthal, Director, Engineering has appointed **E. M. Hinsdale** as Staff Engineer, Engineering.

Services

D. C. Baker, Vice President, Administration, Random House, Inc., has appointed **A. G. Kliger** as Controller.

D. M. Knight, Division Vice President, Educational Development, has appointed **A. J. Batuska** as Manager, Educational Management Systems.

Management Information Systems

E. S. Kauffman, Staff Vice President, has appointed **J. R. Sandlin** as Director, Management Information Systems Administration and Project Evaluation.

Commercial Electronic Systems

Gordon W. Bricker, Manager, Professional Electronic Systems Department has appointed **F. R. McNicol** as Manager, Engineering.

Consumer Products and Components

C. H. Lane, Division Vice President and General Manager, Industrial Tube Division has announced the organization of the Industrial Tube Division as follows: **W. E. Bradley,** Manager, Quality & Reliability Assurance; **D. W. Epstein,** Manager, Technical Planning; **W. G. Hartzell,** Manager, Microwave Devices Operations Department; **V. C. Houk,** Manager, Marketing Department; **C. C. Simetal,** Manager, Financial Controls and Planning; **C. P. Smith,** Manager, Power & Electro-Optics Products Department.

D. W. Epstein, Manager, Technical Planning has announced that the Engineering Services Activity in the Operations Services Organization has been transferred to the staff of the Manager, Technical Planning. **H. A. Kauffman** will continue as Manager, Engineering Services.

L. R. Kirkwood, Chief Engineer, has announced the organization of the Engineering Department as follows: **J. Avins,** Manager, Circuit Development, Somerville; **R. D. Flood,** Manager, Technical Operations, Rockville; **C. W. Hoyt,** Manager, General Engineering and Administration; **T. C. Jobe,** Manager, Resident Engineering, Memphis; **G. E. Kelly,** Manager, Color Television Engineering; **R. J. Lewis,** Manager, B & W Television Engineering; **M. J. Obert,** Manager, Components Engineering; **R. W. Rhodes,** Manager, Advanced Development; **J. M. Wright,** Manager, Resident Engineering, Bloomington.

Electronic Components

R. E. O'Brien, Plant Manager, Mountaintop plant, Solid State Division has appointed **H. A. Kellar,** Manager, Production Support and **P. R. Thomas,** Manager, Manufacturing and Production Engineering—Low Frequency Silicon Devices.

Information Systems

J. Stefan, Division Vice President and General Manager, Magnetic Products Division has appointed **W. A. Ragan** as Chief Engineering, Engineering Department.

S. P. Marcy, Division Vice President and General Manager, Memory Products Division has announced the organization of the Memory Products Division as follows: **J. V. Fargano,** Manager, Financial Controls; **H. P. Lemaire,** Manager, Core Operations; **R. E. Ochs,** Plant Manager, Needham Plant; **G. M. Patterson,** Manager, Personnel; **B. Walley,** Manager, Marketing Department; **P. K. White,** Chief Engineer, Engineering Department; **R. A. Wissolik,** Manager, Memory Products Division, RCA Taiwan, Ltd.

Astro-Electronics Division

C. S. Constantino, Division Vice President and General Manager has appointed **A. Schnapf** as Manager, Program Management.

C. S. Constantino, Division Vice President and General Manager, has appointed **M. G. Staton,** Division Vice President, Marketing and Advanced Planning.

Aerospace Systems Division

J. R. McAllister, Division Vice President and General Manager, Aerospace Systems Division has appointed **E. A. Williams** as Manager, Space Programs.

Defense Electronic Products

W. V. Goodwin, Division Vice President of the Aegis Program, has appointed **D. A. Rose** as Manager, Engineering and **D. Lesser,** as Manager, Quality Assurance and Value Engineering.

Missile and Surface Radar Division

P. A. Piro, Division Vice President and General Manager, has appointed **J. C. Volpe,** as Manager, Multi-Function Array Radar (MRAR) Program.

P. A. Piro, Division Vice President and General Manager, Missile and Surface Radar Division has appointed **H. G. Stewart** as Division Vice President, Marketing.

Defense Communications Systems Division

M. L. Long, Division Vice President and General Manager, Defense Communication Systems Division has appointed **J. W. Kinnally** as Division Vice President, Marketing.

RCA Global Communications, Inc.

H. R. Hawkins, President, RCA Global Communications, Inc., has appointed **P. Schneider** as Vice President, Engineering and Leased Systems.

P. Schneider, Vice President, Engineering and Leased Systems, has appointed **J. M. Walsh** as Manager, Satellite and Radio Engineering.

Graphic Systems Division

N. R. Miller, Division Vice President and General Manager, has appointed **D. Meredith,** Manager, Programming Development. Mr. Meredith has appointed **T. A. Korn** as Manager, Systems.

G. O. Walter, Chief Engineer, has appointed **R. S. Eiferd** as Manager, Font Development.

Awards

Aerospace Systems Division

Mario A. Pesando, Senior Engineering Scientist, Systems Development and Applications was selected as Engineer of the Month for December for his outstanding performance on the Cobra Night Fire Control System program.

Joel J. Camiel, Engineering Scientist, System Development and Applications was selected as Engineer of the Month for January 1970 for his outstanding work in analysis and design of airborne elecro-optical IFF systems.

The Microelectronics Facility team of **D. R. Bokil, W. N. Cox, E. F. Duratti, C. W. Ford, R. Klucken, M. A. Ponti, M. Spector,** and **J. P. See** received the Technical Excellence Team Award for January. The award recognizes the outstanding work of the team in the design and production of the analog switch hybrid circuit for the LCSS Program.

The $\phi\pi$ (Fault Isolation by Parameter Identification) Program team of **D. A. Aievoli, R. F. Barry, G. R. Brune, G. A. Chamberas, H. M. Fichtelberg, W. F. Fordyce, T. G. O'Brien, D. Wellinger,** and **R. J. Wildenberger** has been selected for an award for February 1970 for the successful demonstration of the $\phi\pi$ technique.

Defense Communications Systems Division

Paul Bura of the Defense Advanced Communications Laboratory, Somerville, was cited as the first Technical Excellence Award winner for 1970 for his development of integrated parametric amplifier systems. He has demonstrated 2 amplifiers, one operating at 4.2 GHz using a microwave stripline Gunn oscillator as a pump (11.5 GHz); and a second amplifier at 7.5 GHz using a 35 GHz solid-state pump.

The Memory Buffer System Design Team of **R. N. Van Delft, J. Knoll, W. Bittle, N. Coleman, M. Meer, C. McFee, F. Baumeister, S. Simmons, C. Kasian** from Digital Communications Equipment was cited for its skill and enthusiasm in the successful design, fabrication, test, and delivery of a complete memory buffer system in 8 weeks. The system included a 64K word high-speed memory, 130 logic and interface modules, control panel, power supply, and complete interface cabling.

Electronic Components

Lewis R. Gormay, a Manufacturing Engineer at the Woodbridge plant, has received a 1969 RCA Achievement Award. Mr. Gormay was selected "for noteworthy contributions to the development of improved receiving tube construction." These contributions resulted in significant cost savings in the manufacture of receiving tubes for use in consumer, industrial and military equipment applications.


The Apollo 11 team of Armstrong, Aldrin and Collins sent official thanks to the RCA team Bogaenko, DeVito, Fusillo and Keaveney of Electronic Components for engineering an technical support in assuring safe and successful moon landings for Apollo. Shown left t right are: Sergei W. Bogaenko, engineer; Joseph F. Keaveney, senior technician; Richar Talpey; Manager, Microwave Solid State Subsystems Engineering; Pasquale Fusillo, enginee and Michael DeVito, engineer. They are members of an RCA Microwave Devices Operation Department in Harrison, that is directly responsible for making of critical electronic com ponents used in the landing crafts radars. The team received the Silver Snoopy Grou Achievement Award for the first U.S. Manned Lunar Landing Project Apollo. It is a highl coveted symbol of personal and cooperative achievements. It is signed by Neil Armstrong "Buzz" Aldrin, and Michael Collins.

The team of **Al Thomas, Wally Dietz, Ed McKeon, John Neilson,** and **Jae Yun** was cited for a 1969 Achievement Award "for significant engineering contribution to the development, application and manufacture of thyristors for television receivers." Messrs. Dietz, McKeon, Thomas, and Nielson are at Somerville; Mr. Yun is at the Mountaintop plant.

The team of **Bernie Levin, Bob Heuner,** and **Bob Jones** was cited for a 1969 Achievement Award "for significant engineering contribution to the design, application and manufacture of integrated circuits." As a result of the contributions made by the Engineering team, RCA has established, in 1969, a preeminent leadership position in COS/MOS Integrate Circuits. All members of the team wor at Somerville.

The team of **Henry Blust, Norm Lindburg,** and **Wally Resnick** was cited fo a 1969 Achievement Award "for valuable engineering contributions to the development and design of a novel display tube."

Errata

In the article, "Power supply overloa protection techniques," by F. C. Easte (Vol. 15, No. 6, Apr-May 1970, pp. 44-47), the following correction should b made:

p. 45, the caption for Fig. 3 should be:

Fig. 3—Supply with active current limiting.

p. 45, col. 3, line 5 should be removed and reinserted between lines 12 and 13.

Degrees Granted

P. Abruzzese, Labs., Pr.	J. D. Seton Hall School of Law; 6/70
J. Chludzinski, Labs., Pr.	BA, Rutgers University; 6/70
B. Davis, Labs., Pr.	BS, Rider College; 6/70
T. Farinre, Labs., Pr.	PhD.EE, Univ. of Pennsylvania; 6/70
L. French, Labs., Pr.	PhD.EE, Columbia University; 6/70
P. Heyman, Labs., Pr.	PhD.EE, Princeton University; 6/70
R. Hopkins, Labs., Pr.	PhD.EE, Rutgers, University; 6/70
S. Levy, Labs., Pr.	PhD. Math, Yeshiva University; 9/70
L. Lloyd, Labs., Pr.	MS Eng. Science, Penn State University; 6/70
D. Matthies, Labs., Pr.	MSEE, Princeton University; 6/70
N. Maxemchuk, Labs., Pr.	MSEE, University of Pennsylvania; 5/70
K. McDermott, Labs., Pr.	MSIE, Columbia University; 6/70
R. Mezrich, Labs., Pr.	PhD.EE, Polytechnic Institute of Brooklyn; 6/70
A. Monsen, Labs., Pr.	MSEE, Newark College of Engineering; 5/70
R. Nosker, Labs., Pr.	PhD.EE, Princeton University; 1/70
J. O'Neil, Labs., Pr.	PhD, Computer Information Science, Univ. of Pennsylvania; 6/70
M. Ross, Labs., Pr.	MS Engrg. Mgt., Drevel University; 6/70
D. Staebler, Labs., Pr.	PhD.EE, Princeton University; 4/70
R. Sunshine, Labs., Pr.	PhD.EE, Princeton University; 10/70
F. Van Newkirk, Labs., Pr.	J. D. Seton Hall School of Law; 5/70
W. G. Wright, Records, Indpls.	MBA, Butler University; 6/70

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

fense and Commercial Systems

Defense Electronic Products		
Aerospace Systems Division	**D. B. DOBSON***	Engineering, Burlington, Mass.
Electromagnetic and Aviation Systems Division	**R. J. ELLIS***	Engineering, Van Nuys, Calif.
	J. McDONOUGH	Engineering, West Los Angeles, Calif.
Astro-Electronics Division	**I. M. SEIDEMAN***	Engineering, Princeton, N.J.
	S. WEISBERGER	Advanced Development and Research, Princeton, N.J.
Missile & Surface Radar Division	**T. G. GREENE***	Engineering, Moorestown, N.J.
Defense Communications Systems Division	**A. LIGUORI***	Engineering, Camden, N.J.
Defense Engineering	**M. G. PIETZ***	Advanced Technology Laboratories, Camden, N.J.
	M. R. SHERMAN	Defense Microelectronics, Somerville, N.J.
	E. J. PODELL	Plans and Systems Development, Camden, N.J.
	J. E. FRIEDMAN	Advanced Technology Laboratories, Camden, N.J.
	J. L. KRAGER	Central Engineering, Camden, N.J.
Commercial Electronics Systems	**D. R. PRATT***	Chairman, Editorial Board, Camden, N.J.
	N. C. COLBY	Mobile Communications Engineering, Meadow Lands, Pa.
	C. E. HITTLE	Professional Electronic Systems, Burbank, Calif.
	R. N. HURST	Studio, Recording, & Scientic Equip. Engineering, Camden, N.J.
	R. E. WINN	Broadcast Transmitter & Antenna Eng., Gibbsboro, N.J.
Industrial and Automation Systems	**H. COLESTOCK**	Engineering, Plymouth, Mich.

formation Systems

Computer Systems Division	**S. B. PONDER**	Palm Beach Engineering, West Palm Beach, Fla.
	W. D. STELLMAN* (acting TPA)	Engineering, Marlboro, Mass.
	E. M. MORTENSON*	Instructional Systems Engineering, Palo Alto, Cal.
	B. AARONT	Service Dept., Cherry Hill, N.J.
Magnetic Products Division	**A. G. EVANS**	Development, Indianapolis, Ind.
Memory Products Division	**L. A. WOOD**	Engineering, Needham, Mass.
Graphic Systems Division	**J. GOLD***	Engineering, Dayton, N.J.

esearch and Engineering

Laboratories	**C. W. SALL***	Research, Princeton, N.J.

onsumer Products and Components

Electronic Components	**C. A. MEYER***	Chairman, Editorial Board, Harrison, N.J.
Receiving Tube Division	**R. W. MAY**	Commercial Receiving Tube and Semiconductor Engineering, Somerville, N.J.
	J. KOFF	Receiving Tube Operations, Woodbridge, N.J.
	R. J. MASON	Receiving Tube Operations, Cincinnati, Ohio
Television Picture Tube Division	**J. H. LIPSCOMBE**	Television Picture Tube Operations, Marion, Ind.
	E. K. MADENFORD	Television Picture Tube Operations, Lancaster, Pa.
Industrial Tube Division	**J. M. FORMAN**	Industrial Tube Operations, Lancaster, Pa.
	H. J. WOLKSTEIN	Microwave Tube Operations, Harrison, N.J.
Technical Programs	**D. H. WAMSLEY**	Engineering, Harrison, N.J.
Consumer Electronics Division	**C. HOYT***	Chairman, Editorial Board, Indianapolis, Ind.
	D. J. CARLSON	Advanced Devel., Indianapolis, Ind.
	R. C. GRAHAM	Procured Products Eng., Indianapolis, Ind.
	P. G. McCABE	TV Product Eng., Indianapolis, Ind.
	J. OSMAN	Electromech. Product Eng., Indianapolis, Ind.
	L. R. WOLTER	TV Product Eng., Indianapolis, Ind.
	R. F. SHELTON	Resident Eng., Bloomington, Ind.

Solid State Division

M. B. ALEXANDER	Solid State Power Device Engrg., Somerville, N.J.
T. J. REILLY	Semiconductor and Conversion Tube Operations, Mountaintop, Pa.
J. D. YOUNG	Semiconductor Operations, Findlay, Ohio
I. H. KALISH	Solid State Signal Device Engrg., Somerville, N.J.

ervices

RCA Service Company	**W. W. COOK**	Consumer Products Service Dept., Cherry Hill, N.J.
	M. G. GANDER*	Consumer Products Administration, Cherry Hill, N.J.
	K. HAYWOOD	Tech. Products, Adm. & Tech. Support, Cherry Hill, N.J.
	R. P. LAMB	Missile Test Project, Cape Kennedy, Fla.
RCA Global Communications, Inc.	**W. S. LEIS***	RCA Global Communications, Inc., New York, N.Y.

National Broadcasting Company, Inc.

	W. A. HOWARD*	Staff Eng., New York, N.Y.
Record Division	**M. L. WHITEHURST***	Record Eng., Indianapolis, Ind.
	R. ANDREWS	Record Eng. New York, N.Y.

RCA International Division

	C. A. PASSAVANT*	New York, N.Y.
RCA Ltd.	**W. A. CHISHOLM***	Research & Eng., Montreal, Canada

*** Technical Publication Administrators listed above are responsible for review and approval of papers and presentations.**