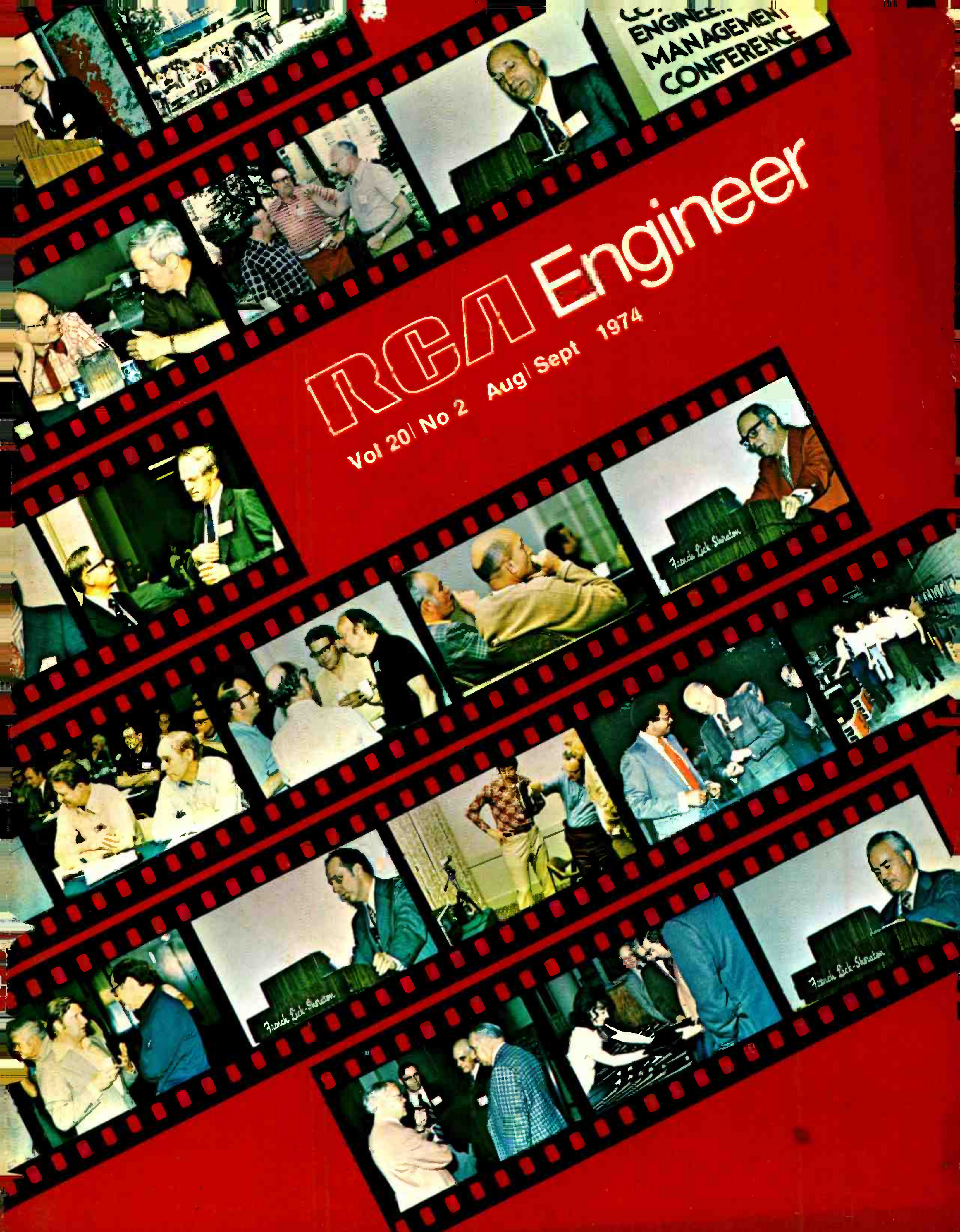

RCA Engineer

Vol 20 | No 2 Aug | Sept 1974

RCA's electronics community

It is, I believe, in the nature of the management role to concentrate a great deal more effort on the solution of problems than on the many successful aspects of our business. The result may tend to be a somewhat distorted and discouraging view unless management periodically takes the time to step back to view the total situation in broader perspective.

Just such an opportunity presented itself at the recent Corporate Engineering Management Conference held in French Lick, Indiana on May 13-15, whose contents are featured in this issue of the *RCA Engineer* under the heading "The RCA Electronics Community".

I believe a review of these articles will clearly demonstrate the vitality, the growth potential, the excitement in RCA's electronics businesses, and the significance of these business to RCA, both today and in the future.

Howard Rosenthal,
Staff Vice President,
Engineering,
Research and Engineering,
Princeton, N.J.

Our cover

...pictures only a few of the many activities — resulting in the free interchange of ideas between members of engineering management — during the Engineering Management Conference held at French Lick, Ind. (5/12-5/15). Business activities of *RCA's Electronics Community* were stressed at the meeting (see descriptive article starting on page 2).

Cover design: Joan Dunn; **Photography:** John Semonish.

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RCA Engineer

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RCA Engineer articles are indexed annually in the April-May issue and in 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 to RCA engineers in a manner most likely to enhance their prestige and professional status.

Contents

Emphasis — Corporate Engineering Conference

RCA Engineering Conference; May 1974

RCA's electronics community — Description and summaries

W. O. Hadlock, Editor

This article is based on information provided by the speakers and on tape recordings of some of the presentations. Certain summaries included in this report are limited in scope and content because of the nature of the topics; however, additional information may be available from the conference speakers. Credit for the audio and visual coverage at the conference is due G.B. DiGirolamo and L.A. Gagliardi of Engineering Education, Engineering Professional Programs. Photography was furnished by John Semonish of Electronic Components.

A CORPORATE Engineering Management Conference, convened at the French Lick Sheraton, French Lick, Indiana, May 12-15, stressed activities of *The RCA Electronics Community.*

About 150 members of top corporate and division management, chief engineers, research directors, engineering managers, market planners and product specialists participated. The three-day program, sponsored by Research and Engineering, dealt with current and future objectives of RCA's electronic businesses and their supporting technologies on a corporate-wide scale.

In welcoming participants from more than 20 RCA divisions and subsidiaries, Dr. James Hillier, Executive Vice President, Research and Engineering encouraged the free interchange of ideas concerning the selection of the most practical and profitable technologies available at RCA.

Time was made available in the program for individual and group discussions on the unique challenges faced in bringing RCA's electronic technologies to the marketplace. Technical product plans of *The RCA Electronics Community* and the important companion roles of engineering were presented. Corporate plans, and divisional programs of Solid State, Government and Commercial Systems, Global Communications, Electronic Components, and Consumer Electronics were reviewed.

First-day Activities

The morning of the first day concentrated on two technical seminars: one devoted to "Computer Aided Design" led by L.J. French, Mgr., Design Automation (SSTC) and A.H. Teger, Head Advanced Systems Research (RCA Labs); the other devoted to "Charge-Coupled Devices" and led by J.F. Carnes, MTS, (RCA Labs) and K.H. Zaininger, Head, Solid State Device Technology (RCA Labs).

The seminar on Charge-Coupled Devices (CCD's) covered the basic principles of device operation and gate structure technologies, as well as the three major areas of applications: image sensors, computer memories, and analog signal processing. Emphasis was placed on the advantages of CCD's over other devices, and the state-of-the art of CCD's within RCA and the industry.

In a separate seminar, computer-aided design (CAD) was pictured as an efficient complement and aid to the engineer in his design work. Examples of using CAD for integrated-circuit design in electronics, and for mechanical design in aircraft and automobile industries were cited. Man-machine interfaces range from very slow processes (punched cards) to time sharing and finally to rapid design processes employing computer graphics.

Computer-aided design techniques have been applied at RCA to antennas; filters; the simulation, layout, and testing of ICs; and to plots of back-plane wiring. Different CAD systems available at RCA such as Logsim (ATL), Alacarte (RCA Labs), Applicon (MSRD), R-Cap (SSTC), and a digitizer plotter by SSTC were described. CRITIC was cited as a modern system for checking all design variations found during the design and manufacture of IC's and COS/MOS devices.

Opening the first-day afternoon session (chaired by H. Rosenthal, Staff Vice President, Engineering, Research & Engineering), were presentations by R.C. Butler, Vice President, Financial Analysis, and G.C. Evanoff, Vice President, Corporate Development.

Mr. Butler in "A Review of the 1973 Operating Results and the Outlook for 1974" discussed major factors in RCA's operating results for 1973 and the first quarter of 1974. Despite an overall 17% decline in earnings for the first three months of 1974, there were several areas where profits improved significantly; notably Global Communications, Solid State, and Vehicle Renting. This is a clear indication that RCA's diversification program and its position in several industries is a source of strength which provides earnings stability in periods of economic uncertainty.

Mr. Evanoff in "An Overview of Corporate Development 1974-1980" envisioned steady growth in sales and earnings per share through 1980 based on the strong market positions of RCA's major businesses. RCA's electronics operations are expected to contribute approximately two-thirds of total sales and profit performance over the next 5 or 6 years and such sales are being supported with a similar proportion of the Corporation's investment in research and development and in projected capital spending.

H.W. Johnson, Staff Vice President, Reliability and Quality, presented corporate philosophy relating to the vital roles of quality and reliability. Current

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Final manuscript received June 19, 1974.

The French-Lick Sheraton in French Lick, Indiana, was the site for the 1974 Corporate Engineering Management Conference. Photo shows attendees assembling for a break between lectures. About 150 participated in the three-day program, which had as its theme "The RCA Electronics Community."

Registration on the first day of the conference.

Dr. James Hillier (left), Executive Vice President, Research and Engineering served as host and chairman for one of the conference sessions. G.W. Duckworth, Division Vice President and General Manager, Industrial Tube Division was one of the speakers.

emphasis on customer needs and product safety challenges our engineering talents. Creating quality lies with the engineer whereas the coordinating, measuring, testing, and policing functions lie with product assurance groups; responsibility of feeding back vital plant and field information to those who can correct and improve the product is mandatory. As part of the program, each division supplies a monthly report for review by the President, A.L. Conrad.

Extended warranties, high-quality engineering, and the rigid manufacturing product specifications needed to meet consumer trends may eventually lead to 100% automated testing methods or simulated equivalents. Marketing functions have a key responsibility in learning what price the customer is willing to pay for such quality...and in determining and reflecting to engineering and manufacturing the level of quality that must be equaled or exceeded in accordance with RCA policy.

G.B. Herzog, Staff Vice President, Technology Centers, cited the rapid progress from early computers involving rooms and racks of equipment to very small computers on ceramic hybrid arrangements to illustrate the trends taking place in solid-state technology during the late 1960's. At that time, Dr. Hillier envisioned that RCA would need a capability to create sophisticated custom IC arrays to stay in the forefront of electronics.

In 1970, therefore, SSTC was conceived as a mechanism for coupling the process technology of RCA semiconductor activities to the diverse operations and systems design objectives of the product divisions. As one of its major functions, SSTC started the fabrication of LSI arrays for those product design activities wishing to pioneer in new applications and systems.

Today, as a function of the RCA Laboratories, the mission of SSTC remains to provide advanced micro-electronics circuitry on a broad scale within RCA and to do so in terms of qualified devices at competitive costs for systems involving a high degree of engineering.

In 1974, about 50,000 special LSI arrays will be produced and shippped. By SSD mass production standards, such quantities seem small but are important for concept design and pilot production.

W. R. Isom, Chief Engineer, RCA Records, Indianapolis, Ind. (and a native Hoosier) gave an interesting and entertaining slide-lecture on "Indian(a) Lore" to conclude the first-day activities.

Second-day Session

On Tuesday, Dr. J. Hillier, Executive Vice President, Research and Engineering, served as Session Chairman to introduce four major RCA electronic division representatives who reviewed current business activities.

B.V. Vonderschmitt, Vice President and General Manager, Solid State Division, presented the business and technology goals of SSD to design, manufacture, and sell solid-state components and subsystems profitably to commercial and defense markets. About 90% of SSD's business in intended to be at the semiconductor package or device level for system and equipment manufacturers. The worldwide semiconductor markets are expected to show annual growth rates between 12 and 25% from 1973 to 1979. The greatest growth is expected in vehicular applications, computers, instruments and controls.

In 1974, IC's will account for 50% of SSD's business and in 1975 the total semiconductor industry's business will be about 50% IC's. SSD's current business is expected to increase about 40% in 1974 (faster than the industry growth rate of 15%) and SSD will show an increase of between 17 and 20% each year up to 1979. The strategies to achieve these goals are: 1) product technology leadership, 2) new product innovations, 3) serving local markets, and 4) provision of effective customer service (applicaiton engineering aid).

Solid State engineering is concentrated in Somerville, N.J., and manufacturing is spread among plants throughout the world. Recently, manufacturing has been extended to the Palm Beach Division. In conclusion, SSD's business could increase by a factor of three by 1979.

Conferees listen to one of the many presentations on the three-day program of the management conference.

Session breaks provide further opportunities for information exchanges.

Howard Rosenthal, Staff Vice President, Engineering, Research and Engineering, was chairman of the first session, which consisted of presentations from several key corporate areas.

F. D. Becken, President, RCA Global Communications, Inc., described the goals of his division of remaining number one in Telex communications, leased-channel, and message-traffic communication services. In addition to the RCA Alascom major telephone service, international telephone service is being provided. Other communication services include marine, television, videovoice, hotline, and telephoto.

Another major goal is the development of new domestic communication services with RCA's SATCOM system. Phase I of SATCOM began in late 1973, using the Canadian satellite, TELESAT. In Phase-II of SATCOM, slated for late 1975 or early 1976, TELESAT will be replaced by our own satellites. Each RCA satellite will consist of 24 transponders, each having capacity for 450 two-way, voice grade circuits or for tv service.

G.W. Duckworth, Division Vice President and General Manager, Industrial Tube Division, reviewed the business activities of Electronic Components. EC activities include Distributor Products, Entertainment Tubes, and Industrial Tubes. Receiving tubes (largely replacements) continue to contribute to profits but business is expected to gradually diminish. Picture tubes offer competitive challenges and opportunities for a major technological breakthrough. Sales outside the U.S. will exceed those within the U.S. in 1976. The innovative precision in-line black-matrix tubes have provided a high degree of performance to support RCA's leadership position.

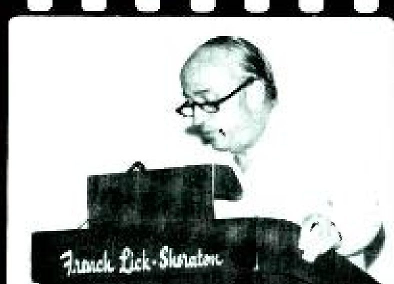
For the industrial tube market, new products are planned such as power tubes for high-power radars; electro-optics devices; camera tubes; and power tubes for broadcast a.m., fm, and television . Low-cost cameras and laser devices will also be introduced. Better engineering effectiveness and better product selectivity are keys to success in meeting the stiff competition of many small entrepreneurs.

I.K. Kessler, Executive Vice President, Government and Commercial Systems, stressed the idea that G&CS success depends on innovation by RCA's 4500 engineers and scientists and presents a challenge to narrow their burgeoning efforts to our best businesses.

The high technology businesses include AEGIS, G&CS's largest single contract. The AEGIS phased-array antenna has a potential of over one billion dollars. The AEGIS phased-array antenna is a unique feature that enables the handling of a large number of targets simultaneously.

An outstanding program described is the PABX telephone switching system, an all-solid-state product in which both Government Communications in Camden and SSTC cooperate.

Another new system cited was the Palm



Dr. William M. Webster, Vice President, RCA Laboratories, served as chairman of the final session which dealt with consumer electronics.

Left, J.H. Scott, Jr., Dir., Integrated Circuit Technology, RCA Laboratories; and B. Vonderschmitt, Vice President and General Manager, Solid State Division.

Left, K.H. Zaininger, Head, Solid State Device Technology, RCA Laboratories; and R.N. Rhodes, Mgr., Video Disc Engineering.

Doris Hutchison, Administrator, Staff Services, handled conference arrangements.

Doris McCallus, Executive Secretary, took care of conference registrations.

W.R. (Rex) Isom, Chief Engineer, RCA Records, provided information and anecdotes on the Hoosier State.

Beach Division's Dataway, a data management system for hotels, motels, hospitals, and similar industrial uses.

Defense meterological satellites and transportable military satellite terminals that can be set up for operation within 20 minutes were mentioned.

Satellite earth stations, automatic vehicle testing systems, multi-array tv and fm antennas, a new 20-lb portable high-quality tv camera, and the TACTEC two-way portable communications system were also discussed.

The future challenge will be to bring precision into the creative process through advanced techniques such as computer-aided design.

Bloomington Plant Tour (Tuesday, P.M.)

J.M. Wright, Manager, Resident Engineering, and F.W. Riedweg, Plant Manager, both of Consumer Electronics (Bloomington) served as hosts and welcomed two bus-loads of conferees to the Bloomington manufacturing plant.

P.G. McCabe, Mgr., Production Operations, briefed the group before touring the plant.

Color tv manufacturing presently runs ten production lines with some black-and-white tv and console stereo assemblies. On the day of the tour, Bloomington produced about 8,500 instruments. There are about 5,700 employees and employment has been as high as 7,000.

Third-day Session

Dr. W.M. Webster, Vice President, RCA Laboratories, served as Session Chairman to introduce the speakers and moderate the final meeting.

R.H. Pollack, Division Vice President and General Manager, Color and Black-and-White Television Division, described the industry domestic color tv market as going from 8.6 million units in 1974 to about 10.6 million annually in 1979. Black-and-white television will maintain a rate of close to 7.0 million and will remain flat through the period to 1979.

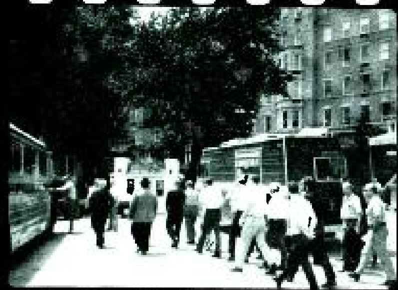
Business considerations that must be coped with include: product safety, cost of quality and reliability, material costs, shortages/lead times, and an inflation which exceeds the rate of cost reduction. Other key factors perceived are...product leadership, proper screen-size, model mix, and "reaching the consumer." Modern all-solid-state receivers are seen as vastly improved over the early "color tv's" of 1954.

Consumerism, product safety, and reliability plus the high level of competition are the challenges ahead for our technical and business management

Left, R.C. Butler, Vice President, Financial Analysis, RCA, New York; and I.K. Kessler, Executive Vice President, Government and Commercial Systems.

(L to R) — Dr. J. Hillier, Executive Vice President, Research and Engineering; A.C. Luther, Chief Engineer, Broadcast Systems, CCSD; H.R.L. Lamont, Dir., European Technical Relations, Licensing; and W.H. Warren, Mgr., Engineering Quality Reliability Assurance, Receiving Tubes, EC.

J.A. Rajchman, Staff V.P., Information Sciences; B. Vonderschmitt, Vice President and General Manager, SSD; and Dr. W.M. Webster, Vice President, RCA Laboratories.



Conference attendees are shown boarding buses for the trip to the Consumer Electronics plant in Bloomington, Indiana.

J.M. Wright, Manager, Resident Engineering welcomes two busloads of Conferees to CE's Bloomington facility.

Conferees observe the assembly operations for color TV's made at Bloomington

resources.

W.S. Lowry, Division Vice President, Color Television Product Management, described programs underway to predispose the customer to select RCA over competition. Over a period of 20 years RCA has sold 14 million color sets. In 1973, RCA sales were up 15% while industry sales increased only 10%.

In the 1974 line, RCA will have all-solid-state receivers in five screen sizes, 15, 17, 19, 21, and 25 inches (diagonal). There will be six chassis providing 55 models. The all-solid-state program (now underway) is one full year ahead of schedule and ahead of competition. All picture tubes are negative black-matrix types providing substantially greater brightness than non-matrix types. The solid-state models will use up to 50% less energy and provide greater reliability, 1-year PS (Purchaser Satisfaction) warranties, and advances in overall performance.

New and imaginative merchandising and adverstising programs were described in support of the 1974-75 programs.

R. Mentzinger, Director, Black-and-White Television Product Management, described how RCA's B&W "tunes in with the times." Although industry color sets will grow to 10 million or more, remember that B&W will also remain at an annual industry rate of about 7 million sets. However, the business has changed from a market where consoles were once dominant to current demands for portable models with 40% or more using 12-inch screen sizes. In 1974, 75% of the receivers will have screen sizes 12 inches and under with about one-half slated for use in bedrooms.

Population has increased from 142 million in 1946 to 210 million in 1974, with steady income increases and with about 80 million gainfully employed. So, there will be a market for more television sets with gains of 40% in buying power. Future models will reflect the needs of a younger, better educated and more sophisticated consumer having a higher income. This younger consumer shops carefully with firm ideas concerning reliability and product safety.

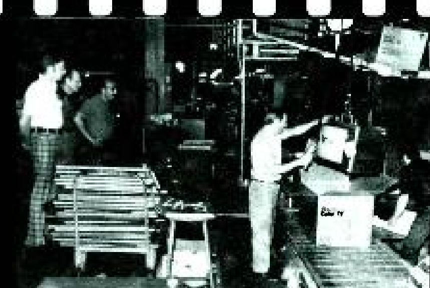
Worldwide inflation and intensified domestic and foreign competition will require innovation, and creativeness in making decisions concerning technical features, style, and performance. RCA's product and marketing programs are oriented to these challenges and opportunities.

The conference was organized under the direction of H. Rosenthal, Staff Vice President, Engineering, Research and Engineering, assisted by Doris Hutchison, Administrator, Staff Services, Engineering, Research and Engineering.

Summaries and descriptions covering a majority of the subjects presented at the conference are included in the pages that follow.

A group of the visitors watches the testing of color TV receivers as they move down the test line. The test gear moves with the sets providing progressive powered testing and alignment.

Visitors watch as RCA color tv sets are readied for final shipment.



Conferees are shown at the Consumer Acceptance Laboratory which samples 4% of the product each day under rigorous test conditions.

"Computer Aided Design"
...by L. J. French and A. H. Teger
"Charge Coupled Devices"
...by J. E. Carnes and K. H. Zaininger

Session 1 - H. Rosenthal, Session Chairman

Welcome
...by J. Hillier
"'A Review of the 1973 Operating Results and the Outlook for 1974"
...by R. C. Butler
"An Overview of Corporate Development (1974–1980)"
...by G. C. Evanoff
"Reliability, Quality and Responsibility"
...H. W. Johnson
"The Solid State Technology Center--Goals and Achievements"
...by G. B. Herzog
"Indian(a) Lore"
...by W. R. Isom

Session 2 – Dr. J. Hillier, Session Chairman

"SSD Business and Technology Trends"
...by B. V. Vonderschmitt
"RCA Globcom – A Look Ahead"
...by E. D. Becken
"EC in Review"
...by G. W. Duckworth
"G&CS – Electrons at Work"
...by I. K. Kessler

Session 3 – Tour of Bloomington Plant

Session 4 – Dr. W. M. Webster, Session Chairman

"RCA Television—A Status Report"
...by R. H. Pollack
"Color TV Overview: What RCA is doing, Why we are doing it, and What RCA expects to accomplish"
...by W. S. Lowry
"RCA Black and White TV Tunes in with the Times"
...by R. Mentzinger

Description and summaries (cont'd)

Technical Seminars

Two technical seminars were devoted to current topics of wide interest to engineers and scientists at RCA. One dealt with the potential of using computer aided design techniques—the other considered current and future applications of charge-coupled devices.

Charge-coupled devices

J. E. Carnes, MTS.
Process & Applied Materials Lab,
RCA Laboratories,
Princeton, N.J.

K.H. Zaininger, Head,
Solid State Device Technology,
RCA Laboratories,
Princeton, N.J.

Carnes

Zaininger

The seminar on Charge-Coupled Devices (CCD's) covered a wide range of topics including the basic principles of operation and gate structure technologies, as well as the three major areas of application: image sensors, computer memories, and analog signal processing. Emphasis was placed upon the advantage of CCD's over existing devices, and the present state-of-the art within RCA and the industry.

The CCD is an analog shift register based on MOS technology and capable of large scale integration. It uses an externally applied clock drive which controls the shifting of charge packets which represent the signal. Thus, it can be considered as an analog signal device with digital addressing. Since a semiconductor-based analog delay line has never existed before, the CCD is a unique device with unique capabilities. It can shift charge packets over very long distances of silicon without exposing the charge to recombination of a high capacitance. It can store analog signals for up to .1 to 1 second before thermal leakage currents destroy the signal modulation.

So far, CCD's have had the greatest impact in the area of all-solid-state, self-scanned image sensing. Here the ability of the CCD to move charge from the point of photogeneration to the on-chip output amplifier without degrading the signal-to-noise ratio is a key advantage. CCD imagers have high signal-to-noise ratios and high dynamic range. Pictures are free of striations due to clock feedthrough, and uniformity and grey scale renditions are excellent. Devices with 512 vertical resolution elements (with interlace) and 320 horizontal elements have been built on a developmental basis at RCA. A 256 × 160 element RCA camera was demonstrated at the seminar. Present problems with CCD imagers include achieving good processing yields on the extremely large chips required, and control of the dark current non-uniformities which can cause cosmetic blemishes on the display.

However, the prognosis for CCD imagers is good especially for closed-circuit and medium quality industrial TV applications. Widespread use here is predicted within 2 to 4 years. Use of CCD imagers in broadcast appears too out of reach of present technology and is probably 5 or so years down the line.

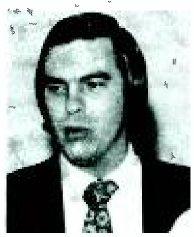
Another area of potential CCD use where the dollar volume is very large is in computer memories. When coupled with a refresh or regenerate state, the basic CCD shift register can be used for serial digital memory. The potential advantage here lies in the fact that only one to three capacitor plates are required to store one bit of information. Areas per bit of .5 mils^2 or less are predicted which should result in single 250×250 mil chips with 64,000 bits. Since access times can be as low as 100 μsec, a performance advantage over existing drum and head-per-track discs can be achieved. RCA is presently fabricating a 16,000 bit chip and hopes to replace ruggedized military drum memories with CCD memory. Other memory work is concerned with devices which can be used as auxiliary memory in general purpose computer machinery. If the cost advantage over more conventional semiconductor random access memories is large enough (four-to-one, or so) then widespread use of CCD memory is likely. Failing that, there are many smaller volume, but specialized applications, such as ruggedized drums, air borne radar memories, and display refresh, where CCD memory looks good.

The other area of application for CCD's is in analog signal processing where delay, re-formatting and filtering functions can be implemented with great cost, size and power consumption advantages over existing techniques. Time delay-bandwidth products of 1000 are possible with maximum delays of 500 milliseconds and maximum bandwidths of 5-10 MHz. (Buried channel devices may provide bandwidth capability of several hundred MHz.) Electronically variable delay is relatively easy to achieve using CCD delay lines.

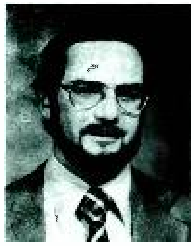
It is fully expected that CCD's will soon be used in various radar and communications systems, but only on a custom-design, low-volume basis. At present no standard components (aside from possibly delay lines) are envisioned as having enough volume to be "off-the-shelf" items.

Computer aided design

L.J. French, Mgr.,
Design Automation,
SSTC, Somerville, N.J.



A.H. Teger, Head,
Advanced Systems Research,
RCA Laboratories,
Princeton, N.J.



This seminar will give you an understanding of what Computer Aided Design is, what application areas it is being used in today by industry, and then as an example of one area within RCA where it is being heavily used, we will concentrate on Computer Aided Design in the IC design and manufacturing process.

By Computer Aided Design, or CAD, we mean any use of a computer to complement or aid a human in the design process. Design Automation, or DA, has an unwarranted implication of mechanization to the exclusion of the human; in fact, this can never happen completely—the stress is on improving the human's design capabilities, not eliminating the designer. We will treat CAD and DA as synonomous terms.

The use of computer tools in both mechanical and electrical design has grown enormously during the 1960's and early 70's. Interactive systems, some using graphic displays, are now being used in production environments for designing automobiles, airplane fuselages and parts, ships, and machine tooling in many industries. Design aids in the electrical area have centered on circuit analysis, filter and antenna design, and logic simulation, as well as placement, wiring, and testing of finished circuits.

Computer Aided Design has had significant impact within RCA particularly in the design and manufacture of circuits—hybrid, printed circuit board, backplane wiring and integrated circuits. We will restrict our discussion to CAD's impact on the design and manufacture of IC's. An overview of the major steps involved in the design and manufacture of an IC will be given, followed by a discussion of the computer aids available at each step.

The IC cycle begins in response to a customer's request. Once the request has been clearly communicated, the design of the circuit begins with the creation of a logic diagram. The design is verified both for circuit and logical correctness. Then, the electronic components comprising the circuits must be placed and routed. Placement is the assignment of the geographical location of each component on the IC, and routing is achieving the electrical interconnections between the components.

All IC's are manufactured using photo-masks to control processes which affect the parameters of the silicon material in a desired fashion. Seven to fifteen photo-masks are typically required to manufacture an IC and each photo-mask contains from 300 to 1,000 identical patterns – each representing an IC. A photo-mask is made from another photographic plate, which is one pattern at ten times actual size, called a reticle. After placement and routing the next step in the IC cycle is to make a reticle which is photo reduced and stepped and repeated to make the photo-masks. The photo-masks in turn are used to manufacture the IC wafer.

After processing, the next step is to generate a set of tests that will ascertain whether or not the IC meets the customer's specifications. The tests are used by a computer controlled automatic test system to apply stimuli and measure responses.

CAD has impacted virtually every major step of the IC cycle. Designs are verified for circuit and logical performance using computer simulation programs (*e.g.*, LOGSIM for logic simulation and RCAP for circuit analysis) that provide greater flexibility and accuracy than manual techniques. Placement and routing can be performed automatically via a CAD program called PR2D, or manually using interactive computer systems. Automatic placement and routing offers great savings in design time while the computer aided manual approach offers greater efficiency in the utilization of silicon area.

CAD has had its greatest impact on the IC cycle in making the reticle. A variety of interactive computer systems and programs have been created to provide techniques for input of a circuit description into the computer, for verifying that it is correct, and for providing a magnetic tape to drive the automatic pattern generators on which reticles are made. The artwork systems available today are the Digitizer-Plotter System (DPS), the Ala Carte system, and the Applicon System, as well as several checkplotter systems. The computer aided artwork system has reduced the design time, reduced the number of errors, and has made our entry into the large scale integrated circuit business possible.

Test generation can also be accomplished via a computer program called TESTGEN. This program aids greatly in determining the stimuli and expected responses in verifying the logical operation of the circuit, and in evaluating a given set of tests. As we move in the direction of larger IC's, computer test generation programs will play an ever-increasing role. Process monitoring and characterization is intimately connected with test generation and testing in general. This is a rather new area of CAD within RCA that already has shown success. We are attempting to monitor the IC process such that we can properly characterize the process. If we succeed, we can then predict when the process is drifting out of specification and also what might be done to prevent that from happening. Initial work on analyzing test data has shown that 10% of all IC's are bad before any process has begun on the wafers. CAD test data analysis programs have shown that mask defects account for an immediate reduction in yeild of 10%. As a result, new mask inspection techniques are being evaluated. This is just the beginning of an area of work in CAD that could have far ranging impact on yield, reliability and the cost of manufacturing IC's.

Current research in CAD is being directed toward improving the artwork systems and toward creating a unified CAD data base. The artwork systems have been dramatically enhanced by a design rule verification program, called CRITIC, that checks for geometric violations. Enhancements are being added to this program as well as to the other systems, and they are now being distributed to other interested Divisions in RCA.

The unified CAD data base, currently being tested at Somerville, brings together many of the independent programs described above in order to eliminate redundant input and to provide easier access to the programs. A new user-oriented CAD language has been developed in order to provide a single input mechanism to the data base. Each of the simulation, layout, testing and artwork programs accesses the data base for its data upon request of the designer. This system will provide a foundation for future growth of CAD programs in design areas essential to RCA.

A Corporate View

Two presentations by representatives of Corporate Development and Finance operations provided a review of corporate development and of 1973 operating results plus a look at 1974 potentials. Another paper described the corporate role in quality, reliability and responsibility for programs to achieve challenging goals. A fourth presentation described the Solid-State Technology Center — a corporate group that assists and cooperates with engineers from all RCA divisions to provide special LSI arrays for new applications and systems.

A review of the 1973 operating results and the outlook for 1974

R.C. Butler, Vice President,
Financial Analysis,
RCA, New York City

The composition of the new "line of business" reporting which was introduced for the first time in RCA's 1973 Annual Report was described in detail. The new reporting system basically represents an expansion of the number of business segments previously used from four to seven.

The first segment, *Electronics - Consumer Products and Services*, includes the total operating results of the Consumer Electronics Division and RCA Records, the Consumer Services part of the Service Company and also the profits on intra-company component sales from Electronic Components and Solid State to the Consumer Electronics Division.

Included in the second major segment, *Electronics - Commercial Products and Services*, are the operating results of Electronic Components, Solid State and Commercial Systems including Aviation Equipment and the Technical Services group of the Service Company.

The third, fourth and fifth segments each cover the operating results of a single operating unit of RCA. *Broadcasting* reflects the complete results of NBC, *Vehicle Renting and Related Services* covers Hertz, and *Communications* includes the revenues and earnings of RCA Globcom and Alascom. It was decided to use generic terms in describing these segments rather than the proper names in order to provide for future flexibility.

The *Government Business* segment includes the traditional Government Contracts as well as the Government Services section of the Service Company and the profits on Solid State and Electronics Components sales to government agencies.

The *Other Products and Services* segment includes the operating results of Banquet, Coronet, Random House and Cushman & Wakefield. Should any of these companies grow significantly in sales and earnings in the future they could easily be reported as a separate segment.

The principal reason for the new "line of business" reporting was to provide a more accurate picture of RCA to the investing public. While most people know RCA, few know with any degree of accuracy the principal sources of the Company's earnings and the improved balance in earnings achieved in the past few years. The initial reaction from the financial community to the new segmentation has been *very* favorable.

1973 Results

In reviewing the 1973 operating results of the *Electronics —Consumer Products and Services* segment, it was noted that earnings declined despite a sales increase which principally reflected operating losses at RCA Records and a severe price/cost squeeze in Consumer Electronics products. However, these unfavorable results were more than offset by increased earnings in *Electronics—Commercial Products and Services*, principally in the area of Solid State devices.

In the *Broadcasting* segment NBC's revenue and profits were up over 1972 levels despite "Watergate preemptions". It was reported that a sales and earnings record was established by Hertz Corporation as they recorded a strong year in Rent-A-Car, Truck Operations and Car Leasing. In *Communications* a sales and earnings record was also established by RCA Globcom and its subsidiary RCA Alascom reflecting volume increases in all areas of the business: international telex, telegram, telephone and leased channel communications.

In *Government Business* sales were lower reflecting reduced expenditures by the Department of Defense and NASA. However, earnings were only marginally lower than prior years indicating well-controlled operations. In the category *Other Products and Services*, sales increased 28% but earnings increased modestly principally reflecting the impact of price controls on Banquet Foods operations, and the cost increase at Random House associated with the acquisition of Ballantine Books

1974 Results

Commenting on first quarter 1974 results it was noted that while earnings were 17% lower for the first quarter 1974, RCA competitors provided a lot of company. Zenith earnings were down 50% - Magnavox was off 58% and Westinghouse net earnings fell by 28%. While the unfavorable results did reflect a general softening of the market for Consumer Electronics products, there were several areas of RCA where profits improved significantly over the 1973 period: notably Globcom, Solid State and Hertz.

In regard to investor reaction, many Wall Street analysts were not surprised by the earnings decline and were pegging full year 1974 earnings in the range of $2.00 to $2.25 per share. In fact, one major brokerage house noting this range of earnings said, "We believe that if RCA does this well, it will be a strong point in favor of management's careful diversification over the years, as well as evidence that RCA's strong competitive position in several industries provides considerable earnings stability in difficult periods."

An overview of corporate development

G.C. Evanoff, Vice President,
Corporate Development,
RCA, New York City

In describing "An Overview of Corporate Development 1974-1980", it was envisioned that there will be a steady growth in sales and earnings per share through 1980 based on high market share positions of RCA's major businesses. RCA's electronics operations are expected to contribute approximately two-thirds of total sales and profit performance over the next 5 to 6 years and are being supported with a similar proportion of the Corporation's investment in research and development and in projected capital spending.

It was pointed out that the pace of RCA revenue and profit growth for the remainder of the 1970's is expected to be more rapid than the U.S. economy (GNP).

Also highlighted were major goals of the Corporate Development group which was formed in late 1973. These goals are:

- Inventory corporate strengths and match with market potential.
- Test business significance, fit, growth contribution, etc.
- Establish criteria and reallocate funds to meet objectives.
- Develop a 1980 Corporate profile placing emphasis on revenue growth.

The broad strategy being pursued by RCA encompasses the following elements:

- Expand present business
- Upgrade quality of business mix
- Build stable leadership positions in a limited number of major business areas.
- Pursue international market aggressively
- Introduce new products and services
- Integrate business objectives with social and customer needs

Although no specific forecast of results was given, it was suggested that

RCA sales volume could exceed $8 billion by 1980 with electronics, communications, services and non-electronic home products each yielding important contributions to this overall performance.

Reliability, quality and responsibility

H.W. Johnson, Staff Vice President,
Reliability and Quality,
Manufacturing Services and Materials,
RCA, Cherry Hill, N.J.

RCA's top management has made a strong commitment to quality. This is clearly expressed in the *Corporate Policy* which states that RCA products and services will be equal to or better than those offered by competition. Further evidence of this commitment is shown in the requirement for each division to supply to the Corporation's President and Chief Operating Officer, a monthly report indicating the quality level of the output of that operation.

Quality means the conformance to requirement or specification, and the first step in achieving quality is to establish detailed specifications and product plans.

While the responsibility for quality is that of top management, it is also shared and delegated to others. Ultimately it is the engineer who must design quality into a product that will meet the product plan and win the race with competition.

The Quality Assurance department coordinates, measures, tests, and monitors the quality of the product, and they have the vital responsibility to feed back plant and field failure information to those who can correct problems. In addition, they keep everyone alert to the cost of quality. In today's environment of extended warranties, the dollars needed to meet the profit improvement goals of some divisions can be found in their cost of quality reports.

Marketing's responsibility for quality takes the form of knowing what the consumer wants and is willing to pay for. Marketing must know what products will be equal to or better than competition far enough in advance so that other groups in RCA will have time to do their jobs. Specific needs must be detailed in a product plan which is easily understood by Engineering and Manufacturing. Such information is used to establish reliability and quality standards against which Quality Control will measure.

A prime responsibility of Engineering for quality is the holding of frequent and formal design reviews that span the product cycle from concept through six months of production. Such reviews encourage suggestions and changes that improve the product and give everybody a better opportunity to prepare for their part in perfecting the design before delivering the product to the customer.

Engineering also has a responsibility to design to reduce human error. Designs requiring tests or inspections that are complex or lengthy are designs that lead to human error. Designs featuring simple assembly and automatic testing reduce human error and achieve maximum conformance to specifications.

Manufacturing's responsibility for quality is in terms of inspecting and testing the product through the many stages of assembly and delivering a customer acceptable product at minimum cost. Manufacturing also must develop and make available new technologies that will produce error-free products.

High levels of quality can be achieved through good communications between marketing, manufacturing, and engineering. Quality, itself, has to be achieved through compatibility of design and manufacturing processes, not through the costly steps of inspecting defects out of a product.

SSTC Goals and Accomplishments

G.B. Herzog,
Staff Vice President,
Technology Centers,
RCA, Somerville and Princeton, N.J.

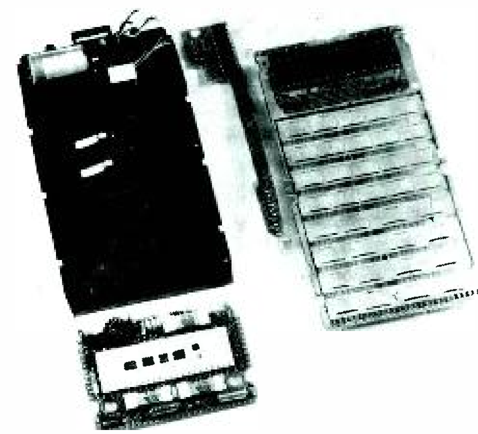


Fig. 1 — HP-65 30,000-bit memory demonstrates feasibility of LSI.

The SSTC exists to provide for the Corporation the ability to apply advanced semiconductor technology to new systems concepts. It is clear today that many products are economically and technically feasible only when they use large scale integration (LSI) techniques. The HP-65 pocket computer, which employs over 50,000 transistors and 30,000 bits of memory, illustrates such a product, Fig. 1. In anticipation of this fact, Dr. J. Hillier created the SSTC in 1970, and it reports to him today via the RCA Laboratories under the direction of Dr. W. Webster. Because the SSTC is truly a corporate entity, it receives direction from a Board of Directors representing G&CS, SSD, EC, and CE, as well as the Laboratories.

Since the key to LSI is the creative use of computers to help prepare the chip layout artwork, simulate the complex circuits, and run complex test programs, the SSTC includes a sizable group that develops design

Fig. 2 — Design automation software programs at RCA.

	ART	*CRITIC*	*MAP*	*ALACARTE*	*R-CAP*	*PR2DFL*	*PR2D*	TESTGEN	ARTDWM	PDP-11 * *Software*
Burlington	X	X	X		X	X	X	X		X (not sent yet)
Camden	X	X	X		X	X	X	X	X	
Moorestown	X	X	X			X	X	X		X
West Palm	X	X	X	X		X	X	X	X	
Cherry Hill	X	X	X							
Hightstown				X						X (not sent yet)
Princeton	X	X		X	X	X	X	X	X	
Somerville (IBM 158)					X					

* PDP-11 Software: Art, Applicon conversion routines, plots compiler, MTDK, MTDUMP.

automation software and special hardware. This Design Automation group, supervised by Dr. Larry J. French, acts as a corporate focus for programs relating to semiconductor fabrication. It distributes such programs throughout the Corporation, Fig. 2, so that groups wishing to actively participate in the design of LSI arrays may do so. In addition to programs developed within the DA group, programs developed elsewhere in the Corporation are also included in the distribution. Two such programs deserve special mention, PR2D or APAR and TestGen. These were created in G&CS and have been of significant benefit to the Corporation as a whole as well as to G&CS government work.

The pilot lines for LSI fabrication are in the Custom Monolithic group managed by Stan Rosenberg. The group interfaces with corporate engineers at various levels of IC design and produces sample quantities for product evaluation. Quantities of up to a few thousand can be produced for field evaluation of systems or for applications where only limited quantities are needed such as in space satellites, for instance. The capability exists to screen units to high-quality standards suitable for space and other high-reliability applications. Because the engineering costs of a custom LSI design are very large when using traditional techniques, special tools have been developed to reduce the cost of LSI designs for small quantities. The APAR program of G&CS is one such tool. The universal array is another. The universal array consists of a predetermined semiconductor pattern of MOS devices. The user need only supply a metallization interconnect pattern for the devices. Predetermined patterns to interconnect devices as various types of gates, flip-flops, shift registers, adders, etc., exist to reduce the effort required of the user. Although the approach is wasteful of silicon areas, it is the quickest and cheapest way of evaluating an LSI function. Such arrays exist in various sizes up to 276 equivalent, two input NOR-gates, and in most MOS technologies including PMOS, CMOS, and SOS. There are also technology variations such as high and low thresholds, aluminum or silicon gate, and beam leads, although not all possible combinations are presently available. Since no computer or semiconductor expertise is necessary to design the interconnect pattern for such an array, a wide variety of customers can participate in the design of LSI for their system requirements. The universal array has also been used by SSD as a marketing tool and arrays have been fabricated by SSTC for a few select customers outside of RCA.

The Custom Monolithic group does not deal in large volumes of a single type, but rather in small quantities of a large number of types. In 1974, 30,000 to 50,000 units will be produced with mix of over 200 types. By comparison, SSD produces 50,000 COSMOS units in less than a day. Because the SSTC volume is so low and we deal in so many different technologies, the cost of fabricating units is high and subsidized by the Corporation. This allows the charges for arrays to be set at acceptable levels so that systems people are able to use LSI where it is required to succeed in a new system concept. The charges, of course, are still high compared to volume prices quoted for standard LSI. But the use of advanced forms of LSI gives RCA leverage in bidding system jobs. A recent $32M contract on communications equipment would have been unobtainable without the SSTC or equivalent. The RCA developed PABX being sold by the Service Company depends on arrays from the SSTC. The Aviation Equipment Division uses arrays from the SSTC in its commercial products. Astro uses CMOS arrays in its satellite work, and Moorestown has used SOS arrays in its developmental radar signal processing equipment. Although it is impossible to measure the return on investments from this type of activity, suffice it to say that the SSTC Board of Directors recognizes its importance to the Corporation and continues to support it vigorously.

To insure the availability of the most effective LSI techniques for the Corporation, a substantial development effort supports the Custom Monolithic pilot line. This effort is under the direction of J.H. Scott, Jr. and I.H. Kalish. Work is carried out on ion implantation, silicon gates, beam leads, radiation hardening, high-speed bipolar devices, high-power IC s, dielectric isolation, CCD s, and general device reliability and process control. Part of this effort is in the Princeton David Sarnoff Research Center, and part in the Somerville SSD headquarters building.

Recently, a LSI Applications group has been added to the SSTC. Under the leadership of Dr. Robert O. Winder, its goal is to help the Corporation with systems use of LSI. One such effort is the COSMAC microprocessor. In cooperation with Palm Beach Division, a 2-chip microprocessor set has been realized for general use within the Corporation and sale as an OEM product. A prototype kit will be available soon from West Palm Beach to assist users in evaluating the microprocessor for their applications. Software support is also available from the Winder group and accessible via NTSS or by Fortran programs on local computers.

In summary, the SSTC is fulfilling a special need in the Corporation and stands ready to assist any division having need for custom LSI or related technology.

High-Technology Products

Four presentations were given concerning the status of businesses and technology trends in four major divisions in RCA's electronics community. The 1974-75 high-technology programs included Global Communications, Solid-State Division, Electronic Components, and Government and Commercial Systems.

SSD's business and technology trends

B.V. Vonderschmitt,
Vice President and General Manager,
Solid State Division,
RCA, Somerville, N.J.

The business charter and technology goals of SSD are to define the worldwide market...and to design, manufacture, and sell solid-state components and subsystems profitably. To achieve this, the scope of SSD's business must involve commercial and defense customers in both domestic and international markets.

Approximately 95% of SSD's business is intended to be confined to the semiconductor package or device (component) level in serving system and equipment manufacturers. SSD products include power transistors (both hermetic and plastic), IC's packaged in both plastic and ceramic, and liquid crystals. The solid-state worldwide industry market will range from a little more than $4 billion in 1973 to almost $9.5 billion in 1979, as shown below; these figures are at the package level and do not include hybrids and subsystems.

	1973	1975	1979	*%Growth Rate*
U.S.	1870	2405	4100	14
Canada	78	100	175	15
Europe	970	1270	2050	14
Japan	1330	1650	2700	12
R.O.W.	120	220	460	25
Total	4368	5645	9485	15

The annual semiconductor growth rates anticipated, by worldwide market categories are: Vehicular (31%), Instruments and controls (20%), Computer (20%), Communications (18%), Consumer (12%), and Government (11%).

For IC's only, the worldwide potential shows a compounded annual growth rate of about 21%. In 1974, IC's will account for half of RCA's business. In 1975 the worldwide semiconductor business will be half IC's.

SSD's total business is expected to increase about 40% in 1974 (faster than the industry growth rate of 15%), and to show an annual compounded growth rate of approximately 18% over the next five years. The major revenue strategies we have developed to achieve these goals are: 1) product technology leadership, 2) new product innovations, 3) serving local markets, and 4) provision of effective customer service (timely deliveries and application engineering aid).

Over the next several years, technologies and products planned for introduction will include SOS integrated circuits; gate-turn-off thyristors; COS/MOS-liquid-crystal modules; higher-current and higher-voltage power devices; and beam-lead, dielectrically-isolated bipolar devices. Lower-cost plastic packages and rf power modules are other advances. It is anticipated that as many as 75 new IC's will be introduced each year.

Strong competition dictates both cost reductions and greater reliability, which will be achieved through technology improvements in design and manufacture, better wafer handling and processing, projection printing, glass-passivated power devices, and mechanized bonding techniques. Greater production efficiencies will be achieved through improved processing techniques in diversified domestic and international plant locations.

To achieve the objectives of our expanding business, we are planning appropriate investments in capital equipment and in engineering and manufacturing personnel over the next five years. Plant facilities and employees could double during this time. In view of the potential for higher sales in the memory market, the higher market potential for existing products, and a challenging opportunity in the world market, SSD business could increase by a factor of three by 1979.

RCA Global Communications— a look ahead

E.D. Becken, President,
RCA Global Communications, Inc.,
New York City, N.Y.

RCA Globcom is the front runner in the international voice/record communications business. We are number one in participation in telex, leased channel and message traffic services. We provide telephone service internationally, and our subsidiary RCA Alascom is the long lines carrier for telephone service in the State of Alaska and between that state and the lower 48 states. We also provide a number of other communication services such as marine, tv, videovoice, hot line and telephoto.

Our goals for the future are to enhance our favorable participation position in all of our services and to accelerate growth both internationally and in Alaska. A major goal is the expeditious and successful development of new domestic communication services on the RCA Satcom system.

This latter service began on a phase one basis on December 21, 1973 using the Canadian satellite, Telesat. This lease covers up to five full-time and one occasional-use transponder for the provision of message telephone service between Alaska and the lower 48 states, and within Alaska; private line voice grade service between the east coast and the west coast; and occasional tv service.

Our satellite system will become available in late 1975 or early 1976 when two of three satellites being built under contract for us by RCA's Astro-Electronics Division will be launched on augmented Thor Delta Model 3914 launch vehicle provided by McDonnell Douglas. These three axis-stabilized satellites will be equipped with 24 transponders each of which is capable of providing 450 two-way voice grade channels or one tv transmission. The existing earth stations at Valley Forge, Pennsylvania; Point Reyes, California; Anchorage, Juneau, Valdez and Prudhoe Bay, Alaska, will be augmented by additional earth stations near Washington, D.C., Los Angeles, Chicago, Denver, Atlanta, Dallas, and many remote villages in western and northern Alaska.

Our major service - telex - is expanding at about 20% per year and participation was 41.5% of the industry. Further expansion facilities are on order and scheduled for installation in our new Kingsbridge Campus control center in Piscataway, New Jersey by the end of this year. In addition, the new telex facility at our Lodi, California center is being expanded. Innovation of service, such as Telextra and Unicode, has enhanced our participation position and further improvements in service will be pursued.

Our leased channel business is expanding at about 15% per year and the 1973 year end participation was 49.5% of the industry. Our quality assurance program in this area, involving 1100 leased channels extending over all the world, averaged 99.3% in 1973.

Opportunities are available in the application of satellite technology to the marine and aeronautical services and RCA Globcom intends to participate with Comsat and other international/voice record carriers in the utilization of a satellite system being provided to the United States Navy which will have additional capacity for commercial marine services. This system is scheduled for implementation early in 1975. Efforts continue also in pursuing longer range marine development for a dedicated satellite system with a tentative schedule of 1978.

Some special projects under way are the provision of a New York/Camden/Valley Forge microwave system for the RCA Corporation and for RCA Globcom's east coast satellite circuits, the laying of transoceanic cables in both the Atlantic and Pacific Oceans in which we will obtain indefeasible right of user channels for all of our services, and the telex switching projects in Iran. In addition, special regional satellite system projects are under consideration for Brazil, Iran, Indonesia and a special tracking data relay satellite system for NASA.

In summary, RCA Globcom has many telecommunication opportunities with keen competition, but we remain optimistic about the future.

Electronic Components in Review

G.W. Duckworth
Division Vice President
and General Manager
Industrial Tube Division
Lancaster, Pa.

Electronic Components conducts a worldwide business involving the design, production, and marketing of a broad line of active electronic components and subsystems for consumer, industrial, aerospace, and military markets. This presentation concentrates on the Entertainment Tube and Industrial Tube Divisions of EC which are the principal operating divisions resulting from recent reorganizations.

Traditionally, EC serves to integrate the materials and process developments of the technical community (particularly RCA Laboratories) into component items and devices for use in complete systems. Until very recent times, EC has not been involved in end-user items. Sales are made to other divisions of RCA and other equipment manufacturers throughout the world.

In 1966, consultants recommended that receiving tubes be abandoned. However, that advice was not followed and over the past eight years receiving tubes have returned handsome profits to RCA. The receiving tube line admittedly has a finite life time. Yet in 1974 and for some years, it will continue to be profitable. Engineering is at a minimum and facilities are being consolidated to keep pace with the shrinking market.

Color tubes represent one of the most complex marriages of electronics and precision mechanics found anywhere. Manufacturing techniques used in Lancaster, Pa. in 1954 are very similar to those used today. A shadow mask works with three electron sources (R-G-B) to achieve color separation. Many millions of dollars in engineering have contributed to the development and refinement of the color picture tube. Materials technology advances, new phosphors, higher voltage operation, better focus guns, and light outputs up to 200 foot-lamberts have resulted. New black matrix and precision-in-line techniques have made wide-angle 100° deflection tubes a practical reality. Precision yokes and tubes achieve automatic convergence which stays put. Color progress has been achieved in the face of stiff competition yet the color tube product has returned and will continue to return excellent profit to RCA.

Markets for color tubes include U.S., Canada, and the worldwide manufacturers of receivers. Direct manufacturing participation in the foreign markets permits sharing in the growth of those market areas and establishment of worldwide technical leadership for RCA.

There is a trend toward smaller sizes in color tubes. Although the difference in cost between a 25-inch and a 13-inch color tube is not large, the customer expects to pay a smaller price for the smaller tube which inevitably leads to shrinking margins. Although we have made substantial advances technically, cost reduction of initial implementation of new advances (from a factory operation standpoint) and the shrinking margin problem are serious technical challenges.

The Industrial Tube Division is a collection of small businesses each with its own market peculiarities, its own technology needs, widely differing facility needs and intense selective competition. ITD s business is in three main areas: Electro-Optics, Power, and Microwave. Its products find application across many markets.

ITD has many and diverse technologies, and design and development programs. Continuous heavy engineering investments are required to keep abreast of the rapidly evolving technologies.

Application of solid-state technology has enhanced the performance of photomultipliers, and led to development of solid-state lasers and transferred electron oscillators.

We have a leadership position in large-area silicon target camera tubes. Charge-coupled device technology applicable to image sensors, memory systems and a host of other applications is just emerging. New product items include low-cost tv cameras, B/W hand-held cameras for SelectaVision and rugged cameras for automatic bowling score systems. Other mainstays of ITD are power tubes for rf heating, megawatt radars, linear accelerators, and for a wide variety of communication uses. Interesting special devices are lasers, laser systems, and transcalent devices in thyristor, power transistor, and rectifier formats. In the laser field, opportunities exist for photocopying, label reading, duplicating, printing, construction alignment, level sensing and video playback.

The competition for ITD ranges from larger companies such as GE, Westinghouse, ITT, Varian/Eimac, Ampex/Phillips to marginal operators and many small high-technology entrepreneurs.

To achieve our design objectives and maintain technical leadership, we must achieve a high degree of engineering effectiveness and exercise increased project and product selectivity to narrow the number of product lines.

ITD is complicated and represents a skill center unmatched in RCA. Skills range from precision parts making with stamping, machining, chemical milling, and ceramics; heatflow technology in gas, fluids, and metals; vapor deposition skills with sophisticated materials; vacuum sealing of metals and ceramics; circuitry modules with vacuum tubes and solid state; subsystems from cameras to voltage-controlled, solid-state oscillators with wide-frequency ranges and high-speed tuning; and gas tube technology from thyratrons to modulatable lasers.

The above is only a partial listing of the skills involved in the products described earlier. So, in your engineering needs, keep Lancaster ITD in mind. We welcome the opportunity to work with you and your divisions toward our common aim of maintaining RCA's position as a leader in electronics.

Government and Commercial Systems: Electrons at Work

I.K. Kessler,
Executive Vice President,
Government and Commercial Systems,
RCA, Moorestown, N.J.

G&CS success depends on the innovation and technical excellence of its engineers and scientists whose productivity presents a challenge to select appropriate business applications from our burgeoning technology. Dedicated and sophisticated judgment will be required to determine our future businesses and to narrow those fields of technical investigation which can contribute to our businesses.

G&CS high technology business include AEGIS, the largest single contract at about $250 million, with ultimate potential of over one billion dollars. The system's phased-array radar antenna is a unique feature that permits the handling of a large number of targets simultaneously. Another pivotal factor in the success of AEGIS is the extensive use of integrated circuits. The signal and data processing functions necessary to make the AEGIS system work are, as one might expect, prodigious. Also in the radar area, a decade ago the technology simply did not exist to achieve the present capabilities of tracking both low and high flying objects. Now, during tests of the complete system, AEGIS has successfully defended against all simulated attacks even in an intense jamming environment.

Another outstanding advance is the new Electronic Private Automatic Branch Exchange (EPABX) communication project, an all-electronic switching system in which both Government Communications in Camden and SSTC cooperated. EPABX is one-tenth the size of a conventional electro-mechanical switching system of comparable capability. A high percentage of LSI circuits provides the EPABX unit with a capacity of up to 600 lines and results in low power consumption, as well as high reliability. Teaming an EPABX with a minicomputer opens up a great variety of possibilities in combining communications and control of management functions. Potential is $100 million over a 5-year period.

Other systems include the Palm Beach Division's Dataway, a data management system for hotels, motels, hospitals, and similar industrial uses. It provides instant information on the status of rooms, guest charges and all essential daily property management functions.

RCA spacecraft systems have an unparalleled record of never having a payload failure in more than 80 launches. The latest member of the Defense Meteorological Satellite family is a 17-foot tall weather watcher being built for the Air Force. The system embodies functions of both the launch vehicle and the satellite, including data processing, inertial sensing, and power and attitude control. For the first time a satellite will exert control of its own launch vehicle.

In the area of satellite communication, we have developed transportable military satellite terminals that can be set up and made operational within 20 minutes after arriving at a site. The transportable satellite terminals have a 5-year potential of $100 million.

Satellite earth stations in the Canadian operations, automatic vehicle testing systems, multi-array TV and FM antennas, a new 20-lb. portable, high-quality TV camera, and TACTEC two-way portable radios are other high technology G&CS programs.

For the future, remotely-piloted vehicles for reconnaissance and surveillance, high-energy lasers for defense, and automotive computer control for emission and fuel are in prospect.

Our continuing job will be to bring more precision into the creative process, with emphasis on investigation, design and product finalization. This is an area of great fruitfulness for the future, and the G&CS organization will be actively and energetically grappling with it immediately.

Consumer Electronics

Activities for Consumer Electronics included a tour of the CE manufacturing facilities in Bloomington, Indiana — plus three presentations related to color- and black-and-white television receiver programs. The 1974-75 sales and marketing plans plus many new technical features of the lines of receivers were reviewed.

Consumer Electronics: Bloomington plant tour

P. G. McCabe, Mgr.,
Production Operations,
Consumer Electronics, Bloomington, Ind.

J.M. Wright, Manager, Resident Engineering, and E. W. Riedweg, Plant Manager of Consumer Electronics (Bloomington) served as hosts and welcomed two bus loads of conferees to the Bloomington manufacturing facility. The description given here summarizes the briefing given by P.G. McCabe, prior to the plant inspection tour.

Color tv manufacturing presently runs ten production lines with some black-and-white tv and console stereo assemblies. There are about 5,700 employees and employment has been as high as 7,000.

On the day of the tour, Bloomington produced about 8,500 instruments. There are ten test lines and nine of these provide power and signal applications to the chassis as it moves along the test line — and is progressively aligned. The tenth line supplies power and signals to individual "station test positions" (as of this reading, the Bloomington plant is progressively testing on ten test lines).

About 8,600 chassis go each day via monorail from plant No. 1 to plant No. 2 for final instrument and cabinet assembly—ready for tube and chassis packaging. The drive underway is for all-solid-state receivers with precision-in-line black matrix tubes which will increase present production outputs through greater efficiency achieved in assembly and test. Recent reductions in numbers of models, chassis, and picture tube types should lead to a more consistent progression along the learning curves. .and also contribute substantially to greater output, lower costs and higher quality.

The Consumer Acceptance Lab samples 4% of the product each day for rigorous, accelerated testing. Each day, 33 rail cars and 55 trucks are needed to provide materials for the operation.

Acknowledgment is given to the following members of Resident Engineering who guided twelve separate groups on an extended tour of plants No. 1 and No. 2. During the tours, these resident engineers, provided detailed technical information, and answered the many questions of the visitors concerning the products and the manufacturing processes:

E.L. Batz	Leader, Liaison Engineers
L. H. Leonhardt	Senior Liaison Engineer
R. F. Shelton	Senior Liaison Engineer
F. H. Dobbs	Senior Liaison Engineer
W. L. Tyner	Liaison Engineer
J. E. Heffner	Senior Liaison Engineer
J. M. Greggs	Associate Liaison Engineer
V.S. Proudian	Leader, Liaison Engineers
G. F. Drehobl	Senior Liaison Engineer
L.A. Lux	Senior Liaison Engineer
R.W. Green	Associate Liaison Engineer
N.G. Drilling	Senior Liaison Engineer

RCA television—a status report

R.H. Pollack, Division Vice President
and General Manager,
Color and Black-and-White
Television Division,
RCA Consumer Electronics,
Indianapolis, Ind.

The industry domestic color tv market will go from 8.6 million units in 1974 to about 10.6 million annually in 1979. In operation today there are 117 million tv instruments, exceeding such familiar items as automobiles, washing machines and refrigerators. Television is big business. Black-and-white television will maintain a very significant rate of close to 7.0 million and will remain substantially flat through the period of 1979.

Two out of three homes have color receivers; and for the first time, the industry has reached the point where replacement and second-set color tv sales will top the initial purchase figure. Overall, consumer pricing has generally moved up—yet television receiver prices have decreased while costs have skyrocketed to compound our economic problems. There have been substantial price increases on all of our critical commodities such as plastics, wood, copper, packaging materials and capacitors. It is clear that price adjustments are indicated on television products.

Years ago RCA was alone as the competent sophisticated, performance-oriented manufacturer. In contrast, competition today and in the future will continue to heighten among RCA, Zenith, Sony, and Matsushita (Panasonic/Quasar.

It is interesting to note from a recent value appraisal by consumers of a multiplicity of durables, non-durables, and services that B&W tv placed No. 1 and color tv No. 5 out of 44 items. Equally important in assessing value, is how the consumer rates quality; in comparing 1973 with 1968, consumers placed tv in No. 2 position in a survey of 20 items.

Business considerations that must be coped with include: product safety, cost of quality and reliability, material costs, shortages/lead times, and an inflation which exceeds the rate of cost reduction. Other key factors perceived are. . .product leadership, proper screen-size, model mix and "reaching the consumer".

A technical comparison of present-day RCA color receivers with our CT-100 of 1954 shows some remarkable advances: twenty times greater picture tube brightness, reductions in weight by factors of four, elimination of degaussing needs, automatic fine tuning methods, solid-state reliability, greater servicability, elimination of 12 dynamic adjustments for convergence, beam positioning, *etc*: 3-to-1 power reductions, and a 2-to-1 reduction in price. Therefore, modern all-solid-state receivers are seen as thousands of times improved over the early "color TVs" of 1954.

A greater degree of standardization; reductions in breadth of the line; factors of consumerism such as product safety, and reliability; plus the high level of competition are the challenges ahead for our technical and business management resources. Finally, we have not one but three customers. . .the distributor, the dealer, and the user. We must communicate, and reach each one of these customers, as their prioritites and values are different. Our business performance depnds on the satisfaction of each of these customers.

Color tv overview—what RCA is doing—why we are doing it—what RCA expects to accomplish

W.S. Lowry, Division Vice President,
Color Television Product Management,
RCA, Indianapolis, Ind.

Several color television sales and marketing programs designed to predipose the customer to select RCA over other brands were described.

Twenty years ago, the price of an RCA color television receiver (CT-100) was about $1000.00 (optional retail price). Today, prices have been cut in half...and annual industry sales are measured in millions. RCA, alone, has sold over 14-million color sets in a 20-year period.

For 1974, industry sales to dealers are expected to be 8.8 million units, down moderately from last years record breaking 9.2 million units. Results so far in 1974 indicate good sales progress and that industry sales are exceeding their original projection. Through mid June, industry sales were less than 6% down from the corresponding period last year while RCA's sales were actually up 3.5%.

Factors to consider in planning 1974 and future sales programs are: the first time buyer represents less than one-half the market; those buying replacemnts of first sets now make up more than one half the market; and buyers of additional sets account for about 25% of the market.

For 1974 and 1975, RCA will have a 100% solid state line of receivers concentrated in five diagonal screen sizes (15, 17, 19, 21, and 25-inch). There will be six chassis providing 55 models. With the introduction of the "COSMOS", a 21-inch diagonal color tv receiver in 1971, RCA started its move to an all-solid-state line. The ultimate goal of achieving a 100% solid-state product line was attained one full year ahead of schedule, making RCA the first domestic manufacturer to market an exclusively solid-state color tv line. A high level of performance has been achieved with all models featuring negative black-matrix, picture tubes for substantially greater brightness; automatic fine tuning; full-year PS (purchaser satisfaction) warranty; and, advances in overall performance and reliability. Also, 50% less energy is consumed than that of previous tube type models.

Three important benefits should continue to accrue from the all-solid-state commitment:

1) An increased share of the market for RCA.
2) The lowest field failure rate since 1970, becasue of increased quality and reliability.
3) An upward shift (verified by user surveys) of 33% in numbers of consumers favoring RCA over competition, as a result of XL-100 performance records.

Other important internal benefits from our move to 100% solid state are the increased efficiencies in production and inventory control that result from greater standardization throughout the line.

Our fall campaigns will highlight the advantages of the all-solid-state receiver line. Testimonials, tv film commercials and distributer, dealer and retailer sales incentive programs were enthusiastically received.

In conclusion, a strong and cohesive sales program is planned to back up an advanced technical product that promises to continue RCA's leadership in color television.

Black-and-white tv tunes in with the times

R. Mentzinger, Director,
Black-and-White TV Product Management
Consumer Electronics
RCA, Indianapolis, Ind.

As color tv came on stream, black-and-white tv was forecasted to decline gradually to extinction. Instead, B/W annual industry sales have not varied substantially since 1964. Although industry color tv sets will grow to 10 million or more, remember that B/W will remain at an industry rate of about 7 million sets/year.

However, the business has changed dramatically from a market where consoles were once dominant to a current demand for portable models with 40% or more B/W receivers using 12-inch picture tubes. In 1974, 57% of the receivers will use "12-inch and under" picture tubes with about one half of the total slated for use in bedrooms. Solid-state receivers are currently accounting for 25% of the sales in 1974.

Technological and sociological changes and trends must be considered in assessing the customer who will buy our products. Population has increased from 142 million in 1946 to 210 million in 1974, with steadv income increases and with about 80 million gainfully employed. Almost half the women in our society work, thus establishing new homes and living patterns—impacting on tv viewing and buying. So, there will be a market for more television sets with gains of 40% in buying power. Today, 41% of all households have incomes over $10,000/year.

Future models will reflect the needs of a younger, better educated, and more sophisticated consumer having a higher income. This younger consumer shops carefully with firm ideas concerning reliability and product safety. The new consumer shops in different stores — mass merchandisers, discount operations and chains. Price is an important ingredient in the marketing mix. Combine these factors with a new era of government overview and regulation concerning quality and reliability and the equation becomes complicated.

We must be alert to our multiple publics...consumers, dealers, distributors, government and competitors. How will we respond to this composite, complex consumer? New line B/W tv receivers will involve new tv/radio digital clock combinations having 5-inch picture tubes; sensitive monopole vhf and uhf antennas to eliminate the cumbersome "u" ring; solid-state circuitry throughout; and reductions in size, energy consumption, and heat. New models range from hybrid to all-solid-state receivers having picture-tube screen sizes from 5 inches up to 19 inches. More colorful and functional styles will appeal to the younger market and to a leisure-oriented society. The larger 16-inch and 19-inch models will feature a powerful 20,000 volt chassis, dipole antennas, preset fine tuning; and walnut-grain cabinet finishes. Finally, another factor to consider in 1974-75 is that color tv will constitute the prime set and B/W will be the second or third purchase.

In a National Industrial Conference Board Survey, B/W was perceived to be the outstanding value (No. 1) by consumers evaluating a number of consumer-goods items. Some 40% of those participating felt they were getting a better-than-average value for their money with B/W television receivers and black-and-white receivers must continue to offer basic value.

Worldwide inflation, consumerism, intensified domestic and foreign competition will require innovation and creativeness in making decisions concerning reliability, tehcnical features, style, and performance. RCA's engineering, product, and marketing programs for 1974-75 are oriented to these challenges and opportunities.

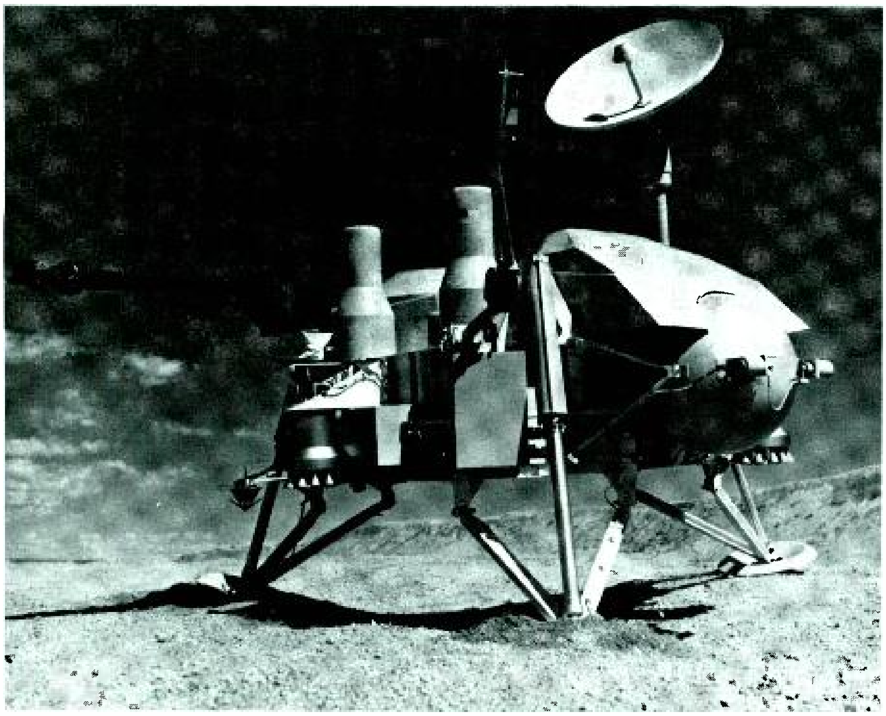


Fig. 1 — Fully deployed Viking Lander.

Communication system for the Viking mission to Mars

I. Brown

The communications system for the Viking mission to Mars comprises a uhf relay link and an S-band communication link. The system design was constrained by mission requirements, which include available launch opportunities, interplanetary distances, quarantine and biological contamination considerations, and the hazards of the Martian environment as well as weight, power consumption, reliability, and command philosophy.

Two unmanned spacecraft are scheduled to land on Mars in 1976 after an eleven month interplanetary trip from Earth. These missions, known as the Viking Project, had their beginnings in studies dating back to the 1960's, while other scientific probes were being launched to Mars via the Mariner program. The earliest Mariners were fly-by missions; the latest was an orbiter; and from them came new knowledge about the Martian atmosphere, its surface features, and other physical properties. But it remains for the Viking Landers to come to grips with the crucial scientific questions about life. Does it exist? If so, in what form? Did it ever exist? Or is life yet to come in the Millenia ahead?

The answers may lie in probing the Martian soil, analyzing the samples for organic and biological content, and in examining high resolution photographs of surrounding terrain. This information and that of other experiments, all automatically controlled by the lander on-board computer, will be digitally encoded and transmitted to Earth by either of two communication links.

Figure 1 shows a fully deployed model of the Lander. In its launch configuration, the Lander will be enclosed in a bioshield to protect it from contamination and an aeroshell to help it withstand entry heating of the Mars atmosphere. The launch vehicle will be a Titan Centaur. The Lander will be mated to a Mariner Orbiter spacecraft, a heavier version of the earlier Mariners. The orbiter's role is to:

1) Guide the mission during the interplanetary cruise, supplying housekeeping power,

2) Inject the mission into an orbit around Mars, positioning the Lander for de-mate at the proper time, and

3) Continue in orbit about Mars, making observations of its own, passing over the landing site once each Martian day, acting as a relay in one of the two communication links to Earth from the Lander.

Figure 2 illustrates the mission.

The active role of the Lander Communication subsystem begins at separation from the Orbiter. Separation thrusters are fired, and the uhf communication link is turned on for transmission of engineering telemetry to the orbiter until after the landing. The descent is slowed first by atmospheric drag starting at 800,000 ft, then by a parachute deployed at 20,000 ft and finally by terminal descent engines from 5,000 ft to the surface. The lander weight of 2,500 lb at orbit separation reduces to 1280 lb by the loss of descent fuel, parachute, and aeroshell. Shortly after landing, which is timed to occur in mid-afternoon, the orbiter will pass beyond the horizon and will not appear over the landing site until the next Martian day, 24.62 hrs. The landed sequence continues with the deployment of the S-band antenna to establish a direct communications link to Earth. Scientific experiments are turned on and their data output is transmitted either directly or recorded for later transmission.

In conceiving and designing both the uhf relay link and the S-band communication systems for the Lander, RCA was guided by the design of the mission itself and its constraints. The most important of these were:

1) The available launch opportunities,

2) The effect of great interplanetary distances on power and bandwidth of the S-band link,

3) Weight,

4) Reliability and survival in the Martian environment,

The prime contractor for the Viking Lander is Martin Marietta Aerospace. Jet Propulsion Laboratory designed and built the Orbiter spacecraft. The total mission is the responsibility of NASA Langley Research Center.

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5) The up-link command philosophy,

6) The landing problems, and

7) The requirements for planetary quarantine and cleanliness.

Launch opportunity affects design

Some hard facts about interplanetary travel and booster energy limitations have a significant effect on schedule and hardware choices. A spacecraft moving from Earth to Mars (or any other planet, for that matter) traverses an ellipse about the sun, which in general intersects the orbits of both Earth and Mars twice. Thus, for each starting point on the Earth's orbit, there are two possible intersections with the Mars orbit.

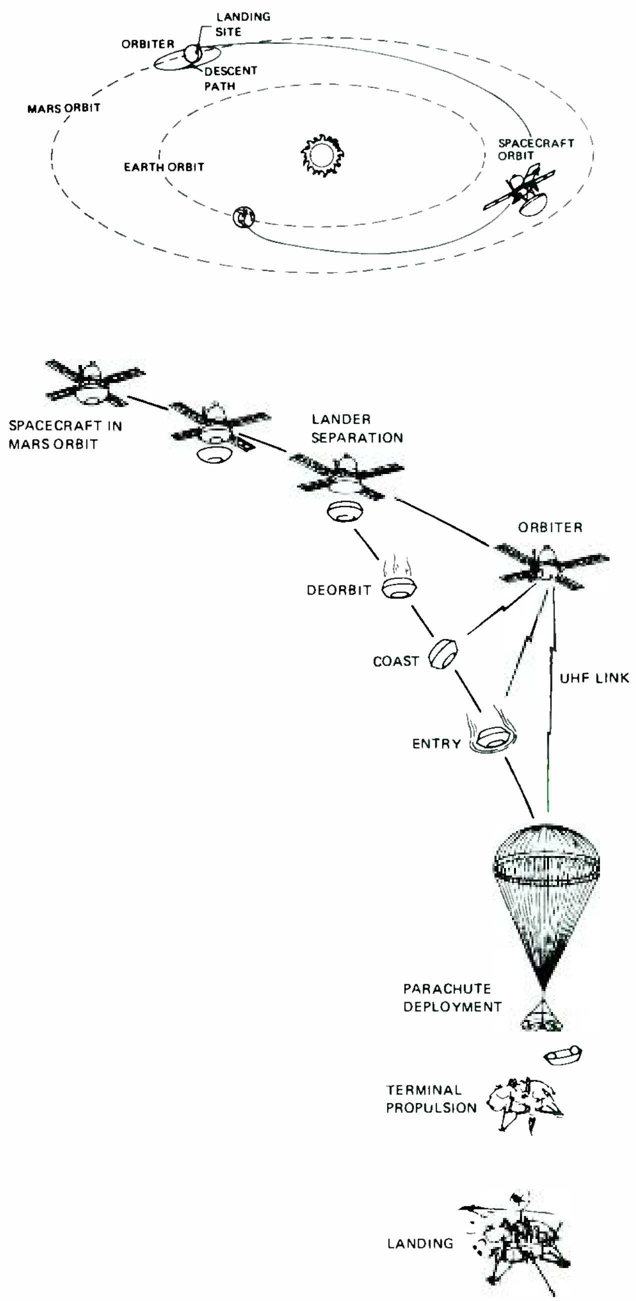

Fig. 2 — Viking mission: (a, top) orbits and trajectories, (b, bottom) launch and landing sequences.

Irv Brown, Mgr., Special Projects, Astro-Electronics Division, Princeton, NJ received the BSEE (cum laude) from the State University of Iowa in 1947, and his MSEE from the University of Pennsylvania in 1948. He was Manager of the Viking Project at AED from 1970 through 1973, leading this program from its initial study phase through the design-release, qualification, and flight construction stages. His previous position was Project Manager for the AED portion of the Nimbus Meteorological Satellite Program, for which RCA supplied the camera, tape recorder, and power-supply subsystems. He has held numerous other management positions in RCA since 1954: in design engineering on the camera electronics for the Ranger VII, VIII, and IX Lunar Probes, on the Talos Landbased Missile System, the MOD-II Shoran Reconnaissance System, and the Astro Airborne Fire-Control System. Mr. Brown has had several papers published, holds three patents, and has taught courses in Electrical Engineering and Project Management at Drexel Evening College and for the RCA-in-house educational program. He is a registered Professional Engineer.

Table I — S-band link, power budget.

Transmit Power	dBm	+42.62		70
Antenna Gain	dB	+22.3		60.1
Losses (Ckt/Pointing/Polariz.)	dB	-1.95		-0.15
Space Loss	dB	(2.3 GHz) -271.27		(2.1 GHz) -270.55
Receive Antenna Gain	dB	+61.3		+4.5
Receive Losses (a) Ckt	dB	0		-1.3
(b) Pointing	dB	-0.03		-3.2
Total Received Power	dBm	-147.03		-140.6
Carrier Performance				
Carrier Mod Loss	dB	-4.05		-2.5
Received Carrier Power	dBm	-151.08		-143.1
Receive NPD	dBm/Hz	(T = 30 K) -183.82		(T 1150 K) -167.99
APC Loop Noise BW	dB	($2B_{LO}$ = 12 Hz) +10.8		($2B_{LO}$ = 20 Hz) +13.0
Required SNR Threshold	dB	+10		8.65
Performance Margin	dB	+11.94		+3.24
Channel Performance:		Science Data	Telemetry Data	Command Data
Modulation Loss	dB	-3.8	-10.37	-4.0
Demod and Process. Losses	dB	-1.1	-0.7	-1.5
Received Data Power	dBm	-151.93	-158.1	-146.1
Bit Rate	dB	(250 BPS) +23.98	(8 1/3 BPS) +9.21	(4 BPS) +6.02
Received ST/NO	dB	+7.91	+16.51	+15.87
Required ST/NO	dB	(WER = 10^{-2}) +3.0	(WER = 5×10^{-3}) 5.2	(BER = 10^{-5}) +11.5
Threshold Subcar. Power	dBm	-156.84	-169.41	-150.47
Margin	dB	+4.91	+11.31	+4.37

However, the relative position of the two planets plays an important role in timing the launch, for the spacecraft and Mars must arrive together at the point of intersection. As it happens, Earth and Mars are correctly positioned once every 780 days to insure such an encounter. The tolerance on the launch date depends on how much the dimensions of the ellipse can be changed, which is governed by the available launch energy. To begin the journey, the spacecraft must acquire an orbital velocity 34 km/s relative to the sun. The Earth imparts 30 km/s by virtue of its own speed about the Sun (rotation about its own axis is an added, but minor, contribution). Thus, the booster supplies only about 15% of the required energy. Together with only a limited in-orbit trim capability, the result is a tolerance on launch of only about 1 month.

With such a small launch window every 26 months, the mission plan demands critical schedules and therefore low-risk equipment designs. To protect the schedule, it was necessary to provide ample slack periods to cope with problems. Subsystem design contracts were awarded in 1971 for flight deliveries in 1974. The baselines rested on in-hand technology, so newer techniques with greater risk were set aside in favor of more conventional approaches which had been proven on previous Mariner flights.

Energy limitations

A second factor influencing equipment design is the squeeze stemming from the limited electrical power available. On one hand, the great interplanetary distance, 4×10^8 km, calls for as much transmitter power and bandwidth as possible; on the other, the limited battery weight and recharge capability plus the power needs of the scientific instruments put a practical limit on power. The operational plan is a compromise to time-share available power, with a design premium put on high efficiency. Tables I and II show the link power budgets, and the small margin which exists, even with large DSN (Deep Space Net) antenna gain and its low system noise (G=61.7 dB; T=30 K). The down link (Mars-to-Earth) data traffic will be about 10^7 bits/day, and the transmitter will remain on only long enough for carrier acquisition and data transmission. Since most of the power consumed by a communication system is in the final stages of power amplification, the design emphasis was on high-efficiency transmitters. The power amplifiers develop 20 W at S-band and 30 W at uhf. In 1971, efficient solid-state devices were available at uhf, but none could compete at that time with available traveling wave tubes at 2.2 GHz. To further conserve power, the antenna gear drive assembly is driven by magnetically-detented stepper motors, which require no standby power as do conventional servomotors.

Weight

A third design influence was the overriding importance of weight. The usual multipliers on payload weight due to launch fuel become doubly important for a planetary Lander because of the added burden of descent fuel. Table III gives the communication system weights.

Reliability and survival

Communication system redundancy took shape from a mission rule that no single failure shall result in data loss. Downlink redundancy exists by virture of two paths, one being the uhf link to the Orbiter with its subsequent S-band relay to Earth, and the other the direct link from the Lander to Earth. However, uplink redundancy relies on the Lander's equipment alone, there being no uplink relay via the Orbiter. Thus, two S-band receivers, command detectors, and decoders are provided, each chain connected to a separate antenna. By providing dual TWTA's, the S-band downlink is made more redundant, though not to the extent that would be achieved if weight and available space had allowed a separate high-gain antenna. Further refinements to enhance system reliability were the cross-strapping of critical signals between redundant components.

The principal environmental threats which are dealt with in the design are:

1) The requirement to survive prelaunch heat sterilization.

2) The effect of Martian wind (40 m/s, gusting to 70 m/s) at ambient pressures of 2 to 15 torr. The possibility of antenna pointing errors due to wind loads was a factor in the design of the gear drive.

3) The blowing density of dust particles, estimated 1.4×10^{-10} gm/cm^3—their size in the 10 to 1000 μm range—was taken into account in the design of rotating joint seals.

4) Temperature extremes which vary from −195°F (night) to +145°F (day). One occurence of 300°F for eight minutes during atmospheric entry affects exterior-mounted equipment such as the antennas.

5) Ambient pressure (2 to 15 torr) is critical, relative to ionization breakdown at high power.

Up-link command philosophy

Interplanetary distances and the method of sending commands to the Lander combine to affect design. Owing to the 40-minute round-trip transmission time, it is not feasible to verify the reception of commands. The communication system itself must possess enough intelligence to recognize valid commands, correcting errors in false commands or rejecting them altogether. In 1971, a change in DSN (Deep Space Net) command transmission strategy was approved for future interplanetary flights which increased the command bit rate from 1 to 4 bits/s, but at the expense of eliminating a separate bit-synchronizing subcarrier. In effect, this increases the command-channel power at some expense in bit-synchronizing circuit complexity in the spacecraft. How much complexity depends on how quickly one must re-acquire lock after signal loss. For missions where the spacecraft remains in continuous view of the 3 DSN Earth stations, the change in circuitry is relatively simple because the odds of losing signal are small. But for the Viking Lander, signal loss is expected to be commonplace — at least once per Martian day barring any other dropouts, possibly more in the event of antenna pointing uncertainties. With command signals transmitted at 4 bits/s, one cannot afford long preambles for system lock-up, so detection and in-lock determination must be rapid.

Orbiting and landing constraint

The margins for the uhf link from the Lander to the Orbiter were derived from, and to some extent influenced, the mission design. Upon encounter with Mars, the Orbiter-Lander is injected into a highly-elliptic orbit around the planet. The dimensions and period of orbit were chosen to satisfy several requirements:

1) Orbit insertion ΔV limitation.

2) Keep the Lander-to-Orbiter transmission distance as short as possible to save communication power.

3) Provide enough contact time between the Orbiter and Lander to transmit 10^7 bits.

4) Provide enough contact time between the Orbiter and the Earth so the data relay via the low-bandwidth S-band link can be completed without interruption by Mars occultation.

5) The Orbiter should pass over the landing site once per day, preferably overhead.

An orbit which satisfies these requirements has a periapsis of 1500 km, apoapsis of 32,500 km, and its period is synchronous with the Mars rotation rate of 1 r/24.6 hrs. The maximum slant range from the lander site to the Orbiter is about 2650 km at an elevation of 21° above the horizon. The contact time, depending on landing location errors and surrounding terrain can vary from 13 min., worst case, to a nominal 23 min. At 16 kb/s, this provides time to transmit up to 2×10^7 bits. The uhf-link budgets are shown in Table II. An added complication in the uhf transmitter design was the need to reduce power immediately following separation to conserve power and to avoid overloading the Orbiter receiver at close range.

Planetary quarantine and cleanliness

A strong influence on design, manufacture, and test originated in the US commitment to maintain planetary quarantine of Earth biota, and in a concern voiced by instrumentation people that the Lander's own body odor, (*i.e.*, organic volatiles of Earth origin) would interfere with the gas chromatograph, mass-spectrometer, and x-ray fluorescence experiments. Together, they became the basis for these requirements:

1) Probability of Earth biota contamination less than 72×10^{-6}; and,

2) Probability of organic contamination of soil samples less than 1×10^{-6}.

The first is met by dry-heat sterilization prior to launch, which became a design and test qualification requirement for the equipment to survive dry heat soak at 125°C for 300 hrs. In-process heat exposures kill entrapped organisms. Surface biota due to handling in final integration are killed in the terminal sterilization. The second was met by a vigorous program of controlling the use of organic materials, testing them for volatiles, and

Table II — UHF-link power budget.

Transmitter Power, dBm	44.7
Antenna Gain, dB	4.5
Losses (a) Ckt, dB	-1.0
(b) Pointing, dB	-4.6
(c) Polarization, dB	-1.2
EIRP	42.4
Receiver Antenna Gain, dB	+4.5
Losses (a) Ckt, dB	-1.0
(b) Pointing, dB	-3.3
Space Loss (385 MHz, 2000 km)	-150.4
Received Carrier Power, dBm	-107.8
Receiver NPD (T=630 K) dBm/Hz	-170.6
Limiter Loss, dB	+1.0
Predetection BW, dB-Hz	+51.2
Carrier-To-Noise Ratio, dB	12.6
Threshold CNR, dB	4.5
Performance Margin, dB	8.1
Estimated Lobing Loss, dB	-2.7
Performance Margin (nominal), dB	5.4

Table III — Communications subsystems, weights and power consumptions.

	Weight (lb)	Power (W)
S-Band Subsystem		
Up-link Command Antenna	0.8	
Down-link High-gain Antenna	16.5	
Transponders (2)	7.8	9.7 (Note 1)
TWTA (2)	19.0	86.6 (Note 2)
CCU (1)	11.6	13.4
MCA (1)	5.32	—
Cables and Misc	1.5	—
Total S-Band	62.52	109.7
UHF Subsystem		
Transmitter	10.5	120.7
Antenna	4.0	—
	14.5	120.7
Total Communications	77.02	120.7 or 109.7

Notes: 1. Both receivers and one modulator-exciter on; receiver power = 3.0 Watts

2. One on at a time

by building, handling and storing equipment in clean rooms.

UHF transmitter design

Figure 3 is the uhf transmitter block diagram. The antenna[1] is shown in Fig. 4, and the transmitter is shown in Fig. 5. The antenna has 4.5-dB gain (measured on axis) and is circularly polarized. Since most of the radiation is confined to the forward hemisphere by the tuned ground plane, the antenna behaves almost as an omni in communicating with the Orbiter. However, some shadowing due to nearby lander structure tends to modify the field pattern. The ends of the dipoles are enclosed in foam "cans" to prevent corona in the low-pressure Mars environment.

The transmitter provides 30 W output at 385 MHz. It contains an rf power amplifier, FSK modulator, dc-dc converter, and a logic circuit for changing the power to 10 W, the mode mentioned earlier for initial de-orbit, and 2 W— an emergency mode. This mode provides an output by feeding the driver output directly to the antenna. The entire transmitter was packaged in a pressurized container to avoid corona.

The power output is achieved by a pair of 2N6105's whose outputs are added in a combiner. Individual stage gains are shown in Fig. 3. The relay contacts carry

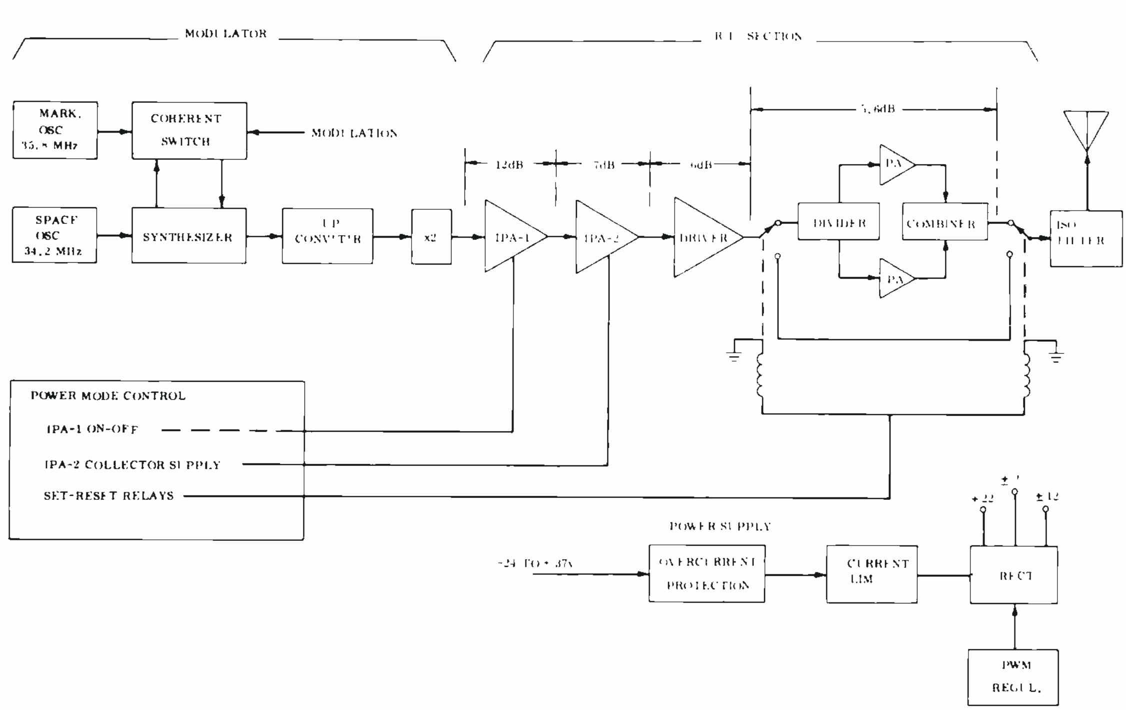

Fig. 3 — UHF transmitter, block diagram.

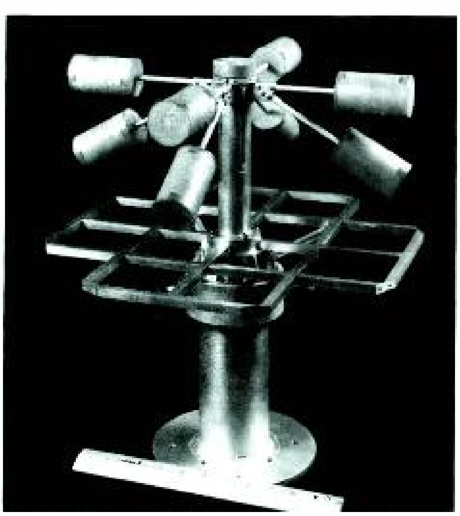

Fig. 4 — UHF antenna.

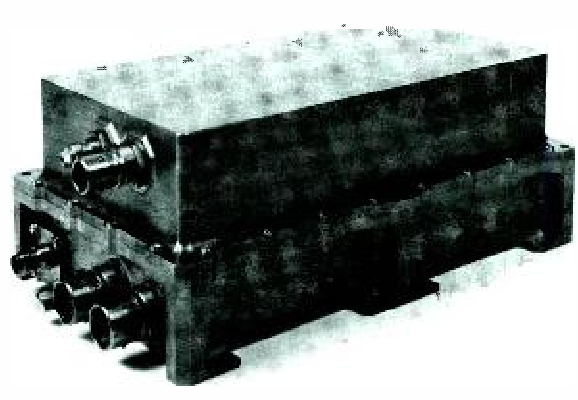

Fig. 5 — UHF transmitter.

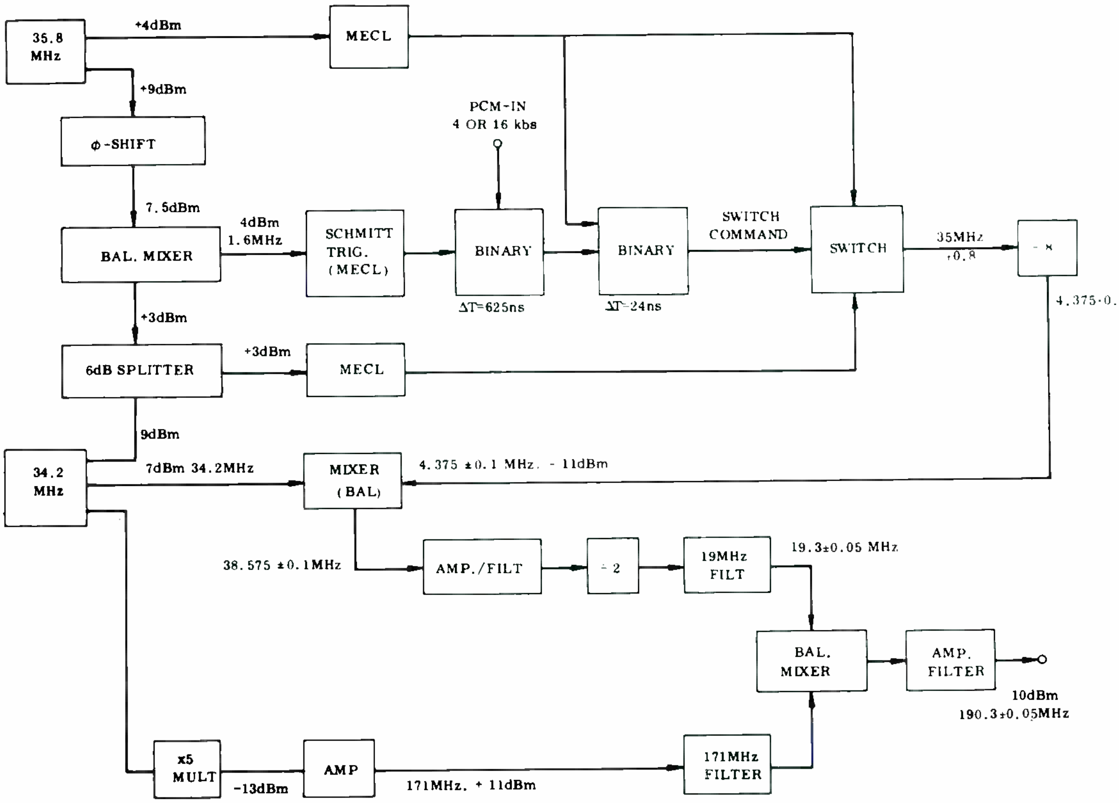

Fig. 6 — UHF modulator, block diagram.

the full rf power and, to protect them during switching, the mode-control logic turns off rf drive prior to contact transfer.

The modulator presented an interesting design problem. In early studies of the performance of angle-modulated signals in this mission, it was shown that non-coherent FSK would work well because it did not require frequency acquisition and tracking, was reasonable in power, and performed well in a fading and Doppler environment.

The modulator shown in Fig. 6 was designed using two temperature-controlled crystal oscillators as the source for the modulation mark-and-space frequencies. To key between these two frequencies (34.2 and 35.8 MHz) without generating a keying transient, it is necessary to switch when both waveforms are crossing through zero. This event is sensed in the zero crossing of their difference frequency, 1.6 MHz. When *and*-ed with the 16-kb/s PCM data rate, it determines the point of switching from one frequency to the other. There follows further frequency division and bandpass filtering until the frequency difference is 19.3 MHz ±50 kHz. Mixing this with the 5th multiple of the 34.2 MHz oscillator, (5 × 34.2 ±19.3) MHz ±50 kHz, provides the modulator output at 190.3 MHz ±50 kHz.

This frequency is doubled to 380 ± 0.1 MHz and becomes the drive to the power amplifier. The Orbiter receiver bandwidth is 130 kHz which allows for the required spectrum plus a Doppler shift in the neighborhood of 10 kHz. Power input to the transmitter is 120.7 watts at 28 Vdc. The Lander computer, which has stored information about the expected time of appearance of the Orbiter, turns the transmitter on and off.

S-band communication system

The direct link to Earth via S-band provides data transmission, tracking, and command reception. Its block diagram is shown in Fig. 7 and the hardware in Figs. 8, 9, and 10.

The system performs the functions of receiving an S-band rf carrier from Earth, detecting the command modulation, and frequency translating the carrier by a fixed ratio (240:221) for retransmission to Earth. The first commands after landing will be received by the low-gain "omni" antenna and receiver-detector channel No. 1, for it is unlikely that the high-gain antenna will be pointed correctly. Later, with pointing errors cleared away, either channel can be used to receive commands. In a typical operating sequence, both receivers and one mod-exciter will be turned on. The retransmission is PSK-modulated by a composite telemetry signal which combines engineering data with scientific data (including imaging) or with a ranging signal. The latter is part of a radio science experiment in which the ranging modulation originates at the Earth station. Mod indices and data rates vary with the type of modulation up to 1.3 radians peak at 250, 500, or 1000 b/s. The S-band system also processes the detected command modulation to provide the Lander computer with decoded and single-error-corrected command data (status information) and receives from the Lander computer antenna articulation and cross-strap commands.

Earth stations of the DSN, located at Goldstone, Cal.; Canberra, Australia;

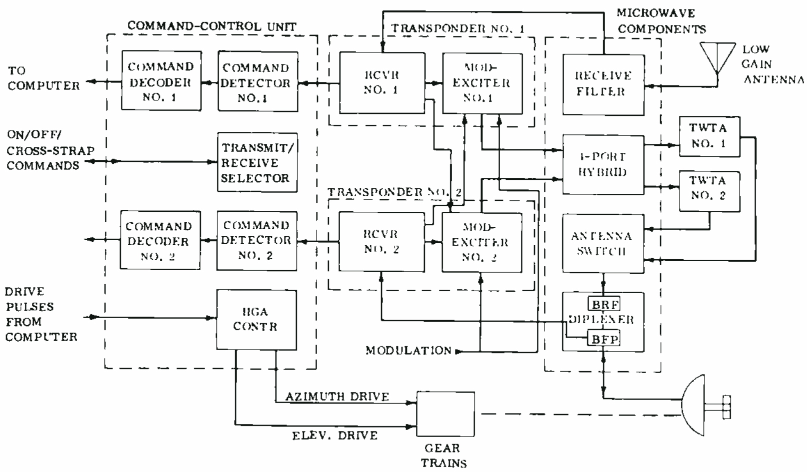

Fig. 7 — S-band transponder and command-control unit, block diagram.

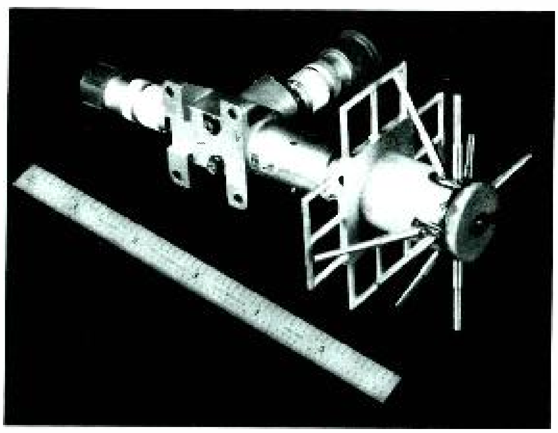

Fig. 8 — S-band low-gain command antenna.

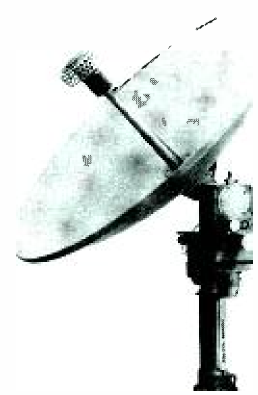

Fig. 9 — S-band high-gain antenna.

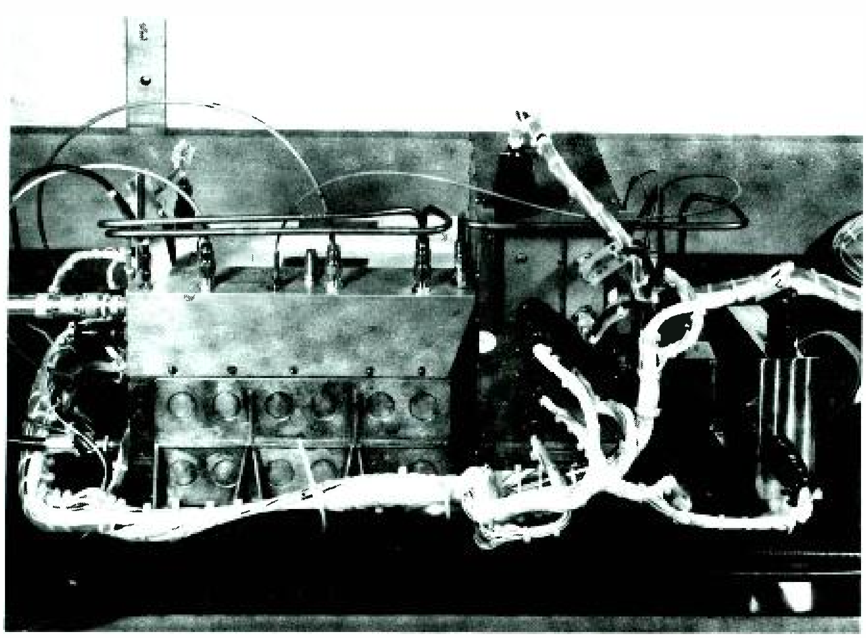

Fig. 10 — Transmitters, receivers, and command-control equipment.

and Madrid, Spain, are equipped with both 64-m and 26-m (diameter) antennas.

Transponder

Each transponder comprises an S-band receiver on 2113 MHz and a modulator/exciter on 2290 MHz. One receiver is connected to a low-gain (4.5 dB on axis) antenna through a receive filter for command reception, the other to a high-gain antenna via a diplexer which allows simultaneous transmission on the downlink. Each contains 1) a phase-locked loop to force its vco local oscillator to track the up-link frequency; 2) a frequency translation in the ratio of 240/221; 3) an auxiliary-oscillator frequency-multiplier to provide a carrier in the event the up link is lost; 4) a command subcarrier demodulator and exciter; and 5) dc-converters to separately power the receiver and mod-exciter. The output from either receiver can drive either of the two mod-exciters. Fig. 11 is the transponder block diagram.

The receiver vco phase-locked loop, is capable of tracking the uplink frequency acquisition sweep ±126 kHz at input levels down to −120 dBm and ±63 kHz down to −148 dBm. This range accommodates both Doppler and uncertainties in knowing the best lock frequency of the oscillator.

Microwave components

All the S-band switching and filtering are in a package shown as the Microwave Components Assembly (MCA). The antenna switch is a 3-port switchable ferrite circulator with port-to-port isolation of 25 dB and 0.35 dB insertion loss. The antenna diplexer contains two filters and a common junction to the antenna. Since the TWT is a broadband high-gain device, spurious outputs from the mod exciter at the receive frequency could easily be amplified and imperil the system by causing a ring-around lock-up. To help prevent this, a band reject filter provides a 50-dB attenuation in a 16-MHz band centered at the receive frequency. Together with a 60-dB filter in the TWTA it reduces mod-exciter output spurs in the receive passband to a safe level. These filters also attenuate the −35

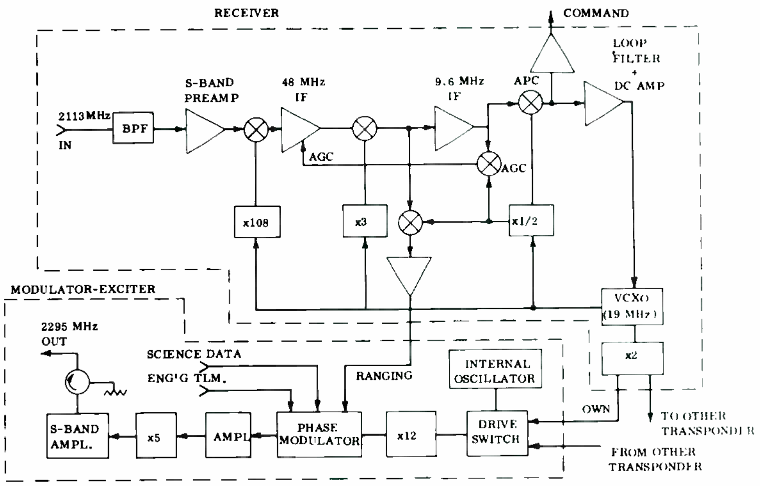

Fig. 11 — S-band transponder, block diagram.

dBm broad-band noise output of the TWTA. The other filter is a 20-MHz bandpass filter (BPF) in the receive leg to further limit noise from the antenna terminal. The common junction is foamed to prevent partial pressure breakdown, especially under adverse vswr conditions which might arise in test. The four-port hybrid allows either S-band output of the two mod-exciters (only one operates at a time) to feed either of the TWTA's. A second receive band-pass filter between the low-gain antenna port and the second receiver performs the same noise-limiting transponder.

Command detection and decoding

As previously mentioned, the command detector and decoder function posed an interesting design problem. It performs the following functions: 1) synchronizes an internal oscillator with the subcarrier to detect its phase-shift-keyed modulation, 2) recovers the bit timing, 3) analyzes the demodulated signal to determine when the system can be considered safely in lock, and 4) decodes and formats the detected signal for use by the computer. The modulation structure is a one-minute 4 b/s idle sequence of alternate 1's, 0's followed by the command data format with an average transition density of 4 transitions/32 bits. With an input E_b/N_o (from the receivers) of 11.5 dB, the error rate is less than 10^{-5}. with a probability of falsely indicating phase in-lock status less than 10^{-6} and out-of-lock less than 2×10^{-5}. It corrects single bit errors and detects double errors.

An interesting challenge in testing these circuits is proving BER performance when the data rate is only 4 b/s, which requires either a very long wait to count errors or some other means of deducing the error rate. During test, voltage samples from the command subcarrier presence integrators (circuits which ramp up or down in voltage depending on whether the sub-carrier phase represents "1" or "0") are obtained to get a time history of their variations with respect to threshold, the point at which an error would, in theory, occur. Given enough samples of these "near misses" it is possible by a calculation in statistics called the Extreme Value Theory to infer the error rate. A period of about 4 hrs. is allocated during test to get the required number of samples and perform an off-line computation.

For a complete discussion of the antenna control electronics and the S-band antennas, the reader is referred to Ref. 1.

Power amplifiers

The two redundant TWTA's provide 27.5-dB gain at 20-W output. Input drive for output saturation is 50 mW. The mod-exciter drive to the TWTA is about 200 mW, providing a 6-dB margin on input drive. The output is isolated for protection against accidental vswr's greater than 1.5 (any phase) and filtered, as mentioned above. Gain variation over the passband is less than 0.1 dB/MHz. Since the downlink is phase modulated, the amplifier performance in amplitude-to-phase-modulation conversion, group delay, and phase stability was specified to avoid degrading modulation. The TWTA was protected against corona at all its high voltage points by encapsulation.

Landed operations

The post-land operation of the S-band system starts with erection of the antenna and aiming its dish toward Earth. The Lander computer generates antenna azimuth and elevation commands based on stored emphemeris data, estimated latitude and longitude of the landing site, and attitude of the Lander body relative to local vertical. To acquire frequency lock-up on the up-link, the Earth station begins a slow sweep through the receiver frequency aperture. Twenty minutes later, this transmission arrives at the Lander. At the point during the sweep when the input frequency coincides with the idling frequency of the receiver VCO, which is the receiver best lock frequency, the receiver locks-on. Since it is not possible for the Earth station to know when lock has occurred, the sweep is allowed to progress through the entire range and return to center. The downlink is established either by a carrier fixed in relationship to the uplink [$f_d = (240/221) \times f_u$] or by an internally generated carrier to which the Earth station acquires lock. It will require approximately 2 hrs. of data transmission each day to return the scientific and engineering data.

Acknowledgments

In accomplishing the communication system design, program managememt, and design and manufacture of several component boxes and ground support equipment, the Astro-Electronics Division acknowledges the contributions of Missile and Surface Radar Division in supplying the antennas and the contributions of several important subcontractors: Watkins-Johnson, Wavecom-Inc., and Philco-Ford in the areas of the TWTA, Microwave Components, and Transponder, respectively.

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Optical fiber communications systems

Dr. J.P. Wittke

The development of low-loss optical fibers has opened a new technology for communications. This paper discusses the most important factors connected with fiber optical communications systems. Dispersive effects limit the available information bandwidth of the fibers, although graded-index fibers, with narrowband sources, permit gigabit information rates. Fast (approx. 200 MHz) light-emitting diodes (LED's) have been developed, but the small amount of optical power that can be coupled from them into fibers limits the information they can transmit and hence their usefulness. Injection lasers overcome many of the disadvantages of LED's, but as yet they have too short an operating lifetime to be useful. Silicon avalanche diodes are the preferred detector. Non-linearities in the sources and the relatively low *S/N*-bandwidth products available make long-distance, broadband analog systems less desirable than digital ones, where regenerative repeaters permit transmission links to be cascaded without serious degradation of the signal quality.

OPTICAL FIBER is a completely new medium for the long-distance transmission of information. Currently, hundreds of scientists and engineers throughout the world are engaged in exploring the new possibilities to determine where the benefits attendant upon optical fiber communications can best be utilized. The properties of optical fibers provide many advantages over conventional metallic transmission media. They have very low transmission losses, and, since they are made of glass, are completely free of electromagnetic interference and the noise and pick-up problems associated with low-frequency ground loops. They are very light in weight and can be used without danger in inflammable or explosive environments, both of great importance in applications on aircraft. Moreover, such links are difficult to tap surreptitiously and hence are 'secure'. Claims of huge bandwidths are also frequently made in connection with optical fibers, but we shall see that, for the present at least, this is more of a potentiality than a reality.

This paper gives an overview of the field by first considering the main components of optical fiber systems — sources, fibers, and detectors — and then discussing the systems performance available with these components. We shall also try to estimate how future developments in this fast-moving field might affect the situation.

Dr. James P. Wittke, Optical Electronics Research Group, Physical Electronics Research Laboratory, RCA Laboratories, Princeton, N.J. received the ME from Stevens Institute of Technology, Hoboken, New Jersey in 1949, and the MA and PhD in physics from Princeton University, Princeton, New Jersey in 1952 and 1955, respectively. At RCA, he has engaged in paramagnetic resonance and microwave maser studies, in research on optically excited crystal lasers, and in investigations of the motions and properties of impurities in rutile. He has also worked on various classified projects. In 1967, Dr. Wittke was awarded an RCA Fellowship for a year of study abroad, which he spent at the Clarendon Laboratory at Oxford, England. Since then, he has studied the luminescence of heavily doped *GaAs*, helped develop new infrared-stimulated light emitting phosphors, and worked on the generation of ultra-short laser pulses, using mode-locking techniques. He is currently studying optical fiber communications systems, including making measurements of the characteristics of fast light-emitting diodes and of various low-loss fibers. Dr. Wittke is a Fellow of the American Physical Society and a member of the Optical Society of America, of IEEE, and of Tau Beta Pi. He is the author of numerous technical papers and the co-author of a text on quantum mechanics.

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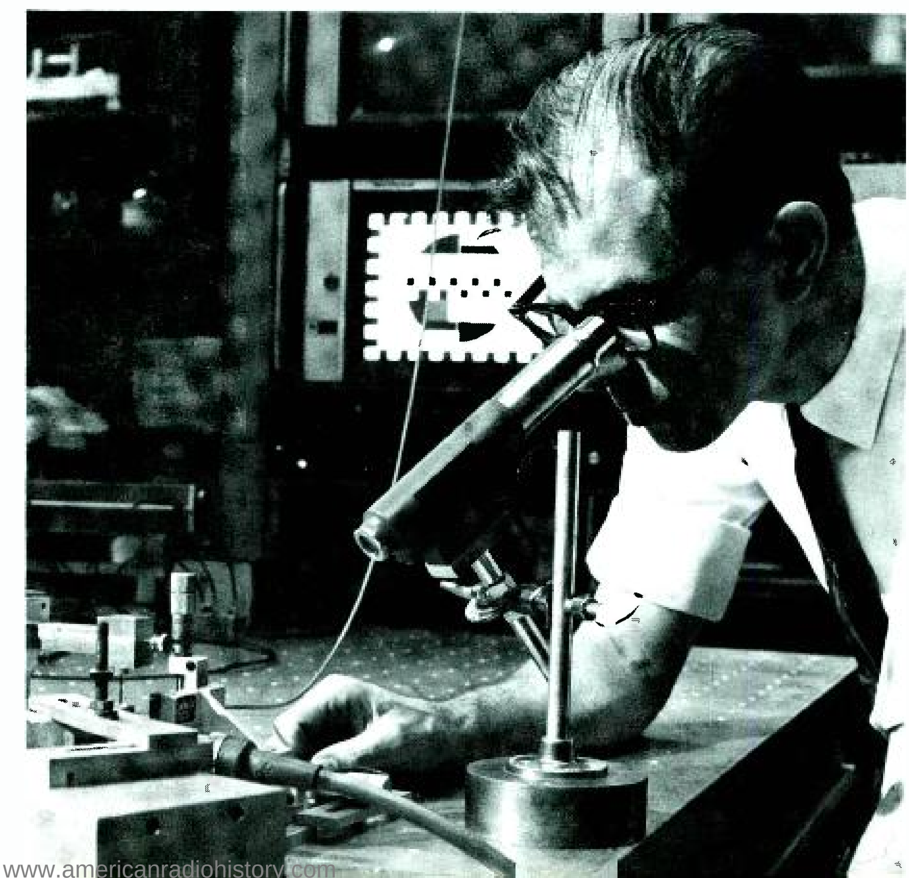
Light sources

Only the two most promising light sources will be discussed in any detail. These are the semiconductor junction sources, incoherent light-emitting diodes (LED's), and their close relations, the injection lasers. Other sources, such as gas lasers, may ultimately prove very important, but their application in practical systems seems much farther off.

Incoherent light-emitting diodes

LED's possess important advantages over all other light sources which make them of primary interest in systems considered for immediate implementation. They are small, inexpensive, require drivers at only a few volts, and can be made with operating lifetimes of the order of 20,000 hours or longer. The output wavelengths depend on the precise composition of the diode materials; efficient diodes of $Ga_xAl_{1-x}As$ have outputs in the 800 to 900-nm range where current optical fibers have low optical losses (see Fig. 1). The exact composition can be tailored to avoid absorption peaks in the region. Work at RCA has shown that LED's can be made with a frequency response out to about 200 MHz, as shown in Fig. 2, where the output current from a suitable (square-law) detector is



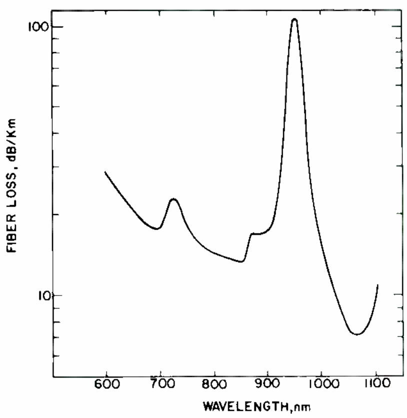


Fig. 1 — Wavelength dependence of transmission losses in an early low-loss optical fiber.[1]

plotted as a function of frequency for a constant input current level.

While the above advantages of LED's make them strong contenders for first consideration as light sources for fiber optical communications, they unfortunately also possess some serious disadvantages. As incoherent sources, their radiation patterns are basically omnidirectional. This is modified somewhat by their planar geometry and the absorptions and reflections inherent in their structures and mountings. As a result, the typical radiation pattern from an edge-emitter LED is a somewhat forward-peaked quasi-Lambertian distribution, as shown in Fig. 3. This broad-angled emission pattern makes it difficult to couple the radiation into the propagating modes of a fiber transmission line, as will be discussed in more detail below. Other limitations stem from the broad emission spectrum of LED's, typically of the order of 30 nm. This great breadth causes dispersion in the material of which the fiber is made; also velocity spread due to the propagation of energy in many modes of the fiber can distort signals and reduce the useful information bandwidth.

Perhaps the most severe limitation imposed by the use of LED's, however, is due to their low overall power efficiency. What matters in a fiber optical communications system is the optical power that can be coupled from the source into the fiber (or fiber bundle) for a given drive current through the LED. This depends critically upon the effective diameter and angular aperture of the fiber optic line. LED's are comparable in size to single fibers, and, as noted, their emission pattern is over a wide range of angles. Butting an LED against the end of a fiber permits only that part of the LED radiation emitted at angles within the acceptance cone of the fiber to be coupled. Optical elements, such as lenses and reflectors, can be used to confine much more of the radiation to an acceptably narrow cone of angles, but only at the cost of expanding the size of the light bundle. This is a major reason why bundles of fibers, with their much larger effective diameters than single fibers, are of interest in conjunction with LED's.

Noise originating in the LED must also be considered. LED noise has been studied by several investigators. Lee and Burrus[2] found that the noise in a photodetector illuminated by an LED exceeded the expected shot noise by a factor that dropped roughly as $1/f$ with increasing frequency. Shot noise was dominant at frequencies above about 100 kHz, and, in the better diodes, about 10 kHz. Lee and Burrus concluded that much of the excess noise was due to contacts and could be reduced or eliminated by better fabrication technology. Since their measurements were made at a level of 150 μA of photocurrent in the detector, at the lower current levels to be expected with LED's in a communications system, the additional "$1/f$" noise will be unimportant at even lower frequencies.

Finally, we consider the linearity of LED's. LED's are nonlinear for two reasons. At low injection current levels, there is an important nonradiative (tunneling) component to the current, leading to low radiative efficiency. At high current levels, this component saturates and can be neglected. However, at high current drives there is diode heating, which also leads to a decrease in efficiency. These two processes are clearly seen in Fig. 4. The result can be intolerable distortions and intermodulations in high-quality analog signals. Just how serious this is will depend upon the exact nature of the signal as well as the characteristics of the LED.

Semiconductor injection lasers

This second type of light source possesses most of the advantages listed above for incoherent LED's, and also offers very important additional ones. The output from a laser is much more directional, permitting greatly increased output coupling into the fibers. Moreover, with

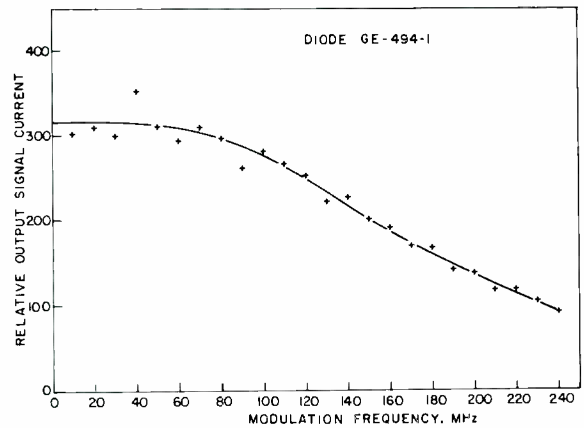


Fig. 2 — Frequency response of an incoherent LED. (The fall-off at high frequencies may be caused, in part, by the frequency response of the detector circuit.)

the laser, the response time is that required for the coherent optical field to build up in the optical cavity, since the injected carriers can be *stimulated* to emit in much shorter times than they will spontaneously recombine (the determining factor in LED's). This buildup time is generally well under a nanosecond. Thus, laser diodes are inherently much faster than LED's. Also, the spectral width of a laser can be only about 2 nm, making dispersive effects much less important. In addition, the power efficiency and output power available from lasers are much higher than those available from LED's.

As concerns linearity, above threshold one expects the output to accurately follow the drive current, except for heating effects. Since current densities are generally considerably higher in lasers than in LED's, one must expect the temperature-induced non-linearities associated with high drive levels to be somewhat greater in lasers than in LED's.

Injection laser noise has been the subject of considerable study. Armstrong and Smith[3] show that laser noise can be modeled by the response of a van der Pol oscillator to random-noise excitation. The result is that, near threshold, the noise level can be considerably above that associated with shot noise. Just how much above shot noise depends on the signal level and the coherence time of the noise, which, in turn, depends upon just how close to threshold the laser is operating. Well above threshold, the saturation properties of the gain mechanism lead to an amplitude limiting that greatly reduces the noise level, in most practical cases, to that of shot noise.

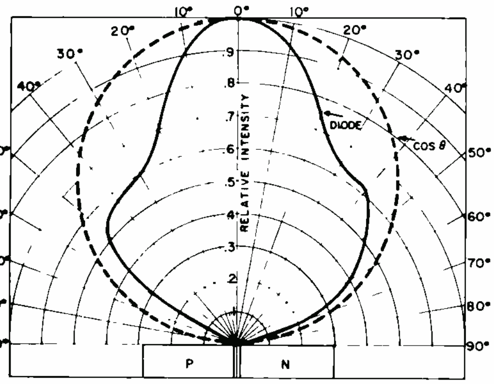


Fig. 3 — Angular pattern of light emitted from the face of an incoherent LED.

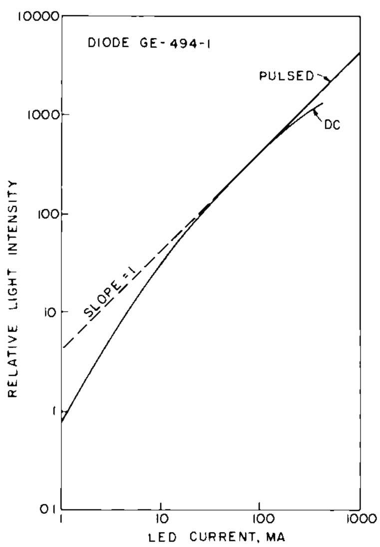


Fig. 4 — Linearity of an LED. At low drive currents, non-radiative currents lead to superlinear behavior. At high currents, diode heating lowers efficiency and again introduces non-linearity. If the diode current is pulsed with a sufficiently low duty factor, the curve remains linear to high drive levels. (In this diode, steady-state conditions were reached after about 2 to 3 ms.).

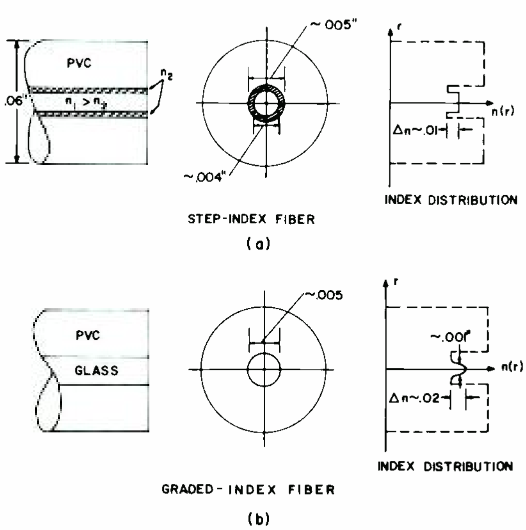


Fig. 5 — Schematic representation of the construction of optical fiber guides, including index of refraction profiles: (a) step-index fiber; (b) graded-index fiber.

It would appear from these considerations that the injection laser would be so far superior to LED's that one should not consider incoherent diodes at all. However, to be truly useful, the laser must be able to operate on an essentially continuous (cw) basis, at room temperature, for tens of thousands of hours. The subject of cw-laser-diode reliability is under intense study, and rapid progress is being made. Recently, room-temperature lasers that have been operating continuously for over 3000 hrs have been reported. This is still significantly short of the desired lifetimes for field operation, but the new results are important for two reasons: they constitute an 'existence proof' that lasers can be made with lifetimes at least approaching those needed, and they resulted from a large-scale experimental and theoretical effort to find the causes of laser degradation, and show that at least some of the sources of degradation are becoming understood and susceptible of correction. Thus, it appears possible that this most serious of problems with laser diodes may shortly be eliminated.

Optical fibers

Optical fibers have been made and studied for many years. However, it was only a few years ago, when Corning announced the development of fibers with attenuations of under 20 dB/km, that fibers could be considered seriously for long-distance transmission of information. To obtain the reported very low losses, it is necessary to reduce the impurity levels in the glass fiber to extremely low levels — many parts per billion of transition metals or of water are intolerable. By carefully controlling purity, Corning has attained losses of under 4 dB/km in special test fibers, and their commercial fibers have losses under 10 dB/km. These values are to be compared to 23 dB/km at 10 MHz for RG-8/U, a medium-sized (0.405-in. diam.) flexible coaxial cable and 43 dB/km at 10 MHz for RG-58A/U, a small-sized (0.195-in. diam.) flexible cable. Since losses in coax are copper losses, they increase with frequency due to skin depth effects, making the corresponding losses at 100 MHz about 65 dB/km and 161 dB/km. Rigid ¾-in. diameter coax used for CATV trunk lines is much better: 6dB/km at 10 MHz and only 18dB/km at 100 MHz. With coax, the frequency dependence of the losses requires significant periodic equalization; such equalization is not required with optical fibers, whose transmission losses (at optical frquencies of the order of 3.8×10^{14} Hz) are independent of the modulation frequency.

Optical fibers are of two types: step-index fibers, in which a high-index core is surrounded by a lower index cladding (which is often surrounded by a plastic coating for protection in handling, *etc.*); and graded-index fibers, in which the index of refraction of the fiber varies continuously as one proceeds radially out from the center. These are illustrated in Fig. 5. In general, either type can propagate many modes of the electromagnetic (light) field. However, by properly controlling the dimensions and indices, fibers can be made that will allow only one mode to propage without severe attenuation. However, because the dimensions of such single-mode fibers are so small, it is very difficult to maintain the very close tolerances on angular and positional alignments required to couple useful amounts of power into them. For this reason, there is little work on single-mode fibers at present.

As signals propagate down the fibers, they are distorted as well as attenuated. The distortion is the dominant factor in limiting the available information bandwidth and is due to two factors. (Only the first is relevant in the case of single-mode fibers.) The first factor is material dispersion: a signal will contain a range of optical frequencies, and since the group velocities are not constant over this range, material dispersion will alter the shape of the modulation envelope (the signal). The spectral range on an LED (30 nm) will lead to far greater dispersive effects than that of an injection laser (~ 2 nm).

A quantitative estimate of the distortion can be obtained by considering the spread of group velocities across the (incoherent) spectral line of the LED. For typical quartz-like fiber materials, this corresponds to a spread of travel times of about 3 to 4 ns/km of propagation path, indicating that modulation frequencies of 100 MHz or more will be 'washed out' in distances of the order of one kilometer. For laser sources, the correspondingly lesser dispersion is not apt to cause serious problems.

The second factor distorting signals is a more serious source of bandwidth limitation. This is the spread of energy propagation velocities associated with the different optical waveguide modes of the fiber. In the case of a step-index fiber (Fig. 5a), a simple ray-optics picture gives an estimate of this effect. Consider light in the fiber mode that corresponds to a ray traveling along the axis of the fiber. Such a ray travels a distance, L, through the core material in reaching the detector. If, instead, the (meridional) ray travels at an angle θ with respect to the axis, it will be reflected at the core-cladding interface and travel a distance $L/\cos\theta$, through the core in reaching the detector. If the ray angle, θ, is less than the critical angle $\theta_c = \arccos(n_{clad}/n_{core})$, it will be totally (internally) reflected. If $\theta > \theta_c$, reflection will not be total, and some light will be lost at each reflection, leading to high losses. Thus, the effective acceptance cone of the fiber, described by its numerical aperture,

$$N.A. = \sin\theta_o^* = n_{core}\sin\theta_c = [n_{core}^2 - n_{clad}^2]^{1/2}$$

[*Here θ_o is the maximum permissible angle from the fiber axis at which light can be incident and still couple into the propagating modes of the fiber.]

is related to the spread of ray transit times by

$$\begin{aligned}\Delta T &= T(\theta_c) - T(0) \\ &= [n_{core}L/c][\cos^{-1}\theta_c - 1] \\ &= [n_{core}L/c]\{[1 - (N.A.)^2/n_{core}^2]^{-1/2} - 1\} \\ &\approx [n_{core}L/c][\theta_c^2/2] \\ &\approx L(N.A.)^2/2n_{core}c\end{aligned}$$

For a low-loss Corning step-index fiber

$$N.A. = 0.14$$
$$n = 1.5,$$

giving

$$\Delta T = 22 \text{ ns/km}.$$

There are several factors that can modify this result. Clearly, if the light is coupled into a smaller cone than that corresponding to θ_c, the spread of transit times will be reduced. In other words, if only a portion of the available fiber modes is used, the signal distortion can be reduced. Secondly, even if energy is coupled into all possible modes, the slower modes, which correspond to more energy propagating in the cladding material on the wave picture, are expected to have higher transmission losses; and so, although this effect leads to a higher overall loss of optical power, it can reduce the effects of signal distortion considerably.

Finally, there is another phenomenon which can be used to reduce signal distortion greatly, although in general it too will lead to somewhat increased losses. This is mode-mixing. As energy propagates down a fiber in a given mode, imperfections in the fiber — due, for example, to bends or to small structural defects (inhomogeneities in the fiber materials or roughness of the core-cladding interface) — can couple energy between the modes. If this mode coupling is sufficient to mix all modes within the propagation length of interest, energy will move back and forth between the modes, traveling first at one speed and then at another, and ultimately averaging out the single-mode propagation-time differences. This is essentially the 'super-mode' concept recognized by Personick at Bell[4], and it leads to a (reduced) spread of transit times that varies at the square root of the fiber length, rather than directly as the length. Evidence of such behavior has recently been obtained.

Graded-index fibers are of considerable interest because a considerable number of the modes of such fibers can have the same group velocity, and hence can carry energy down the fiber at the same velocity. This is related to the quasi-parabolic distribution of the index in the radial direction. Obvious physical restrictions limit the radial extent over which one can achieve the index profile required for strict equality of modal velocities. However, experiments have shown spreads of transmit times of the order of one nanosecond in a one kilometer length of such fiber with a numerical aperture of 0.15. Thus, the combination of reduced modal propagation velocity spread and 'supermode' behavior can lead to information bandwidths of hundreds of MHz over distances exceeding a kilometer. In such systems, fiber losses and other factors influencing the S/N ratio will determine the effective information bandwidth limit, rather than these dispersive effects.

Detectors

While other possibilities exist, semiconductor detectors, because of their small size, ruggedness, simplicity, high response speeds, and low cost are currently the preferred ones. Since the present low-loss optical fibers have their lowest transmission losses in the 800- to 900-nm range and the most promising light sources ($Ga_xAl_{1-x}As$ LED's and lasers) have their emission peaks in this same spectral range, only silicon detectors, which have high quantum efficiency here, will be considered.

The two detectors that will be considered are the PIN diode and the avalanche diode. Both are small, rugged, semiconductor devices that can be made with very fast response times. For high speed operation, the PIN diodes must be biased by voltages of up to 50 V. The gain and response speed of the avalanche diodes also depend on the bias voltage. However, since the detector noise power rises faster with voltage than the gain, there is an optimum bias voltage somewhat below breakdown for best signal-to-noise ratio.

The breakdown voltage in an avalanche diode changes significantly with ambient temperature. For constant avalanche gain, therefore, some form of temperature-compensation must be used. However, since the optimum operating voltages may be considerably below the breakdown voltage, one can probably do away with temperature compensation in many applications. The avalanche diode, as the name implies, has a built-in avalanche gain mechanism, while the PIN diode does not. The signal levels from an avalanche detector, therefore, are considerably higher (perhaps 30 to 40 dB) than from a PIN diode, and the requirements on the noise figure and gain of the following amplifier are correspondingly less stringent. On the other hand, the avalanche multiplication process introduces additional noise due to the statistical nature of the gain mechanism.

Because of the gain mechanism, the primary noise source in an avalanche detector is usually shot noise associated with the electron stream before multiplication, modified by the noise introduced in the multiplication process. This makes the signal-to-noise ratio from the detector

$$(S/N)_{aval} = (\eta m^2 P)/(4 h\nu \cdot BF_o)$$

Here, P is the average optical power incident on the detector; m is the modulation index; η is the quantum efficiency of the detector; $h\nu$ the photon energy; B the modulation bandwidth; and F_o the 'noise factor' associated with the multiplication process. A commonly used approximation for F_o that is quite good is $F_o = G^{1/2}$, where G is the avalanche current gain.[5]

PIN diodes, on the other hand, are generally limited in their signal-to-noise ratio by the thermal noise in the resistive load on the detector (the input resistor to the following amplifier stages). Also, since they have no intrinsic gain mechanism, they must be followed by an amplifier that we assume has a noise figure F_1. In this case, the signal-to-noise ratio is

$$(S/N)_{PIN} = (m^2\eta^2e^2R\cdot P^2)/\left[8kT\cdot B(h\nu)^2F_1\right]$$

We can compare these two expressions and find that

$$\left(\frac{S}{N}\right)_{PIN} = \left(\frac{S}{N}\right)_{aval} \times \left(\frac{e^2\eta}{2h\nu\cdot kT}\right)\frac{R\cdot G^{1/2}\cdot P}{F_1}$$

One can thus improve the PIN S/N relative to that of the avalanche diode by increasing the load resistor R, a well-known fact. However, diode capacity then limits the response time of the detector. This can result in a signal with high S/N, but one that is distorted by relative loss of high frequency components. In principle, this can be corrected in the succeeding amplification stages. In practice, however, if the RC time of the detector is much longer than the desired response time, the correction is apt to introduce distortions of its own which will preclude use of such a high R. Assuming, then,

$R = 200$ ohms

$\eta = 0.7$

$G = 40$

$\lambda = 900$ nm,

$F_1 = 2$

we have

$$(S/N)_{PIN} = (S/N)_{aval} \times 6200 \cdot P \text{ (watts)}$$

Thus, the two types of detectors have, for the assumed parameters, equal S/N ratios when the optical power incident on the detector is about 160 μW, which is considerably more than can be expected at the detector in an LED-driven system. Thus, for those systems in which the bandwidth requirements force the load resistance to be as low as 200 ohms,

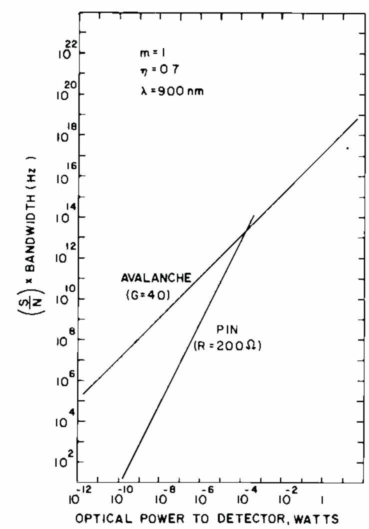


Fig. 6 — Output S/N ratio times modulation bandwidth *vs.* optical power to the detector for two types of silicon detectors: an avalanche diode with a gain of 40, and a PIN diode (without gain) with a load resistor of R = 200 ohms. A modulation index m = 1 is assumed.

avalanche detectors will yield a better system S/N, if the source is an LED. For digital systems in which the necessary S/N is much lower (*i.e.*, the optical power can be much lower), it seems clear that better results will almost always be achieved with avalanche detectors than with PIN diodes. These results are summarized in Fig. 6, where S/N ratios (multiplied by the bandwidth) are plotted against optical power for both avalanche and PIN silicon detectors. Again, $\eta = 0.7$; $\lambda = 900$ nm; and $G = 40$ have been assumed.

Systems considerations

In designing a system to transmit a given type of information, the systems designer must decide whether to use digital or analog transmission. Some forms of signal, such as television, are more naturally transmitted as analog signals, while others (*e.g.*, computer outputs) are naturally sent in digital form. However, there appears to be a growing tendency to send all signals in digital form, even such 'analog' ones as television and telephone.

Illustrative analog system

Consider the transmission of one base-band 5-MHz television channel over a fiber link, using an LED source. About 50 μW of light can be coupled into a low-loss fiber channel from an LED. Assume the fiber link introduces 20 dB of losses. This corresponds to a few kilometers of fiber. With a numerical aperture of 0.14, the spread of modal propagation times is ΔT = 22 ns/km. Experimentally, one often finds somewhat less spread than that given by the simple model used to derive this: perhaps 15 ns/km is more realistic. This broadening then will limit the available information bandwidth to about 30 MHz over the few kilometeter path assumed. This is not the major limitation on system performance. The fiber losses of 20 dB will reduce the optical power to the detector to about 0.5 μW, or about 2.3×10^{12} 900-nm photons/second. With an avalanche current gain of 40, the detector noise factor is 6.3, leading to a S/N ratio of 41.0 dB, for a 5-MHz television signal with modulation index $m = 1$. While this corresponds to a reasonable quality tv signal, there is clearly no margin for cascading such links to increase the transmission range or for greater bandwidths to send more than one channel. Clearly, we are not limited here by the bandwidth of the fiber link, but by the maximum power that we can obtain from the LED.

When future developments produce lasers that can operate continuously at room temperature with adequate lifetime, powers into the fiber of 20 mW might be realized. This is a factor of 400 greater than assumed for the LED, and would increase the S/N ratio by 26 dB. This would permit much greater ranges. Alternatively, one could use the increased power to fill the 30-MHz bandwidth of the fiber with 6 channels. With such increased bandwidths, however, one would have to consider nonlinear distortions and inter-modulation effects carefully.

There are a number of applications, such as intra-building closed circuit tv, or remote tv pickups on space satellites, where the parameters of the currently-achievable system are more than adequate.

Illustrative digital system

It is well-known that much lower signal levels can be used to transmit high-quality signals if some form of digital coding of the analog signal is used. In the following, we assume simple two-level, pulse-amplitude, binary PCM is used. To send the analog information in our 5-MHz tv channel, a minimum transmission rate of $10n$ Mb/s is required. Here n is the number of binary digits required to encode the quantized analog signal with the required S/N ratio. This can be accomplished in a channel of $5n$-MHz width. Experience indicates that to transmit good quality color tv, three samples/cycle of color subcarrier are required, about 11 million samples/s and that, for adequate quality, 8 bits/sample are required, leading to a required data rate of 88 Mb/s, or a minimum channel bandwidth of about 44 MHz. [Sophisticated coding schemes and adaptive threshold detectors, *etc.*, can reduce this 'required' bit rate (and bandwidth). The given figures are meant to illustrate the performance of a relatively simple digital system.] This can be obtained with step-index fibers only by limiting the transmission path to about one kilometer between repeaters. This will correspond to fiber losses of only about 8 dB, giving a power to the detector of 7.9 μW, and a S/N ratio of 43.6 dB. (Again, $m = 1$ is assumed.) For digital transmission, if the pulse S/N exceeds about 25 dB, there are essentially no errors made in the transmission.[6] Thus, for this system, we are limited by the bandwidth of the fiber and not by the available power.

We have seen that graded-index fibers can have information bandwidths considerably in excess of those of step-index fibers. Assume, as above, a 20 mW injection laser and that a graded-index fiber, with mode mixing giving an effective bandwidth of $300/L^{1/2}$ MHz, where L is in kilometers, can be used. The situation now changes considerably: one can fit three channels into the fiber bandwidth and maintain adequate (25 dB) S/N over a transmission path of 5.2 km. It does not seem a desirable trade-off to restrict the information bandwidth to one channel, increasing the S/N and permitting longer distances between repeaters: the repeater spacing only goes to 6.6 km. Alternatively, seven channels can be sent over links slightly under 1 km in length. (At three or more channels, for the example chosen, the fiber bandwidth is the determining factor on repeater spacing; while for one or two channels, S/N limits the length.)

Future developments

In the above, we have tried to indicate what sort of systems can be built now, and what effect the development of long-lived injection lasers might have on the conclusions reached. We now try to guess how other future developments might alter things.

With regard to improved light sources, current work at the Laboratories on $Ga_x Al_{1-x}As$ LED's indicates that we are now probably close to the ultimate limits on speed, efficiency, and available optical power for these devices, and it appears rather unlikely that the major developmental effort required to investigate alternative material systems for this application will be mounted. Thus, we should now be capable of predicting quite closely just what systems performances can be attained using LED's.

At present, one cannot design systems around CW injection lasers because their mean time to failure cannot yet be predicted. However, considerable effort is currently being placed on eliminating this problem, and it appears reasonable to assume that, in the coming years, digital systems employing these devices will come into prominance. The resulting effects on systems capabilities have already been indicated.

The use of other types of lasers, such as gas lasers, depends very strongly on the availability of suitable modulators to impress the information on the optical beam. Presently available modulators appear too expensive and inefficient for practical use. There is considerable work on new types of modulators, including thin-film 'integrated optics' ones. If these can be made at low cost with high speed and, most important, low effective insertion loss, one will have to consider these alternative laser sources.

The area of fiber development that would prove the greatest benefit is the reduction of dispersive effects and the increase of the information bandwidth, coupled with geometries that permit the reliable coupling of LED's and/or injection lasers to them. It is believed that the major thrust of current research effort is toward the increase of effective bandwidths, with work concentrated on graded-index fibers. This work should come to fruition in the near future, and such improved fibers could become commercially available within a few years. Cost is still somewhat of an open question, but it seems that, with volume production, costs on fibers could be brought down considerably, and, from what is known about methods of producing graded-index fibers, it is reasonable to assume that their ultimate cost will be comparable to that of step-index fibers.

Finally, for the detection of low-level pulses at the *circa* 800-nm wavelengths where quartz-based fibers have their lowest losses, it is hard to beat the current silicon avalanche diodes. The big improvement to be hoped for with silicon detectors is in cost and in methods for the temperature stabilization of their circuit properties.

Conclusions

At the present time, only incoherent LED's are practical sources for fiber optics communications. When used for the direct analog transmission of information, they can provide perhaps 5 to 10 MHz of bandwidth with S/N ratios of about 40 dB over paths of the order of a kilometer. The basic limitation is in the power available from the LED. With developments in LED geometry, mounting, *etc.*, they can also be used in digital systems in which the data rate is limited by pulse broadening in the fiber. If fiber developments remove this limitation, LED's can be used at pulse rates of the order of 100 Mb/s for digital transmissions. Great progress will be made in practical fiber-optical systems when injection lasers can be made with long lifetimes on a production basis. Apart from special military-type applications, in which weight, freedom from electromagnetic pickup, etc., are the determining factors, fiber optic communications will only come into use when costs of the overall system drop sufficiently to make them more than competitive with alternative electrical transmission systems.

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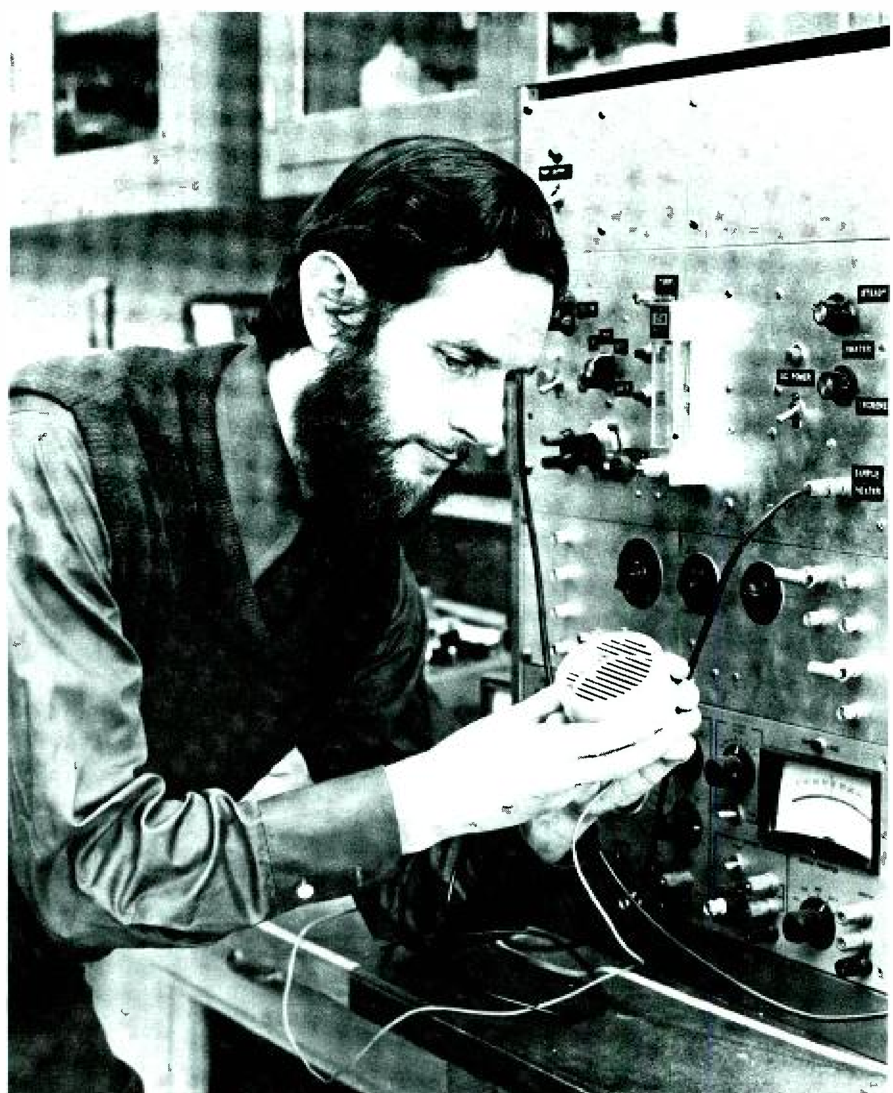
Pyroelectric detection of moving warm bodies

Dr. P.D. Southgate

A convenient way of dividing a pyroelectric detector into a number of series elements to match an amplifier is described. The sensitivity of this arrangement to thermal radiation from moving warm bodies, using either an optical imaging system or an interposed grating, is discussed. The analysis shows that low-cost pyroelectric polymers compare favorably with the more strongly pyroelectric crystals as thermal detectors in this system.

Dr. P. David Southgate, Materials Research Laboratory, RCA Laboratories, Princeton, NJ, studied at London University, receiving the BSc in Physics in 1948, the MSc in Mathematics in 1952, and the PhD in Physics in 1959. From 1948 to 1959, he was also employed at Mullard Research Laboratories, working on a variety of problems including mechanical properties of defects in solids and high-speed oscilloscope and camera development. He moved to IIT Research Institute, Chicago, in 1959, where he headed a group concerned with acoustic studies of point defects and dislocations in insulators and semiconductors, and with acoustic amplification in semiconductors. In 1966, he joined RCA Laboratories, Princeton, N.J., where his interests have included luminescence and hot electron effects in semiconductors, nonlinear optical effects in organic crystals, pyroelectric properties of materials and their use in thermal detectors. He is a member of the American Physical Society.



PYROELECTRIC radiation detectors operate on the bolometric principle, using the rise of temperature of the pyroelectric material as a measure of the intensity of the incoming radiation. Thus, to sense the presence of a warm body by its thermal radiation, the detector material should be made as thin as possible with maximum area presented to the incoming radiation.

Fairly strong pyroelectric properties exist in some polymers, making it attractive to exploit the fact that polymers can indeed be made thinner and of larger area than more strongly pyroelectric, but more expensive, single crystals. Thin sheets of this kind do not, however, immediately give a good electrical impedance match to an amplifier. Two alternative arrangements have been discussed by Putley:[1] a parallel one with electrodes on opposite faces of the pyroelectric material and a planar one with electrodes along opposite edges. Usually, the first has too low and the second too high an impedance. The electrode configuration described in this paper is convenient to fabricate, allows optimum detector geometry to be used , and yet gives a good impedance match to the amplifier. When used with an optical imaging system or, as will be described, with an interposed grating, it gives sensitivity to moving warm bodies but not to uniform changes of background temperature.

Electrode configuration

The detector, formed from a pyroelectric sheet uniformly polarized perpendicular to its plane, is shown in Fig. 1a. Electrodes are laid down in separated areas on both faces, each area overlapping two on the opposite face so that the sheet is effectively divided into a number of separate elements, shown by the broken lines, connected in series. The total detector capacitance may therefore be matched to that of the amplifier by adjusting the number of elements in the array. The elements form two sets, of opposite effective polarity, so that alternate heating of each set by a moving heat source focused on the detector gives an alternating signal. Although the elements are shown as parallel strips which are suitable for detecting motion primarily in one direction, a two-dimensional array of squares could be used, in which case motion of the heat source in either horizontal or vertical direction gives signals of equal amplitude.

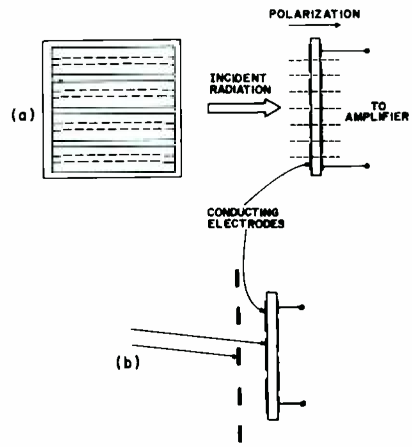


Fig. 1 — (a) Detector showing arrangement of overlapping electrodes. Pyroelectric material poled perpendicular to surface. (b) Use of detector in conjunction with a grating to give signal from a moving source.

An arrangement that does not require the formation of a thermal image at the detector is shown in Fig. 1b. Here, an opaque grating blocks the radiation which would be received by alternate elements, so that a signal is produced by radiation even though the element polarities are such that alternate cancellation occurs of the voltages produced by a uniform heating. If the direction of the incident radiation changes so that the previously blocked elements are exposed, a reversal of signal polarity will be seen. This sensitivity to moving objects and insensitivity to ambient changes makes the arrangement particularly interesting as a thermal detector.

Calculation of sensitivity

When used with an optical imaging system, the object is imaged directly upon the detector so that motion of the image across the detector generates a signal. If the image is small compared with the element size, then the current generated by the element when the image first falls upon it is the product of the incident intensity and the pyroelectric coefficient divided by the heat capacitance, that is,

$$I_O = HA_O p/cd$$

where A_O is the area of the optical aperture; p is the pyroelectric coefficient of the detector material; c is the volume specific heat; and d the thickness. The portion of the excess heat flux incident per unit area of the system which is absorbed by the detector is

$$H = \sigma\,(T_1^4 - T_O^4)\,\alpha\phi/\pi$$

where σ is the Stefan-Boltzmann constant; T_1 is the object temperature; T_O is the temperature of the background over which the object moves; α is a loss factor which includes losses in the optical system and the emissivity product of the object and detector; and ϕ is the solid angle subtended by the object at the detector. If now the number of elements in the detector is selected so that the total series capacitance of the elements, C_o, is equal to that of the following amplifier, the output voltage is maximized, and the optimum number of elements will be

$$N = (A\epsilon/dC_O)^{1/2} \qquad (1)$$

where ϵ is the permittivity of the pyroelectric and A the total detector area. The voltage generated by a moving object across the amplifier input will then have a triangular waveform which can be shown to have a peak-to-peak amplitude

$$V = H(A_o/A^{1/2})p\tau/2c(d\epsilon C_o)^{1/2} \qquad (2)$$

where τ is the time the image takes to traverse each element. It is assumed that this time is short compared with the radiative time constant of the pyroelectric sheet.

When a grating is used in conjunction with the detector, as shown in Fig. 1b, the analysis follows similar lines. For a source of small angular subtence, the grating completely blocks the radiation which would fall on alternate elements. For an optimized number of elements, the total peak-to-peak voltage may be shown to be

$$V = 3HA^{1/2}p\tau/16c(d\epsilon C_O)^{1/2} \qquad (3)$$

The form is very similar to Eq. 2. When $A = A_O$, the equations differ only by a factor 3/8. Of this, a factor 1/2 accounts for the heat blocked by the grating; the factor 3/4 is present since, during most of the traverse of the object, the incident heat falls to some extent on elements of either polarity.

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If the source object is of finite size, the incident radiation will spread between elements of opposing polarities to a greater extent, causing a reduction of generated signal to a value below that given by a compact source. Fig. 2 shows the effect that variation of size of a constant temperature source of rectangular shape will have on the thermal flux falling on any area of the detector. For a small-area source, the grating throws sharp shadows (a) and the flux falls only upon one set of detector elements; but since the source is small, the flux will be small. As the source size increases, the flux increases but the grid shadows become less well defined. When the source reaches such a size that the shadow region is entirely penumbra, the flux distribution is triangular (b), and the difference in flux reaching each set of elements is a maximum. For larger sources, the flux variations become less marked and become zero for certain angular subtences. The variation in net voltage generated by the two sets of elements (d) is a series of maxima between nulls. For a source of irregular shape and nonuniform temperature, sharp nulls of this kind would not be expected in general. The modified signal is calculated by integrating the thermal radiation received over each set of elements and then integrating the resultant net current in time. The result is that a factor $(1-\tau_2/2\tau)$ must be applied to Eq. 2 for the imaging system and a factor $(1-5\tau_2^2/9\tau^2)$ to Eq. 3 for the grating system. Here τ_2 is the transit time of the object past any point; the expressions are valid for $\tau_2 < \tau$.

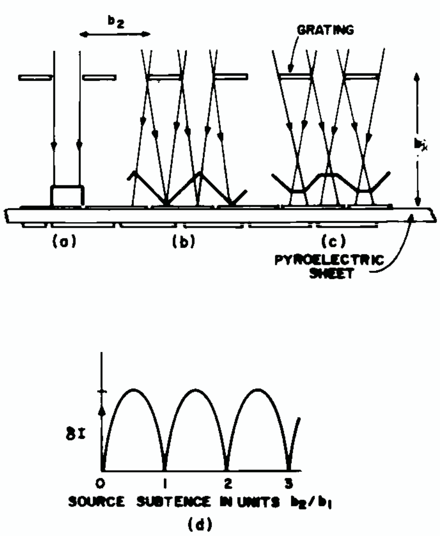

Fig. 2 — Thermal flux distribution for sources of increasing size (a through c); variation of resulting net detector current with source size (d).

Equation 2 shows that sensitivity in the imaging system increases as detector size decreases. This increase, however, is accompanied by a reduction in field of view. If the field of view and the numerical aperture of the system are specified, then the ratio A_O/A is fixed and sensitivity can only be increased by increasing A. For wide fields of view, the grating system will, in many applications, give equal sensitivity to the imaging system, as well as being more convenient to use.

Materials and performance

In Eq. 3, the detector paramters are contained in the factor

$$S = (p/c)(A/d\epsilon)^{1/2}.$$

Choice of an optimum pyroelectric material depends not only upon the intrinsic material parameters but also on the feasibility of making a thin self-supporting sheet having a large area. Table I shows a comparison between triglycine sulfate (*TGS*) and the pyroelectric polyvinylidenefluoride (PVF_2) The dimensions differ for the two materials, reflecting the fact that large thin sheets of PVF_2 are readily available, while *TGS* cannot conveniently be made more than 2-cm square and less than 40-μm thick. Values of the constants for the materials are taken from the literature[1,2] and from manufacturers' data. It can be seen that, with these engineering constraints, PVF_2 will give a sensitivity close to that obtainable with *TGS*.

Table I — Material parameter values.

	TGS	PVF_2
p (coul cm^{-2} K^{-1})	3×10^{-8}	2.4×10^{-9}
c (j cm^{-3} K^{-1})	2.5	2.4
ϵ/ϵ_o	40	11
A (cm^2)	4	25
d ($\times 10^{-4}$ cm)	40	12
S (coul$^{1/2}$ cm^2 j^{-1})	0.20	0.14

For a detector using the grating system the expected sensitivity to a moving person may be calculated. The person is taken to be 2-m tall, 25-cm wide, having an emissivity of 0.5, a temperature 10°C above the surroundings and walking across the field of view at 1 m/s at a distance of 20 m. The detector element is of PVF_2 having the dimensions of Table I, with detector elements subtending an angle 0.13 at the grating and an amplifier input capacitance of 10 pF. The output voltage under these conditions, from Eq. 3, should ideally be 120 mV, well above expected noise levels. The optimum number of elements in the array, from Eq. 1, is 46.

Prototype detectors have been constructed and have borne out these theoretical expectations. Since the motion to be detected is not very fast, an amplifier having a narrow bandwidth of the order of 1 Hz may be used. Detectors were constructed with both the detector element and amplifier in a container of 3-in. diameter and 1½-in. deep. Tests showed that motion of a person could readily be detected at a distance of 20m within a cone of angle 90°. At a distance of 5 m, slight hand motions generated signals an order of magnitude above noise level. The system appears insensitive to many forms of external interference and well suited to application as a low-cost intruder indicator.

Acknowledgments

It is a pleasure to acknowledge the assistance of D.S. Hall who fabricated the sensor elements and constructed the detector, J.O. Schroeder who designed the amplifier circuit, and the encouragement of H. Kressel who suggested the making of the detector.

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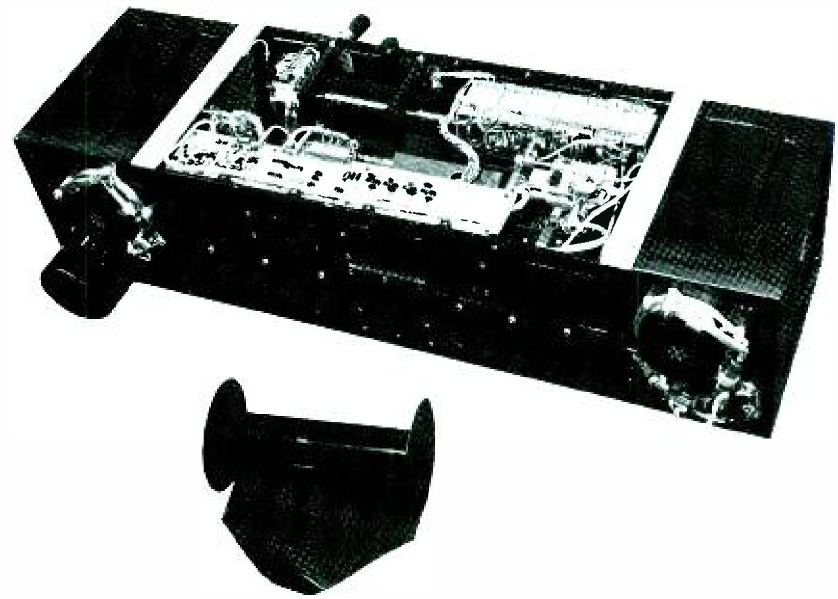

Fig. 1 — PAR-5 precision line-scan film recorder.

PAR5 — a breakthrough in laser/film recording

C.R. Horton| F.P. Tyrrell

PAR5 is a precision line-scan film recorder designed to convert video data to 9.5-in.-wide film data. The technology behind its five micrometre resolution, 150-MHz bandwidth, and multi-mode flexibility represents ten years of related development efforts at RCA. Modular design of PAR5 established this device as the baseline configuration for a family of cost-effective RCA recording systems. Its construction provides for operation in adverse environments including high-performance aircraft and ground-transportable units. Variable scan speed and simple computer interface are made possible by a digital front-end buffer.

Charles R. Horton, Ldr., Government Communications and Automated Systems Division, Camden, N.J. graduated from the University of Maryland in 1966, and joined the Recording and TV Equipment Section (now Recording Systems) in Camden He participated in RCA's Graduate Study Program at the University of Pennsylvania where his studies led to the masters degree. In his initial assignment, he participated in the design and development of a miniature spaceborne television recorder delivered to NASA in Houston. Mr. Horton continued development work on special purpose television recorders including the electro-mechanical design for the CVR62, and the advanced design for the AN/USH-17, a 2-channel 6 MHz bandwidth airborne recorder presently in production. In 1969, he was assigned to laser recorder development and became responsible for the LR70 and LR71 high resolution laser scanner/recorders. In this capacity, his primary responsibility was to see laser recorder technology transferred from Advanced Technology Laboratories to Recording Systems, a product group. In 1971, Mr. Horton was promoted to Group Leader with responsibility for laser programs where he became program director for PAR5 development program. He is now engaged in design effort for many new systems made possible by PAR5.Mr. Horton holds one United States patent.

F. Peter Tyrrell, Electro-Optic Laboratory, Advanced Technology Laboratories, Camden, N.J., received the BSEE from Northeastern University in 1970 under the Cooperative Engineering Program. Presently, he is pursuing the MSE at the University of Pennsylvania. Upon completion of the RCA Engineering Rotational Program, he became a member of the Recording Systems Group, where he has been involved in the design of several laser recording systems. His assignments on both a 100-MHz laser signal recorder and the LR70CVR 30-MHz laser recorder/reproducer have included laser systems, acousto-optics and electro-optic light modulation, video processing circuitry, time-base correction electronics, and control systems. Mr. Tyrell had complete responsibility for the specification, design and testing of the laser system, wideband electro-optic modulator, drive amplifiers, and the phase/amplitude equalization network for the PAR5 airborne laser recorder. Recently he participated in the design of a low cost laser facsimile system. Mr Tyrell is a member of the IEEE and Eta Kappa Nu.

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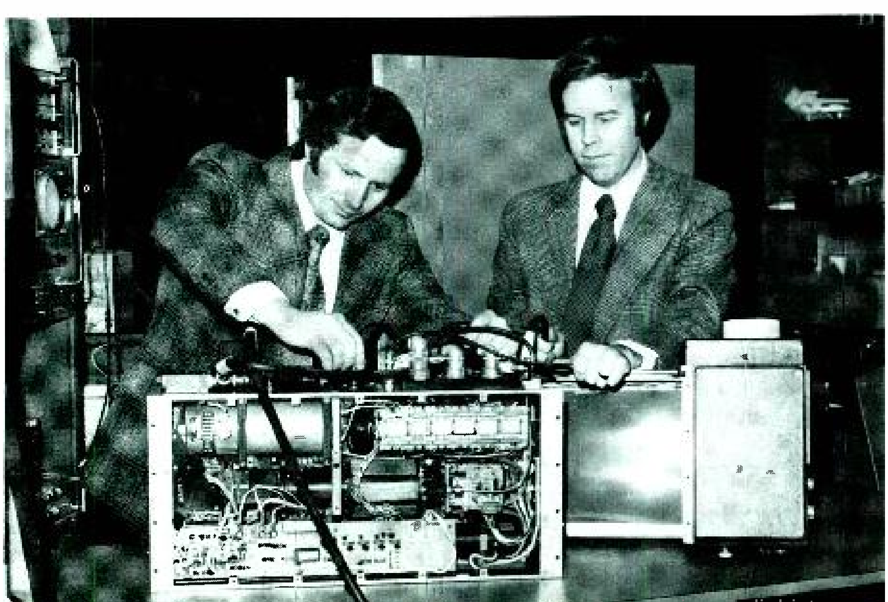
Authors Horton (left) and Tyrrell.



A relatively new technology — laser/film recording — is now available to a wider applications community. The PAR5 precision line-scan film recorder allows cost-effective application of laser recording to many systems now being served by inferior display techniques. In general, laser recording offers higher resolution, dynamic range, bandwidth, and scan speed than other alternatives.

The modular design and rugged construction of the PAR5 are shown in Fig. 1. This recording system can serve as the baseline display configuration for any application featuring a line-scan data source. Both image and signal versions have been built and tested. In addition, systems have been built to include scanning capability. This allows image transparencies to be digitized. Conversion of imagery to electrical signals has been done at a 75-MHz analog data rate.

Typical application

The collection and analysis of remotely sensed data is a necessity if we are to locate, identify, and manage the Earth's natural resources. Such remote data must

Fig. 2 — Contact print of RCA laser display output. Note Hawaii under partial cloud cover at bottom of print. This image data was received from the RCA-built ITOS-D satellite and recorded at the National Weather Service Facility, Redwood City, Ca. The analog data was digitized, corrected for geometric and radiometric errors, and recorded on film by a system utilizing PAR5.

be accurate, high resolution, of specified-wavelengths and repetitive. Further, to enable wide effective use, the data must be timely, in man-usable format, and economically obtainable. The systems for sensing such data are highly developed. Laser/film recording provides the link to users because, for the first time, image data is delivered in large format, with unprecedented quality, at reasonable cost.

The RCA-built ITOS-D meteorological satellite provides a source of such data. The resolution and dynamic range obtained by proper matching of sensor to display is demonstrated in Fig. 2. No other display technique can do justice to the VHRR (Very High Resolution Radiometer) sensor onboard.

This example is but one of many earth resources, reconnaisance, and meteorological systems requiring improved display performance.

Sensor/display match

System designers continually mismatch sensors with displays. Most often, the design error falls into one of two categories:

1) MTFA (area between Modulation Transfer Function curve and "noise floor"). [This subject is discussed at length by Schade.[2] In simple language, MTFA is an image evaluation concept which combines dynamic range and resolution considerations into one unified subject. It is to spatial frequency what spectrum analysis is to temporal frequency.]
2) Error signature, both radiometric and geometric.

In the case of MTFA, the match is relatively straightforward, once the problem is defined, since functions may be cascaded by multiplication.

In the second category, proper matching involves more subtle considerations. Each error must be matched with the display system's ability to correct that error type. For example, one finds the electron beam recorders are well suited to return-beam vidicon cameras; laser recorders are a good match for mechanical scanners such as the VHRR.

Fig. 3 shows MTF cascading for a typical mechanical scanner system. The very high resolution of a laser recorder provides system output almost equivalent to sensor output. This figure demostrates the benefit of laser recorder resolution. This high resolution is inherent to the technique and does not adversely affect cost. Complete analysis indicates that dynamic range, noise floor, and error signature are also compatible.

System description

The laser recording system is shown conceptually in Fig. 4. The light beam from a laser is intensity modulated by the input video. The beam is expanded to fill the imaging lens and then focused to a diffraction-limited spot. A rotating mirror, located within the focus of the imaging lens, deflects the modulated spot. The appropriate recording medium is transported past the scanning laser beam through a curved film platen and is exposed along transverse tracks. The laser recording process retains the information as a latent image on film. Subsequent development of the film yields a direct signal or image recording. Immediage processing of dry silver media is also feasible.

PAR5 test philosophy

To verify performance of the PAR5 recorder, a thorough test program was conducted. The testing was divided into two categories: recorder system and subsystem performance. The subsystem testing determined the electro-optic video response. The system testing included the more problematic effects of film and film development.

To avoid missing subtle areas which might affect system performance, both system simulation and compatibility testing were performed. System simulation testing allowed trade-off of the effects of amplitude response, phase response, and system impulse response. A highly accurate RCA Network Analyzer was used to make extremely refined trade-off, such as increased cubic phase error for decreased amplitude ripple. System compatibility testing employed synthesized systems inputs to the recorder and subsequent processing of the image data by the remainder of the system. The purpose of this type of testing is to assure that the laser recorder will meet specified performance in the intended application.

Fig. 5 is the simulation output for PAR5 employed in a side-looking synthetic-aperture radar application. In this case, mainlobe shape was optimized by trading off distribution of parasitic sidelobes.

It must be recognized that measurements taken to predict performance of a high performance laser recorder will fully tax the accuracy and precision of the measurement system. For this reason, many of the recorder performance measurements include a comparison of recordings to themselves and comparison of results obtained by conventional optical techniques (microdensitometer and moving-table microscope) with those obtained by diffraction pattern techniques. In cases where an absolute result was not assured, sound engineering judgment prevailed.

For measurements relating to the geometric fidelity of the recorder (transport jitter, scan jitter, scan linearity, *etc.*), standard optical techniques provide the required accuracy. However, coherent optical techniques are used as an aid in determining the nature of any geometric distortion. For the moving-table microscope measurements, precision is ±0.25μm. Further improvement results from taking many samples.

In areas such as Modulation Transfer Function (*MTF*), signal-to-noise ratio (*S/N*), amplitude transmittance uniformity, or amplitude transmittance linearity, standard microdensitometer techniques may not provide sufficient accuracy and may miss subtle errors which could affect system performance. Coherent optical analysis provided the required accuracy for measuring these parameters. The coherent optical

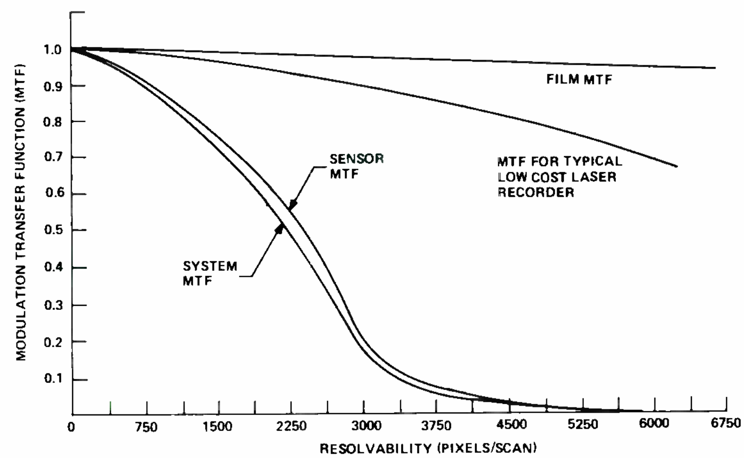


Fig. 3 — MTF for a typical low-cost laser recorder.

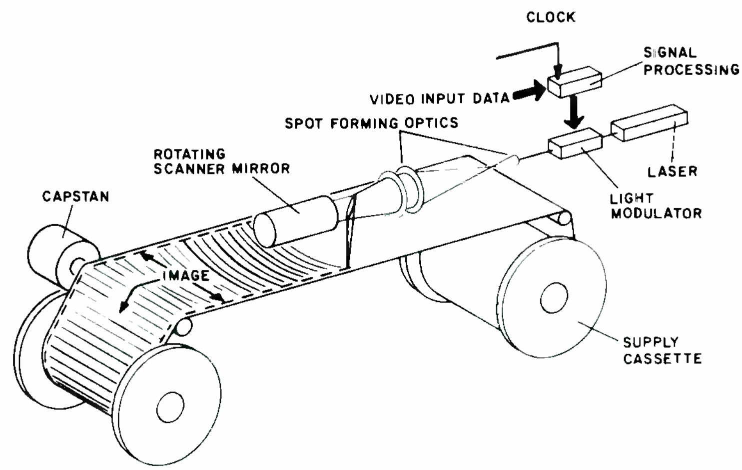


Fig. 4 — Laser recorder concept.

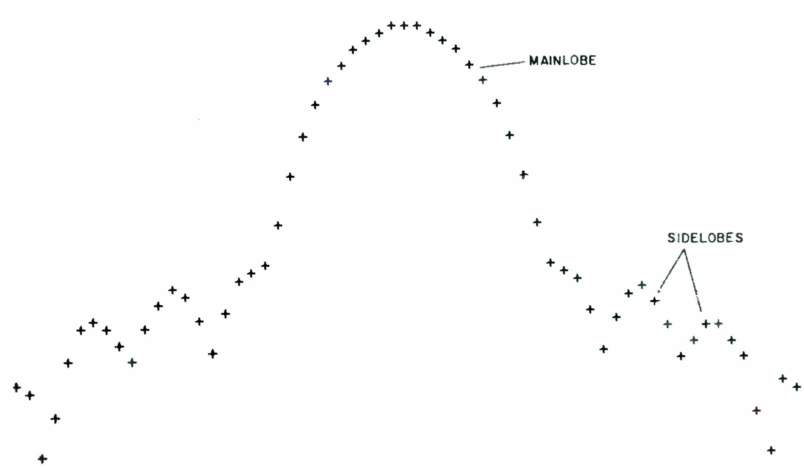


Fig. 5 — Simulation output for PAR-5 used in a side-looking synthetic-aperture radar application .

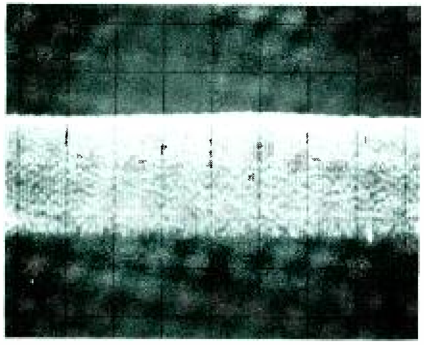


Fig. 6 — Frequency sweep of video and electro-optic sections of PAR-5.

analyzer employs an RCA *HeCd* laser, beam expander, liquid gate, Fourier transform lens, and translatable spatial filter/photodiode. The complex field amplitude distribution in the back focal plane of the lens is the two-dimensional Fourier transform of the test recording. By measuring this distribution with a photodetector/spatial-filter combination, the pertinent characteristics of the test recording were determined.

Fig. 6 shows the extremely flat frequency sweep of the video and electro-optical portion of the PAR5 laser recorder. For this test, the laser beam was photodetected by a wideband (1-GHz) ITT photodiode (model FW-114A) and measured by the RCA Network Analyzer. Although the recorder has useable frequency response from 200 kHz to beyond 200 MHz, the bandpass has been optimized by linear-phase amplitude equalization networks for its present bandwidth.

Fig. 7 shows the deviation from an ideal linear phase response for the electro-optic portion of the PAR5 laser recorder. Again, for this test the laser beam was photodetected by a wideband photodiode. The excellent phase linearity obtained by the recorder can be attributed, at least in part, to the selection of the widest bandwidth subsystems available. A phase-equalization network provided additional phase corrections.

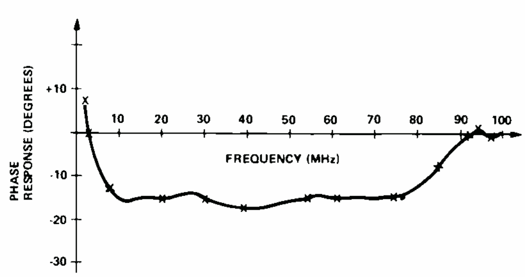


Fig. 7 — Deviation from ideal linear phase response.

Table I summarizes other important test results. The system MTF of 25% at 100 LP/mm was measured using coherent optical techniques. Microdensitometer results indicate higher MTF. The operating point is adjustable. The 400 μW of spot power is sufficient to expose dry silver films at the scan rates required by many operations.

The high geometric fidelity, low scanner jitter, and lack of film transport "banding" result from refined, phase-locked servos, ScanLoc, electronic time-base correction, and smooth film transport with simple, on-axis, curved-platen scanning.

The high scan linearity is a result of the curved-platen scanning. Flat-field scanning increases the cost of scan linearity, and/or results in low video duty cycle. For this reason, a curved-platen is usually the best choice for high resolution applications. Flat-field scanning is very applicable, however, to lower resolution systems.

The scan-linearity results listed in Table I include the effects of any non-linear film shrinkage of an acetate base film. When tested in this manner, the scan linearity for the laser recorder is approximately ±0.05%. Tests with mylar films indicate higher performance.

Modular applicability

Several configurations of PAR5 allow this basic design to be applied to many uses. Earth Resources Technology Satellite (ERTS), meteorological (MET), Image Transmission System (ITS) and various reconnaissance ground stations can benefit from PAR5 design. Table II summarizes many of the possibilities. Cost savings on selected subsystems and integration allow the PAR5 to compete with higher resolution CRT/film recorders and electron beam recorders while providing dry process film capability and superior performance.

Table I — Other test results.

MTF (incl. video, E/O, film, jitter, *etc.*)	25% @ 100LP/mm
Geometric fidelity	< 2 μm, rms error
Data skew	± 14 arc sec
Scan linearity	± 0.05%
Operating point (@ mid point)	400 μW spot power
Weight	182 lbs.

Applicability to ERTS

In a manner similar to that demonstrated by Fig. 2, PAR5 can make Earth Resources Technology Satellite data more useful.

Viewers and/or photographic enlargement to a scale factor of at least 1,000,000:1 are required for full utilization (for proper match to the eye). A high percentage of the total system geometric and radiometric error results from this. The solution is laser-beam recording. Laser recording provides extremely precise, large format imagery; *i.e.*, already 1,000,000:1!

Present ERTS film products have been corrected by analog techniques within the electron-beam film recorder. Computer-compatible tape (CCT) is essentially raw data: *i.e.*, limited geometric corrections and no radiometric correction. The film product cannot be further corrected, limiting data manipulation possibilities. The CCT product is uncorrected, but correctable via data processing. At present, "one time only" corrections must be repeated, wasting computer time and capability.

Both products should be made equivalent whenever possible. One-time corrections should be applied to both products via common processing. Techniques for photographic data distribution which allow interactive manipulation should be developed and offered as a user option. One such technique, color recording on black-and-while film via diffraction-grating encoding, is described later.

The data equality (film and tape products) requirement implies completely digital data processing. Recent advances in component and system technology make this realistic. Analog correction at the film recorder will no longer be required (or desired) with the laser beam recorder. (LBR). PAR5, in-

Table II — PAR5 applicability to other systems.

Parameter	*Capability*	*Remarks*
Resolution	5,000 to 50,000 pixels per scan	A performance/cost trade-off
Dynamic Range	Up to 500:1 contrast	500:1 configuration employs acousto-optic light modulation
Geometric fidelity		
—dynamic error	1 part in 50,000	This is made possible with simple, curved platen scanning scanning technique
—long-term error	±0.05%	
Bandwidth	–dc to 5 MHz	Low cost, acousto-optic
	–dc to 25 MHz	Medium Cost, acousto-optic
	–others to 200 MHz	Higher cost, electro-optic
Scan rate	Up to 12,000 scans per sec	Configurations as low as 6 scans per sec have been tested
Film format	9.5 inch cont. (250 feet)	Dry process film optional
Construction	Transportable or airborne	Same modular design applies to each

tegrated into such a system, has been renamed LR72.

Improved utilization of multi-spectral data is achieved via a perfect registration technique recently developed by RCA. This technique, synthetic grating laser/film recording, also provides all four ERTS MSS data channels on one frame of low cost black-and-white film. The application of this development allows the user to manipulate color balance and perform spectral studies with a simple viewer without geometric registration problems. Hard-copy color output is also provided. The laser-beam recorder technique also provides direct print-out of black-and-white data in large usable format. This eliminates the major source of systematic errors, which occur during enlargement from 70mm to 9.5-in. format.

Perfect color registration

With the addition of the LR72 electronic color encoding option, the user is also able to perform color manipulation and mixing of spectral bands, dynamic-range splitting of individual bands, and produce perfectly registered composite pictures for the first time, while maintaining image quality, resolution, and geometric accuracy.

With this color-encoding technique, the LBR provides a black-and-white data film which contains all color-data channels superimposed on one frame. The color data is encoded as amplituded modulation of separate diffraction gratings at various spatial frequencies and/or orientations. Color hard-copy output or display is made on a simple projector.

Since the creation of these gratings is synthetic (generated electronically in the time domain) the transformation to the spatial frequency domain (on black-and-white film) is made with a single channel of electro-optics. This results in perfect registration in an almost absolute sense. No other technique can do as well.

Since the data film is black and white, no system resolution is lost because of the diffraction gratings. Referring to Fig. 8, note that even though the gratings occupy part of the spatial frequency domain, black-and-white film resolution far exceeds that of color film. Thus, the extra bandwidth required for encoding is available. Note that 3-channel color data would be placed on 3 carriers —f_1,f_2, and f_3. This means that all system stabilitv requirements, both radiometric and geometric, are placed in the electronic/time domain. No sensitive electro-optic elements can cause relative drift. System performance is limited primarily by the color film used in the hard copy printer.

The color encoding technique offers other data distribution/utilization advantages:

1) Low cost black-and-white film distribution of color data to users.
2) Interactive color balance/intensity studies (for either data screening or for final data utilization) can be performed by users.
3) Color hard copy can be produced off-line.
4) As a general-purpose color display, several types of observations can be made.
   - split dynamic range studies
   - scene characteristic
   - color tv/zoom optics display
   - color microdensitometer
   - false color studies

Conclusion

PAR5 is the first practical high performance laser recorder. Application of PAR5 to the LR72 recording system and other similar systems can be made in a cost-effective manner due to modular design. Film recordings from ITOS-D and ERTS prove its multi-purpose capability. Its precision large-format output is a perfect match for most image systems.

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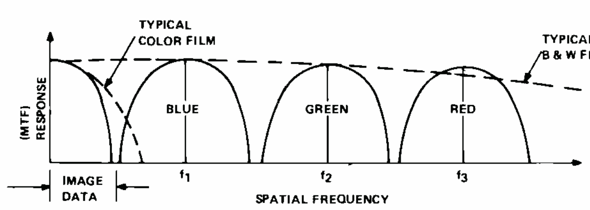

Fig. 8 — Color-encoded signals.

More information and less data from space

Dr. H. M. Gurk

Higher resolution, more spectral bands, and greater frequency of coverage are desires of most users of remote sensor data. However, considering only current programs like the Earth Resources Technology Satellite, environmental satellites, and aircraft-based sensor systems, the volume of data offers a substantial processing problem to NASA. Potential data users are experiencing similar difficulties. Increased facilities and manpower may not be the best solution. Current analyses are revealing how much of the data is redundant. If the important information were extracted from the large volume of data, it would be possible simultaneously to reduce the volume and permit desired improvements in resolution or frequency of observation. Techniques such as data compression, statistical sampling, and mixed-highs multispectral sensing can reduce the data greatly to allow one to "get at the information". Data volume reduction, problems of utilization, and usefulness are discussed for each technique. Experimental results and current programs are presented. Recommendations are made for specific programs.

EARTH observation satellites have been used with remarkable results by researchers and applications scientists since the launch of the first TIROS satellite in 1960. From the beginning of the R&D programs, scientists found that experimentally observed data was useful for planning and monitoring in a particular discipline, and they asked for that data on a regular basis. Once they learned how to take advantage of data of particular types, the users requested additional data that could be even more useful. The resulting increased volume of data from some typical satellites in shown in Table I.

Recently, NASA convened a meeting of some of the foremost "remote sensing" experts in the country, along with a group of earth-resources data users and scientists from government agencies, universities, and commercial organizations. The purpose of the meeting was to have the sensor experts assess alternative techniques for satisfying the desires of the users for data for important applications. The users recognized the technical and data handling problems, but felt that future needs will call for higher resolution, more spectral bands, and more frequent coverage—in other words, more data. Figs. 1 and 2 are taken from the final report of that meeting[1] and show the estimates made for desired data for eight applications. Significantly, the experts in each of the disciplines indicated they were really interested only in the amount of information that could be extracted from the data and applied to their fields. They all agreed that it was more information, not data, that they were requesting.

At the same meeting, Leonard Jaffe, Deputy Administrator of NASA's Office of Applications indicated that the increased loads requested by the users could not be handled now with existing facilities and most probably cannot be handled in the future without some major restrictions. Otherwise, major problems would exist in communications bandwidth for the satellite-to-ground link, in data storage capacities both in space and on the ground, and in all areas of data processing and handling on the ground.

Facilities on the satellites and on the ground can be improved, but the cost is substantial. Moreover, it is questionable whether such brute-force methods are desirable or necessary. There are several ways to reduce this potential data load while still retaining the possibility of extracting the information desired by the user. We shall examine the following techniques briefly, illustrate applications of them, and estimate their potential savings:

- Data compression
- Limited data selection
  - a) Statistical sampling of areas
  - b) Spectral sampling
- Reduced resolution
  - a) Mixed-highs
  - b) Area statistical estimation

Data-compression techniques

The purpose of data or bandwidth compression is to lower the required bit rate for transmission without losing the ability to reproduce the original data. This is accomplished by examining the data, determining what is unnecessary for a particular application, and removing the

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extra data while leaving some marker of what has been done. In some cases, this compression is done with absolutely no loss of information, while in others some destruction takes place but to an acceptable level for the expected application.

There are many ways in which compression can be performed.[2,3] Almost all schemes use some method of comparing a data element with its neighbors in a stream of output signals from the sensor system. Usually, either the difference of values of neighboring elements or the difference between an element's value and that of an average of some neighboring elements is compared with a preset threshold value in order to decide what is to be transmitted. Selection of the threshold at better than the sensitivity of the sensor system will destroy no data. The bandwidth reduction achieved depends on the variations of the observed data and on the coding procedure used to describe the extent of the interval of constant value. If the threshold is set at some poorer value than the system sensitivity, then data will be lost. In this case, the saving depends on the threshold value in addition to the scene variations and coding procedure. Very often for destructive compression schemes, processing is done after the data is received to smooth any artificially induced sharp edges.

Almost all collected Earth observation data can have its total volume reduced somewhat by using compression techniques. But except for limited-savings modulation schemes in which neighboring element differences are always sent, data compression has not been greatly used. There are two major reasons for this: the complexity of on-board equipment for compression and, more important, the fear that the loss of data will cut too severely into the useful information. With the expected substantial increases in data rates, the potentially large savings that compression schemes can provide (2:1 to 6:1, conservatively) should be given greater consideration in determining the adequacy of extractable information.

Figure 3 shows the effects of four levels of

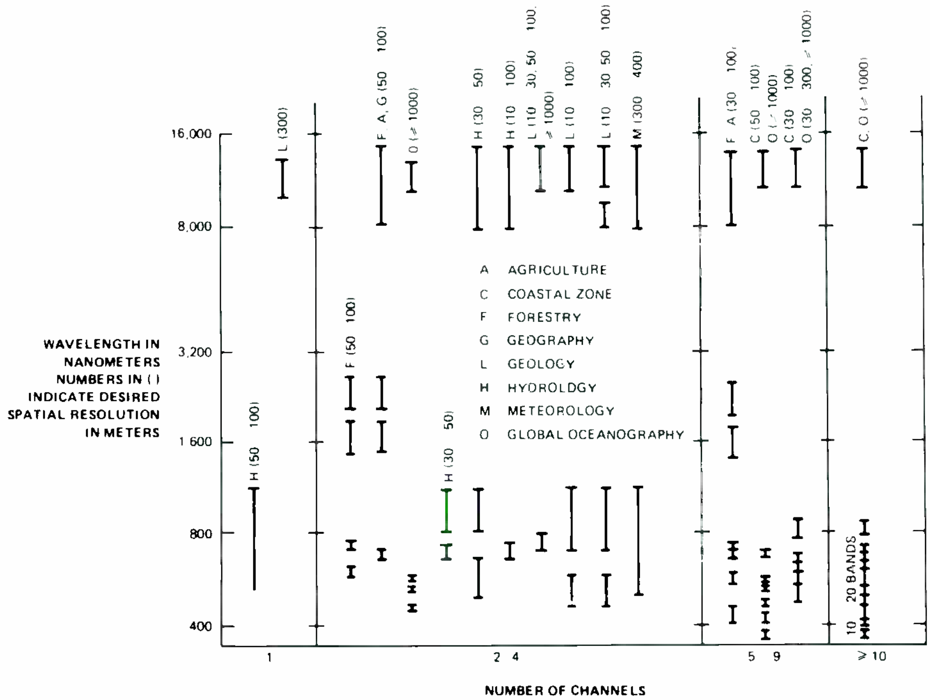

Fig. 2 — Spectral requirements summary for specific applications in several applications areas (each column represents a different application, and each segment in a column represents a spectral band over which the observation is to be made).

Table I — Sensor outputs and rates from Earth Observation Satellite.

S/C	No. of sensors	Total No. of bands	Elements/line	Data rate (Mb/s)	
TIROS I	4	7	1-500	0.5 (low duty cycle)	PAST
ERTS	4	7	3500-4500	30	CURRENT
ITOS D	4	16	1-4000	0.5	CURRENT
Nimbus G	8-12	60-90	1-2000	0.8-2	FUTURE
EOS A	2-6	11-30	2000-6400	70-240	FUTURE
TIROS N	5	22	1-4000	1	FUTURE

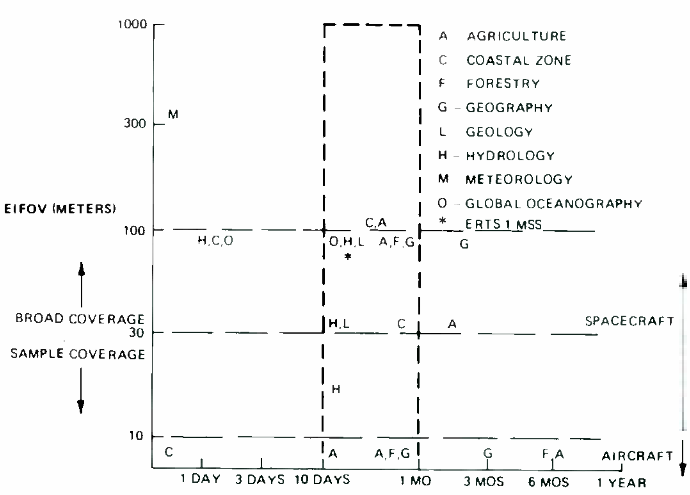

Fig. 1 — Repeat coverage requirements for various applications areas as related to resolution (EIFOV) needs. The vertical and horizontal bands represent the densest region of related coverage/resolution requirements. [EIFOV is Effective Instantaneous Field of View.]

Fig. 3 — Effects of four levels of data compression, From left to right (top): a) 1:1, b) 2.3:1; (bottom) c) 4.3:1, d) 16:1.

compression on an Apollo cloud-cover picture of the Baja California-Imperial Valley area. The scheme used was an averaging procedure with different thresholds to change the compression levels. Final processing included interpolation to smooth artificial edges. Very little difference is detectable between the two lowest compression levels, 2.4:1 and 4.3:1, and the original, and even 16:1 compression produces a usable output.

Limited data selection

Area sampling

One obvious way to reduce the data rates and volumes is by the use of selective sampling and statistical analysis techniques. The Department of Agriculture has used area sampling and statistical techniques for many years for crop acreage estimates, soil surveys, and other agricultural census purposes. For example[4], crop and livestock estimates for states and larger regions in the US are predicted using 17,000 small parcels of land out of a total of 3,000,000 for the continental United States. Enumerations of the items of interest are made for each parcel within the smaller group and extrapolated into estimates for larger areas over regions of similar characteristics.

Sample data for such agriculture analysis has usually been obtained directly by 1) field surveys, 2) questionnaires mailed to individual farmers selected statistically from lists of farms of different characteristics, or 3) observations made of output products. Some sample data is now being obtained by remote sensing from aircraft for crop estimates, but this has been limited. The use of remote sensor data for this statistical analysis is now being investigated in several experiments[5] especially with regard to the use of combinations of current Earth Resources Technology Satellite (ERTS) data along with aircraft and field ground truth measurements.

Sampling of very small areas from satellites will not be efficient without the transmission of additional data beyond that required for the statistical anlaysis. Nevertheless, since the current ground sampling techniques reduce the required data by almost a 200:1 factor (17,000 samples out of 3 million), even inefficient systems could provide worthwhile data bandwidth savings.

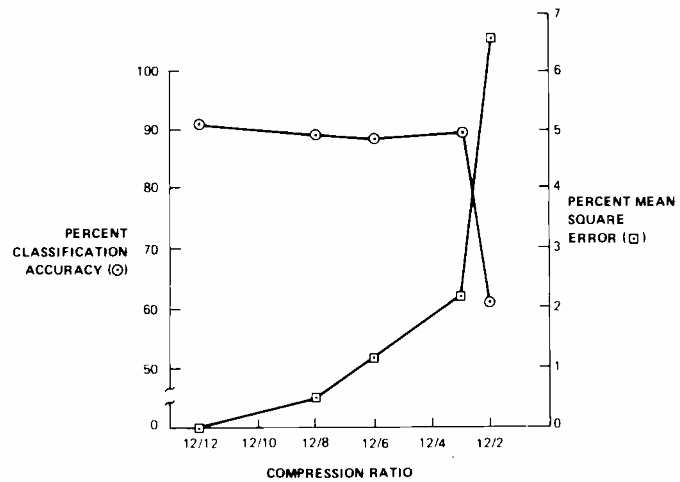

Fig. 4 — Effects of spectral compression on classification accuracy and picture quality (mean-square error).

NASA is currently planning to fly a multispectral High Resolution Pointing Imager (HRPI) on its proposed Earth Observation Satellite (EOS), the next generation Earth resources satellite. HRPI will have much better resolution (about 3:1) and much smaller coverage (a range of 1:4 to 1:25 or less, depending on its use) than other EOS instruments.[6] The HRPI will be used to provide detail in small areas for statistical purposes, such as outlined here, or for examination of discrete areas (*e.g.*, urban areas, estuaries and streams) of high frequency changes.

Spectral sampling

Many Earth observation sensors collect data in several spectral bands to help identify, unambiguously, the elements being observed and to determine their current status. The ERTS Multispectral Scanner has 4 channels; the Skylab EREP scanner has 24 channels. The data from these individual bands is combined in a variety of different ways to aid in the analysis. For example, vectors of the individual channel values are compared to known spectral signatures of crops automatically in a computer, or "false color" photos are made for viewing and analysis. Different processing procedures or combinations of available channels are used for different applications, regions, and times. If one could select and transmit only the data corresponding to the specific combinations of spectral bands of interest at any time, then a large saving in bandwidth might be possible.

In a recent study at Purdue University,[7] the number of channels required for agricultural spectral signature analysis was reduced by selecting a small number of linear combinations of the vectors of radiance values measured by a multispectral sensor. The specific combinations chosen are the principal eigenvectors of the covariance matrix of the vectors of the original band values. The selected eigenvectors correspond to the non-zero eigenvalues. Using a 12-channel radiometer and a specific flight line, the Purdue group was able to select a 3-vector system which permitted classification as accurately as the full 12-band system and from which even the original bands could be reconstructed to within 2% mean squared error. The effects of compression ratios other than 4:1 (obtained by choosing other numbers of eigenvectors) are shown in Fig. 4 (taken from Ref. 7).

The linear combination of the bands could easily be done onboard a satellite to reduce the transmission bandwidths. The question still to be answered by experiment is how often new correlation matrices and corresponding eigenvalues and eigenvectors must be changed for different applications.

Reduced resolution

Use of mixed highs

Another study of interest, also conducted at Purdue, was concerned with the evaluation of digital processing techniques for crop identification using spectral signature analysis.[8] Two methods of statistical analysis were used. One classified individual points into the various categories of crops or non-crops. An evaluation of this scheme was made on a point-by-point comparison with ground truth. The second procedure used fields rather than points as decision units. The results of the field analyses for 174 fields and two different analysis procedures gave an average of 69.8% correct classifications. The point-by-point method gave a correct classification average of 61.3%.

This result suggests that, if one could determine the field boundaries with a single high-resolution channel, then lower resolution data might be acceptable for identifying the contents of the fields by multispectral signature analysis. Such an experiment has been proposed using processed ERTS data to simulate the mixed resolution or "mixed-highs" data for application to agriculture, forestry, geology, and coastal zone oceanography.

As defined for color television systems, in a mixed-high system the high-frequency components of all spectral bands are added in some weighted fashion to form a luminance signal. Low resolution multispectral data is provided by several channels of lower frequency data corresponding to the narrow spectral bands. Similarly, one could consider a system where one spectral band is provided at high resolution and each of the others is at lower resolution. In either case, substantial reductions are made in data volumes. For example, a system with equal resolution of 50 metres in four bands produces three times the data volume as a mixed-highs system with one 50-m band and three 150-m bands.

Some preliminary simulations of mixed-highs data have been generated from ERTS-A data. Fig. 5 shows two different examples of mixed-highs simulations of New York City area pictures as compared with a full resolution picture. A very large, 6:1, difference was taken between the single high-resolution and two low-resolution bands. Nevertheless, Fig. 5b with the near IR band at high resoluiton shows all the water features essentially as well as the original (Fig. 5a); and Fig. 5c, with the red band at high resolution, gives very good fidelity for inland features.

Statistical estimates within a picture element

One additional technique is worth mentioning. A study has been conducted by the University of Michigan of methods of estimating the proportions of objects and materials included within a resolution cell of an airborne multispectral scanning device.[9] A major goal of this work is the extension of such techniques to spacecraft remote sensors.

The technique being investigated is based on a statistical model for signatures of mixtures of object classes of different types within a resolution cell. The estimation procedure determines the proportion of the different classes with the maximum likelihood of being correct. A series of test runs was made, using simulated data to determine the capabilities and limitations of the model and the estimation algorithms. The results for 250 simulated data points for one set of assumed actual proportions is shown in Table II. Although this result looks promising, it was found that some significant variations occured when different combinations were used. More experimenting is desirable to determine if certain combinations of signatures are acceptable while others produce unreliable results. If it can be determined, in advance, which combinations are reliable, then it appears likely that this scheme can be used in practice. With a large resolution cell, at least for some areas or spectral bands, some bandwidth reduction is possible.

Table II — Sample test results using 5 agricultural signatures.

Signature	*Bare soil*	*Sugar beets*	*Weeds*	*Alfalfa*	*Barley*
Specified proportions	0.20	0.20	0.20	0.20	0.20
Average estimated proportions	0.1933	0.1807	0.1968	0.2352	0.1939

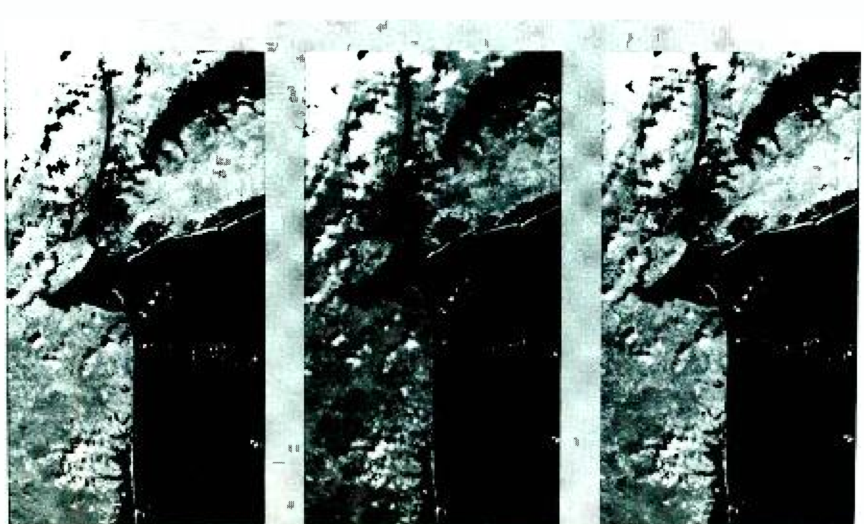

Fig. 5 — Comparison of mixed-highs simulations with a full resolution picture of the New York City area. From left to right, a) original high resolution photo, b) green and red reduced 1:6, c) green and near-IR reduced 1:6.

Conclusions

We have briefly surveyed some of the techniques by which the desires of users for more spatial and spectral detail might be satisfied while reducing, or at least minimizing the increase of data to be transmitted from an observation satellite. It would appear that each of these techniques show promise. However, substantial experimentation is needed, especially in conjunction with ground truth data and analysis techniques, to determine the usefulness of the extracted data for specific applications.

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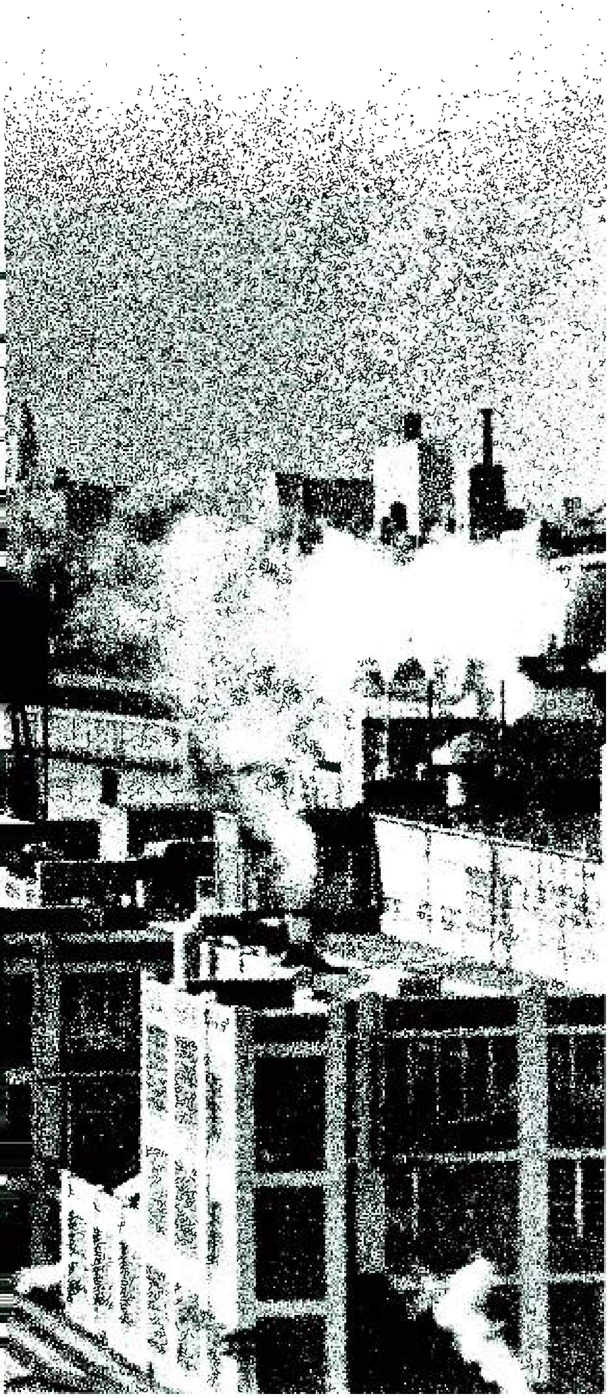
Some general information on air pollution

Dr. E. J. Fjarlie

A knowledge of pollution data is essential in understanding some of the problems associated with making measurements, establishing threshold limits, and determining specific techniques for air pollution monitoring. The author comments on these various aspects to help keep the air pollution problems in perspective.



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POLLUTION arises from energy conversion; accordingly the second law of Thermodynamics tells us that there will always be a pollution problem. But how much is tolerable or how can the pollutant be reconverted into a tolerable byproduct? What matters is the acceptable threshold level, if there is a threshold level (usually given in parts of pollutant per million or ppm), of the specific pollutant concentration. The following describes some of the air pollution problems, gives some currently acceptable tolerance levels, and discusses a few of the instruments used to make pollution measurements.

Pollution measurement

Most pollution measurements are atmospheric transmittance measurements at the selected wavelengths where the pollutant is detectable. Bouguer's law states that:

$$\tau = \exp(-\sigma_\lambda z)$$

where z is the distance over which the transmittance, τ, is measured and the extinction coefficient, σ_λ, may be divided

Glossary of chemical terms used in text

CO_2	Carbon dioxide
CO	Carbon monoxide
SO_2	Sulphur Dioxide
C_xH_y	Generalized hydrocarbon, *e.g.*, C_2H_6
NO_2	Nitrogen dioxide
Particulates	dust, dirt, or any solid matter
O_3	Ozone
H_2S	Hydrogen sulfide
N_xO_y	Generalized nitrate, *e.g.*, N_2O
NH_3	Ammonia
HCl	Hydrochloric acid
CH_4	Methane
NO	Nitric Oxide
O_2	Oxygen

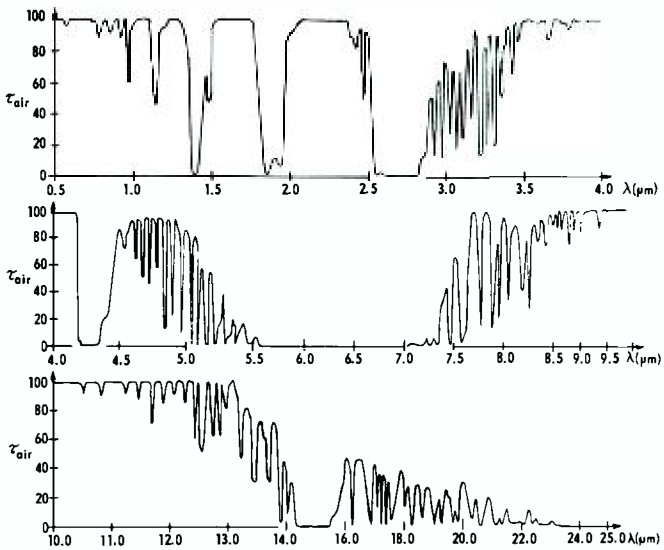

Fig. 1 — Transmittance of 305-mm horizontal air path at sea level containing 5.7-mm precipitable water at 26°C (RCA Electro-Optics Handbook, 1968, p.7-3).

Table I — Sources of pollution.[4] (Values shown are x 10^6 tons/yr.)

	Pollutant						
Source	*CO*	*SO_2*	*C_xH_y*	*N_xO_y*	*P**	*Other*	*%*
Transportation	66	1	12	6	1	<1	60
Industry	2	9	4	2	6	2	17
Electrical generation	1	12	<1	3	3	<1	14
Space heating	2	3	1	1	1	<1	6
Waste disposal	1	<1	1	<1	1	<1	3
% =	50	17	13	8	8	4	100%

*Particulates

into two parts:

$$\sigma_\lambda = a_\lambda + \beta_\lambda$$

a_λ being the absorption coefficient (for gases) and β_λ being the scattering coefficient (for particulates).[2] By using the concepts of scattering cross sections, the number concentrations can be obtained: $a_\lambda = N_a S_a$ and $\beta_\lambda = N_s S_s$. Here N_a and N_s are the number per cm^3 of absorbers and scatterers, respectively, and S_a and S_s are the cross sections. Gases are detected normally by a forward receiving process, and particulates are detected by forward or backward scattering. Other expressions are: $a_\lambda = pm_\lambda^{-1}$ and $\beta_\lambda = ac$, where p is the density in gm/cm^3; m_λ is the mass absorption coefficient, gm/cm^2; a is the Mie concentration function, (1/km ppm); and c is the concentration. It is Mie scattering theory rather that Rayleigh scattering or geometrical scattering which is used due to the typical size of the particulates, 1 to 50 μm diameter. In all cases it is τ which is measured by experiment, z which is known, and N_a, N_s, c, or p which is found when the other values are obtained from a table. The overall equation is:

$$P_{rcd} = E_{trans}\,(A_o/z^2)\;\tau\;\tau_o$$

where P_{rcd} is the received power, E_{trans} is the radiant intensity, A_o is the area of the collecting optics, and τ_o is the transmittance of the collecting optics. Thus: A_o, z, τ_o, and E_{trans} are known, P_{rcd} is measured, and τ is then obtained.

The atmosphere is not a simple transmission medium. The transmittance of 1000 feet of air at sea level is shown in Fig. 1. The spectral bandwidth is from a wavelength of 0.5 to 25 μm. The spectrum is riddled with detail; in fact, it is difficult to find a wavelength which is not affected by one or more of normal air's constituent gases.[3] Hence, the τ above really should be: $\tau = \tau' \tau_{air}$ where τ' is the value due to the contaminant being investigated. Normal air already contains trace amounts of the contaminant; thus, the absorption band or line chosen to monitor the pollution level must be weak at normal concentrations. Other parameters must be measured in order to find τ' correctly; these are relative humidity, temperature, pressure, and α_λ if β_λ is being measured, or β_λ if α_λ is being measured. The problem, as can be seen, is a complex one.

Pollution data

What are the sources of pollution? The general answer is shown in Table I,[4] where the tabulation is in terms of the most common pollutants and their general sources. The C_xH_y and N_xO_y molecules are, for example, CH_4, N_2O, NO, etc. Information is available for the specific sources within a given source list; for instance, exhaust emissions for furnaces by type are shown in Table II[5]. Any of the subject sources in Table I can be broken down into specific sources of pollution and, of course, on a local basis individual organizations may be identified.

Table II — Exhaust emissions from furnaces.[5] (values shown are lb/106 Btu)

Source	Pollutant						
	NH_3	*H_2S*	*HCl*	P*	*SO_2*	*C_xH_y*	*N_xO_y*
Gas furnace	0.1	0.1	0.1	0.1	0.1	0.3	0.5
Oil furnace	0.1	0.1	0.1	0.1	0.1	0.9	0.3
Coal furnace	0.2	0.2	0.2	7.7	1.6	1.9	0.4

*Particulates

The automobile is obviously the main source of pollution; the 2 × 10^8 vehicles on the road contribute a considerable portion of the CO, hydrocarbons, and nitrogen oxides. It is also obvious that the still great number of coal-fired electric generating plants are responsible for the SO_2 and particulates, and that industry is the other main source of SO_2 hydrocarbons, and particulates in the polluted air.

The limits established for health are threshold levels, see Table III,[6] but it must be kept in mind that a long-term exposure to a very low level has a different threshold than a very short exposure at peak levels—the two should not be linearly related; for example, the SO_2 annual mean is 0.03 ppm.

Ozone, O_3, results from a photochemical reaction between sunlight, CO, CO_2 and NO_2. It is a constiuent of Los Angeles-type smog, whereby the ozone concentration is a function of the amount of sun energy, $h\nu$, the air temperature, T, and the amount of the other molecules in the air

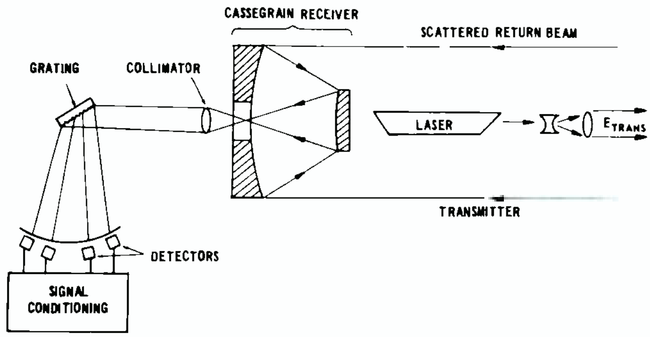

Fig. 2 — Raman scattering system.

Table III — Pollutant concentration limits established for health.[1,6,7]

Pollutant	*Threshold limit*
CO	10 ppm/day
SO_2	0.14 ppm/day, one day/year
C_xH_x	0.4 ppm over two hours
NO_2	0.05 ppm
Particulates	80 μgm/m^3
O_3	0.5 ppm
H_2S	10 ppm

which, in turn, depend on the widespread use of the gasoline-powered internal-combustion engine. The molecular reactions have varying rates and are not firmly established, but the results from the ozone presence in smog are readily noted.

To place the numbers in Table III[7] in perspective, consider the following: estimates indicate that New York taxi drivers are exposed to 200 ppm of CO during rush hour; pack-a-day smokers inhale 3 μgm per day of benzo-α-pyrene, a C_xH_y compound, while inhabitants of the megapolis areas receive 50 μgm per day of the same compound levels which roughly correspond to 0.001 ppm; ozone levels of 0.15 ppm cause eye irritation; and excess chest colds, pneumonia, and bronchitis in children are in evidence when SO_2 concentration exceeds 0.045 ppm. The odor threshold is 0.47 ppm for SO_2. Industrial ash and dust in North America account for 1.6×10^7 tons per year of contaminant compared with 3×10^7 tons for natural dust and 0.3 tons per year for pollen. It is amazing that millions of people recognize a strong allergy source in pollen, but save for small groups, for example, silicosis sufferers, they have put out of their minds any health hazard due to the other particulates. Note that the nose can detect H_2S at a level of 0.00047 ppm. There is controversy over all threshold limits and how the thresholds should be established; for instance, per day, per year, or total accumulation.

Specific measurement techniques

To measure the pollutant concentration, many techniques are used. A few are listed below, including a brief summary of the methods involved. The first two techniques are mainly for particulate concentration.

1) Grey scale chart comparison—The grey scale measurement involves holding a screen at arms length[8] and comparing the effective color of the smoke stack effluent with the estimated color of the screen. By experience, it has been found that color is a reasonable guide to use in measuring particulate concentration. This Ringelmann chart has been available since the 1880's, the measurement chart costs about 10 cents, and the relative accuracy is in orders of magnitude only.

2) LIDAR technique—The LIDAR (light detection and ranging) technique[9] includes the transmitting of a light pulse[10] and the receiving of the backscattered signal according to the equation

$$P_{rcd} = E_{trans}\,(A_o/z^2)\;\tau_o\;\tau^2\;(\gamma\beta L/4\pi)$$

where τ^2 is present since the pulse goes out and returns, γ is a geometry factor due to the overlap of the transmitter and receiver, L is the length of the pulse ($L = cT/2$, where T is the half width in seconds), and β is the backscatter coefficient which depends on the concentration. To achieve good accuracy in ppm, a laser source is mandatory, for the spatial coherence yields a high-power density and thus, a good signal-to-noise-ratio, S/N. However, there is concern throughout the industry about the safety limits for routing measurement purposes. The LIDAR units have been available since 1965 and the equipment costs about $5000.

3) Sampling and analysis—Sampling involves going to the area, taking a sample, returning to the laboratory, and analysing the sample by some standard technique such as absorption spectroscopy, chromatography, mass spectroscopy, or reaction chemistry. The accuracy is adequate; most of the processes have been available for 50 years; and the cost, assuming the equipment already is setup for other testing on a routine basis, should be about $75 a measurement. The basic instrumentation cost can be $20,000 or more.

4) Absorption by the gaseous pollutant—This technique could involve an *in situ* measurement with a standard light source, spectrograph, detector, and electronics or might involve an integrated measurement for an entire area by means of one known source and several receivers previously calibrated for the pollutant being investigated. The source could be the same type in both cases, or it could be the sun. This absorption measurement might also use a laser source. The appearance in 1971 of the PbSnTe tuneable laser holds promise for pollution measurements. The S/N in general can be as good as for any other technique, and the extra advantage is the instantaneous readout. These systems are costly, $20,000 would be a reasonable figure to use, and servicing on a regular basis is mandatory due to the constant exposure to the elements.

5) Correlation spectroscopy—There are several techniques for correlation spectroscopy when the features investigated are weak. These include Benedictine slits,[11] Goody's gas correlator,[12] or Hadamard spectrometry.[13] The measurement consists of designing the spectrometer for detecting a given absorption molecular band. Highly accurate data can be obtained, but the instrumentation is very expensive. Microwave correlation spectroscopy[20] has also been proposed for these measurements which can be much safer than a laser system. Accuracies for correlation spectroscopy are very high, but the instrumentation is dedicated to the measurement of one molecule only and the initial cost can be $50,000 together with regular servicing costs added.

6) Raman scattering — There are two ways to use the Raman effect as a pollution monitor. The direct Raman effect[14] will measure any given pollutant with a laser source, see Fig. 2, but only for short ranges since the shifted lines are weak. The indirect Raman effect[15] gets scattering from the oxygen and nitrogen in the air and the resultant lines become sources to measure the presence of the pollutant in absorption. Here the range can be very great, but only an integrated measurement may be made. In both cases, the basic source may be frequency doubled or tripled to enter another spectral range for other pollutants. These techniques require high laser power which demands close design to control eye safety. These Raman systems eliminate the basic absorption process requirement of having a source emission at the specific absorption wavelength under surveillance. The accuracies for the Raman effect are dependent on power levels used and the cost of a complete station may be $100,000 to achieve a good S/N over long ranges.

All the measurement schemes except the grey scale chart require a high degree of technology to implement; accordingly, the labor charges will be very high. In addition, all of the techniques are affected by meteorological conditions, the $\tau' \tau_{air}$ factor mentioned earlier. When rain, fog, or snow occur, τ_{air} can drop by as much as 17 dB/km which may render all the techniques inoperative except the sampling one. There is a need for new techniques which are less costly and new ideas which bring about detection of 1 part in 10^9 to allow for the industrial processes[1] requiring a cleaner environment control.

Comments

Pollution affects all of us, yet we seem to act as if the atmosphere were an infinite sink able to take up any amount of pollution without change. Organizations still are saying that there is no real difficulty since all that has to be done is to disperse the pollutant and there will be no problem. It is inconceivable that this type of thinking is still tolerated. There are presently two opposing points of view causing a controversy between atmospheric physicists: Whether the CO and C_xH_y and the other pollutants will react at a fast enough rate to produce CO_2 so that the overall CO_2 concentration, which is increasing yearly, will accelerate the greenhouse effect for the upper atmosphere causing the earth's temperature to steadily increase, thereby melting the polar ice caps and flooding the earth[16]; or whether the particulate concentration will increase at a faster rate to increase the scattering in the upper atmosphere to have the earth's temperature decrease, resulting in another ice age![17] There is also speculation that high-flying supersonic and regular jet aircraft will generate so many condensation nuclei that the present 30% cloud cover of the earth will steadily increase to 100% by the year 2000.[18] The cooling process starts when the cover increases to 36%. In addition, these same aircraft are affecting O_3 concentrations which, in turn, determine the amount of ultraviolet radiation received at the earth's surface. There is no controversy about whether pollution is harmful or not—the health problem continues.

It is useful to recall Loschmidt's number, 2.7×10^{19} molecules cm^{-3}, which is the number concentration of a gram molecular weight of a gas at standard temperature and pressure. Cold air at sea level has approximately this concentration. Tolerance levels are normally given as so many parts of pollutant per million, ppm, or per ten million parts of air; thus, pollutant concentrations which may be harmful are of the order of 10^{13} to 10^{14} molecules or particles per cubic centimeter. These are a lot of particles in terms of absolute numbers even though the relative concentrations are only about 1 in 10^6.

Technology is now at the stage where "clean rooms" are increasingly necessary to carry out industrial operations. Low-level electronic circuitry and minute mechanical motions are in widespread use; currents of picoamperes and tolerances of 500Å are common. Already many industrial processes demand pollution levels or contaminant concentrations substantially less[1] than the thresholds required for human safety.

Europe has had pollution problems for a much longer period than North America. The efforts at decreasing the pollution levels there, which have been hailed as highly successful, have generally lowered concentrations to about a factor of 10 higher than the worst cases in North America. Hence one has to be very careful about where he is and what the problem is when discussing threshold levels.

An individual who believes he is escaping the pollution problem by moving away or moving upward is practicing self-delusion. The high-rise dweller lives on an upper floor to escape the CO emissions from automobiles, but he then receives over 20 times the particulates[9] that the street dweller gets because of the air-mass layering characteristics around cities. In addition, his air conditioner is increasing the overall temperature of the city by 3 to 5° giving more problems to the entire population. One who moves to the suburbs is only delaying the day when excess pollution concentrations reach him, and his daily commuting increases that level markedly.

Solving the air pollution problem is a matter of enforcing the laws on an international scale. The existing technology will allow measurements to be made of sufficient accuracy to determine if the threshold levels are being exceeded, but there may be some sources of pollution whicl cannot economically be eliminated. It is a question for society to determine if those sources should be allowed to continue in operation. Still not enough is known to fix threshold limits, but it is possible to enforce the limits that do exist if all will insist on it. In fixing limits, society has to be careful to take into account the absolute numbers; that is, the lowering of the limits by a factor of two today can be offset by the increase in the number of polluters tomorrow to bring the total environment pollution levels to a greater value than ever before. It is also necessary to be aware that the emissions from one source may combine with the emissions from another source to produce a new molecule which is undesireable and which neither source has produced by itself. Not enough is known about minor constituents in the atmosphere, they may act as catalysts in a three-body collision or reaction. Some pollutants are toxic, some react with body elements to give damaging changes, some are harmless in small doses, and some are steadily stored to give a cumulative effect. Economics rules the rate at which the pollution problem is attacked, but economics are not going to do any good if irreversible changes have started. The recent Stockholm Conference[19] was a first attempt to get concerted action.

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A microwave correlation spectrometer for air pollution monitoring

Dr. A.K. Ghosh | Dr. H.J. Moody

A new instrument for air pollution monitoring based on microwave correlation spectroscopy has several definite advantages over the wet-chemical methods widely used today. Such an instrument can reach a sensitivity of as low as 1 in 10^9 with unique specificity.

An IMPORTANT ASPECT of effective air pollution control is the monitoring of the pollutant concentrations in ambient air and emission from the polluting sources. The majority of the monitoring instruments presently available and widely used are based on wet-chemical methods. However, these instruments have serious limitations with regard to specificity, sensitivity, and speed of response. Hochheiser *et al.*[1] of the Environmental Protection Agency, in reviewing the current state of the art of air pollution monitoring, point out "solid state sensors having sensitivity, specificity, and reliability are urgently needed; such sensors would overcome many of the current problems with wet-chemical methods. Furthermore, new techniques will be needed as air pollution control efforts are expanded to encompass less abundant and newly recognized air pollutants." Efforts are therefore being made to develop new instrumentations based on gas chromatography,[2] chemiluminescence,[3] and optical techniques.[4] A significant development in the area of optical technique is the Barringer correlation spectrometer[5] which utilizes the principle of correlation spectroscopy. Various techniques[6,7] based on the application of lasers (*e.g.* absorption, flourescence, Raman spectroscopy) are also being investigated.

A recent promising and powerful technique[8] is the use of microwave spectroscopy for pollution monitoring. This paper reports on a new air pollution monitoring instrument based on the principle of correlation technique adapted to microwave spectroscopy. It is shown that an instrument based on such technique can reach a sensitivity as low as 1 in 10^9 (1ppb) with unique specificity of the gas to be monitored.

Microwave spectroscopy for pollutant analysis

The microwave spectroscopy generally applies to the absorption spectra of polar gases at low pressure in the frequency range of 8 to 40 GHz. A look at the microwave molecular spectra table[9] shows that commonly recognized pollutants such as SO_2, NO_2, NH_3, O_3, some hydrocarbons, etc., have absorption spectra in the K-band (18-26.5 GHz) with characteristic band structures. Because all the molecules have significantly different structural configurations, their rotational spectra offer a distinct fingerprint of their existance in a mixture. About 90% of the common gaseous pollutants of present interest have dipole moments, hence microwave absorption spectra, and most of them have been observed and cataloged. Furthermore, the presence of particulate matter interferes with optical spec-

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troscopic analysis of gaseous pollutants near the visible region, while on the other hand they are invisible to microwave radiation because their diameters are so much smaller than the wavelength. Microwave techniques should therefore be ideal for detecting gaseaous pollutants in the midst of particulates, as in the smoke emitted by a smoke stack. However, conventional microwave spectrographs rely on very high resolution of a single line for quantitative measurement which tend to broaden by the pressure broadening effect resulting in the uncertainty of identifying the species. At present, conventional microwave spectroscopic technique can only be used to detect pollutant down to 1 ppm. However, adapting correlation principle using the characterisitc absorption bandstructure to microwave spectroscopy may immensely improve the sensitivity down to 1 ppb with unique specificity.

Microwave correlation spectroscopy

The principle of correlation spectroscopy[10] is based on the fact that the cross-correlation between spectra of different gases is very small, even if the lines overlap. Therefore, when the absorption spectra of a sample of gas mixture is cross-correlated with the spectra from a specimen of the wanted gas, the correlation depends only on the presence of the wanted gas and can be interpreted in terms of the amount of that gas in the mixture. The technique[5] has been used successfully with multiple slits at optical frequencies. The adoption of this principle at microwave frequencies can be explained with the basic configuration shown in Fig. 1. The source is a swept frequency oscillator which sweeps over a band of frequencies to cover one or a number of lines of any one gas. Part of the signal passes through the gas sample at reduced pressure in the absorption cell. Another part passes through a cell containing only the gas to be measured and also at reduced pressure. Two additional signal paths are used to cancel out the large steady-state component and leave only the change due to the absorption in the gas. The two signals are then fed into a balance mixer which is essentially a magic-tee with two matched square-law detectors to obtain the cross-correlation component between the absorptions in the standard and unknown cells due to the desired gas.

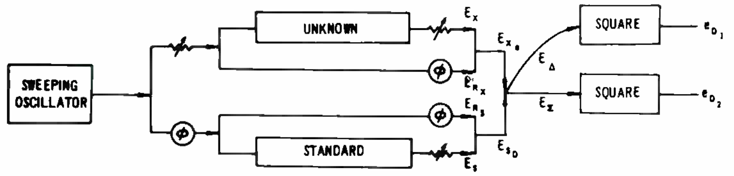

Fig. 1 — Basic cross-correlation spectrometer.

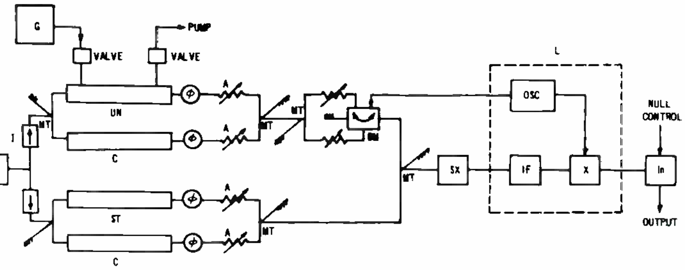

Fig. 2 — Real-time cross-correlation spectrometer.

S	Swept oscillator	In	Integrator
I	Isolator	OSC	Oscillator
MT	Magic Tee	I	PARJB5 lock-in amplifier
ϕ	Phase shifter	UN	Unknown cell
A	Attenuator	ST	Standard cell
BM	Bi-phase modulator	C	Cancellation line
SX	Square-Law detector	G	Gas handling and calibration system
IF	IF amplifier		
X	Detector		

The cross-correlation component may be derived as follows. Assume the spectrometer (Fig. 1) is adjusted with no gas so that E_X and E_{RX} and E_{RS} and E_S are all equal in amplitude and have opposite phase. When gas cells are inserted E_X and E_S will be different due to absorption.

Then:

$$E_{XO} = [E_{RX} - E_{RX}\exp(-\alpha_X L)]/2^{1/2} \quad (1)$$

$$E_{SO} = [E_{RS} - E_{RS}\exp(-\alpha_S L)]\ 2^{1/2} \quad (2)$$

where α_X and α_S are the attenuation constants and include concentration of the gas, and L is the length of the cell. The outputs E_δ and E_σ of the hybrid are:

$$E_\delta = \tfrac{1}{2}[E_{RX} - E_{RS} - E_{RX}\exp(-\alpha_X L) - E_{RS}\exp(-\alpha_S L)]\cos\omega t \quad (3)$$

$$E_\sigma = \tfrac{1}{2}[E_{RX} + E_{RS} - E_{RX}\exp(-\alpha_X L) + E_{RS}\exp(-\alpha_S L)]\cos\omega t \quad (4)$$

where the time variation has been explicitly entered. For small absorption $\exp(-\alpha L) = 1 - \alpha L$, then

$$E_\delta = \tfrac{1}{2}[E_{RX}\,\alpha_X L - E_{RS}\,\alpha_S L]\cos\omega t \quad (5)$$

$$E_\sigma = \tfrac{1}{2}[E_{RX}\,\alpha_X L + E_{RS}\,\alpha_S L]\cos\omega t \quad (6)$$

On squaring and subtracting

$$e_{d(1)} - e_{d(2)} = E_\sigma^2 - E_\delta^2 = \tfrac{1}{2}(1 + \cos 2\omega t)\,E_{RS}E_{RX}\,\alpha_S\alpha_X L^2 \text{ and higher order terms} \quad (7)$$

The term $E_{RS}E_{RX}\ \alpha_S\alpha_X L^2$ is the cross-correlation term depending on α_S and α_X and only appearing if both α_S and α_X are different from zero.

A practical real-time microwave correlation spectrometer

The basic configuration (Fig. 1), although it illustrates the principle of correlation technique, is not practical. Several modifications are necessary to ensure better stability and sensitivity. Two obvious modifications are the following:

1) With the basic configuration shown in Fig. 1, there is a critical problem of matching the two square-law devices. These crystals must be closely matched over wide dynamic range and frequency band. The only way to avoid the problem is by using a single square-law device and time share it between the two signals.
2) The S/N can be improved by making the detection process fully coherent.

Incorporation of these two modifications results in a spectrometer shown in Fig. 2. The spectrometer includes a modulation process which allows fully coherent detection to be carried out. The modulation consists of biphase modulation between 0° to 180° which causes the signal at the output of the magic-tee to alternate between sum and difference signal. In this way, only one square-law device and one amplifier are required, thereby eliminating the problem of matching two square-law devices.

The following calculation demonstrates that the configuration of Fig. 2 produces the cross-correlation component and cancels out unwanted signals.

As before

$$E_{XO} = E_{RX}\,[1-\exp(-\alpha_X L)]\cos\omega t/2^{1/2} \qquad (8)$$

$$E_{SO} = E_{RS}\,[1-\exp(\alpha_S L)]\cos\omega t/2^{1/2} \qquad (9)$$

Let the modulating function be $m(t) = \pm 1$ for biphase modulation. Then

$$E_{XO}' = m(t)E_{RX}\,[1-\exp(-\alpha_S L)]\cos\omega t/2^{1/2}$$

Using the difference port of the magic-tee and approximating $\exp(-\alpha L) = 1-\alpha L$ then

$$E_\delta = (E_i/2)(\alpha_S L + m(t)\alpha_X L)\cos\omega t$$
$$E_i = E_{RX} = E_{RS} \qquad (10)$$

$$E_\delta^2 = (E_i^2/8)(1+\cos\omega t)\,(\alpha_S^2 L^2 + m^2(t)\alpha_X^2 L^2 + 2m(t)\,\alpha_S\alpha_X L^2) \qquad (11)$$

Since $m^2(t) = +1$, the second term remains unchanged; however, the last term containing $m(t)$ alternates between positive and negative with the modulation. Thus the following amplifier sees an approximately square wave signal varying at the modulation frequency with a peak-to-peak amplitude of

$$e_{pp} = (E_i^2/2)\,(\alpha_S\,\alpha_X L^2) \qquad (12)$$

Thus, the configuration of Fig. 2 gives the proper cross-correlation term while using a single receiving channel and providing fully coherent detection.

Estimate of sensitivity

The constants E_{RS} and E_{RX} are adjusted, by means of the various pads, to be equal. The oscillator power of about 10mW is divided four ways, giving 2.5 mW in each branch. The factor ½ E_i, being the power in one branch, it thus equal to 2.5 mW. From Kistiuk and Townes,[9] a strong absorption coefficient is greater than 10^{-5}/cm for 1 mm pressure and 100% concentration. For the unknown this must be reduced by the concentration, while for the standard, 100% concentration will be used. The following parameters are assumed:

Oscillator power:	10 mW
Detector noise figure:	10 dB
Post detection bandwidth: (10s integration time)	0.1 Hz
Standard concentration:	100%
Absorption coefficient:	10^{-5} cm
Cell length:	100 cm
Cell pressure:	1 mm

To estimate the sensitivity, it is necessary to consider the mode of operation. It is assumed that the frequency is swept over a band in which are situated a number of lines of the standard gas. As the frequency is scanned over the band, noise power is received continuously but the signal is only received during the intervals when the frequency is within one of the linewidths of the standard gas. Thus there is a reduction in signal strength by $n\Delta f/\Delta F$ where n is the number of lines in the scanned frequency band ΔF and Δf is the full line width of each line. For SO_2 in the interval 23 to 25.5 GHz, there are six strong lines each with an estimated line width of 50 MHz. Furthermore α is the product of the concentration (ϵ) times the absorption coefficient for 100% concentration. Since the standard is 100% concentration than $\alpha_X = \epsilon\alpha_S$. Thus converting peak-to-peak to demodulated signal, the cross-correlation signal becomes

$$e_d = (2^{1/2}/\pi)(n\Delta f/\Delta F)(E_i/2)\epsilon\alpha_S^2 L^2$$
$$= 0.135 \times 10^{-6}\,\epsilon\ \text{mW}$$

The noise equivalent power received under the same conditions is

$$NEP = -204 - 10 + 10$$
$$= -204\text{dBW} = -174\text{dBm}$$
$$= 0.4 \times 10^{-17}\ \text{mW}$$

Thus, a concentration in the unknown air sample of three parts in 10^{11} of the standard gas should give a signal just equal to that expected from the thermal noise power. It seems evident that thermal noise power of the receiver will present no design problem and that the ultimate sensitivity will be determined by imperfect balance and instabilities.

A further improved system may be considered by correlating the signal from the unknown cell with pre-recorded standards. The recording medium may be multitrack magnetic tape or disc. By using a frequency synthesizer with a code recorded on a separate track on the tape or disc, synchronizing in frequency between the recorded standard and the actual measurement is assured.

Advantages of microwave correlation spectroscopic technique

Several definite advantages of microwave correlation spectroscopic technique include:

1) Excellent sensitivity range — Sensitivity as low as 1 ppb may be measured.
2) Excellent specificity — Because of the uniqueness of absorption spectral characteristic of a particular gas and high resolution possible, the microwave spectroscopic technique has excellent specificity. A recent study[11] indicates some molecules can be identified in a mixture with greater than 95% certainty by measuring only one absorption line. Few pollution monitoring techniques can offer such high specificity for more than a single gas. Incorporation of correlation technique further improves the specificity.
3) Quantitativeness of the measurement — Another very important property of microwave spectroscopy is the quantitative content of the signal. Hence, a microwave spectrometer can be calibrated directly to give the concentration of the absorption species.
4) Very small quantitites of the sample are needed — For detection, 10^{-12} moles of the gas is sufficient. This is important where continuous detection of trace gases in a flow are desirable.
5) The speed of response is good.
6) Several pollutants can be monitored using the same instrument. Thus a correlation spectrometer in K-band (18-26.5 GHz) can be used to monitor SO_2, NO_2, O_3, NH_3, CH_3CHO, isobutane, propane, propene, etc. The instrument using the pre-recording technique offers the possibility of monitoring several of these gases simultaneously.
7) The instrument can be designed so as to make the operation routine with data output in machine-readable format.
8) The pressure broadening effect which might be a limitation for conventional microwave spectroscopy is reduced in correlation technique in which one does not rely on very high resolution of a single line but on a band structure. That way some overlapping may be tolerated.

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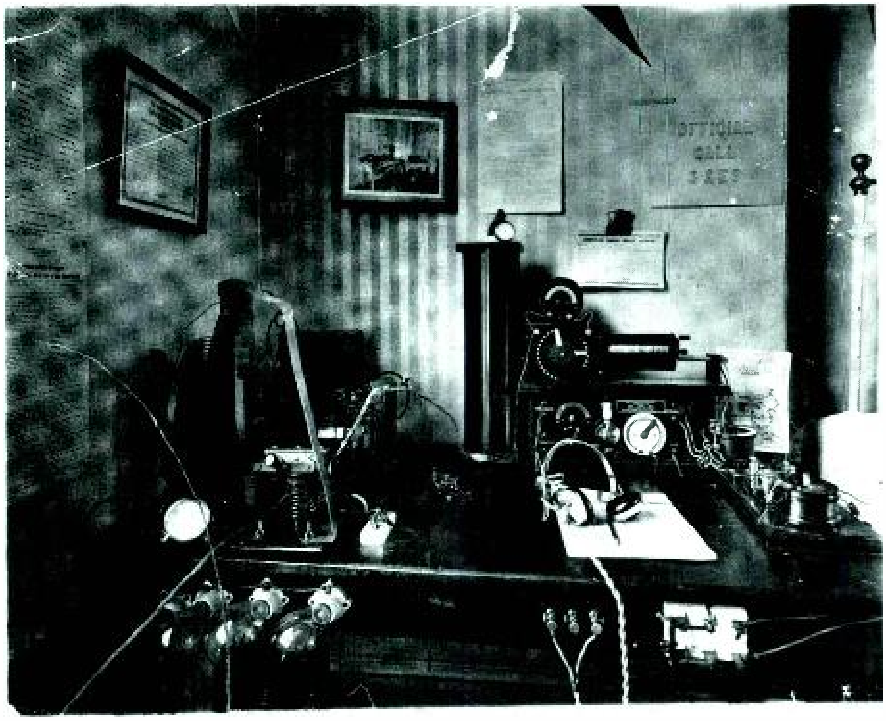

Typical early amateur radio station. (*circa* 1916).

The impact of radio on modern technology and industry

Dr. G. H. Brown

Editors' Note: **This paper by Dr. George H. Brown was presented on the occasion of the Marconi Centenary—American Association for the Advancement of Science, San Francisco, California on February 25, 1974. In describing the impact of Guglielmo Marconi on modern technology and industry, Dr. Brown begins with descriptions of early wireless radio, touches upon early antenna designs, mentions early point-to-point communicaitons, and cites such organizations as Marconi's Wireless Telegraph Company, RCA Communications and National Broadcasting Company. The close relationships between Senatore Marconi and the amateur radio operators (many of them also radio engineers) stimulated the formation and progress of the Institute of Radio Engineers (now IEEE)—and encouraged such pioneer inventors as Dr. Brown and Dr. Beverage whose patents contributed to early radio, antenna, and broadcast transmitter designs. RCA ENGINEER readers will recognize the names of other distinguished inventors such as Edwin H. Armstrong, pioneer of frequency-modulation methods. Also noteworthy is the mention throughout this paper of RCA employees such as: John Cowden, Assistant Traffic Superindentent, RCA Globcom; H.E. Hallborg, veteran engineer, RCA Globcom; George H. Clark, RCA's Historian (and former president of the Veteran Wireless Operators Association, VWOA); and finally General David Sarnoff (a life member of VWOA) who guided RCA Corporation to its leadership position in Electronics.**

Dr. George H. Brown, formerly Executive Vice President, Patents and Licensing of RCA received the BSEE in 1930, the MSEE in 1931, the PhD in 1933 and the Professional EE degree in 1942, all from the University of Wisconsin. In May, 1962, Dr. Brown was honored by the University of Wisconsin with a Distinguished Service Citation for leadership in industry and engineering. In 1933, Dr. Brown joined RCA Manufacturing Company in Camden. In 1942, he transferred to the newly formed RCA Laboratories at Princeton. It was during his career at Camden that he developed the Turnstile antenna which has become the standard broadcast antenna for television. During world War II, Dr. Brown was responsible for important advances in antenna development for military systems, and for the development of RF heating techniques. He and his associates also developed a method for speeding the production of penicillin. From 1948 to 1957, Dr. Brown played a leading part in the direction of RCA's research and development of color and UHF TV systems. In 1952, he was appointed Director of the Systems Research Laboratory. In 1957, he was appointed Chief Engineer of the Commercial Electronic Products Division at Camden, and six months later was named Chief Engineer, Industrial Electronic Products. In 1959 he was appointed Vice President, Engineering, of RCA. He became Vice President, Research and Engineering, in November 1961, and and was named Executive Vice President, Research and Engineering in June, 1965. Dr. Brown has received numerous awards and citations for his pioneering work in research, design, and development and for his work in the community. Dr. Brown is a Fellow of the IEEE, the Royal Television Society, and the AAAS; a member of Sigma XI, The Franklin Institute, and the National Academy of Engineering. A prolific inventor, Dr. Brown holds 80 U.S. patents. He is a Registered Professional Engineer of the State of New Jersey and the author of numerous articles appearing in scientific journals since 1932.

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All photos are by courtesy of
The American Radio Relay League, Inc.

FOR MANY CENTURIES, those who set forth across unknown seas and continents, from the Vikings to Columbus, the explorers of the North American hinterland and the polar regions, Marco Polo and David Livingstone, did so on their own. Anxious friends and supporters bade them farewell and waited months or years, aware that they might have perished through some mishap that would never come to light. Prior to this century, utter isolation enshrouded a ship once it had lost sight of land. Disaster could strike with no one on shore or in nearby vessels being any wiser.

Then Marconi changed it all. Now ships at sea and jet aircraft over the North Pole are in continuous communication with the rest of the world and are safely guided by radio beacons. When Apollo XI left on its flight to the moon on July 16, 1969, almost the whole world watched the memorable start and, through television, rode all the way the with astronauts.

In undertaking the formidable task of describing the impact of Guglielmo Marconi on modern technology and industry, I was led to reflect on a few of my own experiences for only a little over a year ago I addressed an audience at the Royal Institution from, I was so assured, the same podium used by Senatore Marconi when he gave his first of many lectures at the Royal Institution on February 2, 1900.

Early wireless

I was bitten by the wireless bug when I was twelve years old. I had read all that the local library could provide concerning the adventures of a mythical person known as Marconi. My crystal detector was the result of a five-mile bicycle ride from Portage, Wisconsin, to a cluster of houses in a settlement named Galena. Here products of a lead mine were being loaded into railroad gondolas. I returned home with a brown paper bag filled with hundreds of shiny nuggets, one or two of which allowed me to receive code signals from some now forgotten amateur station.

Marconi's birthplace

My interest in Marconi's life and career persisted until finally, five years ago, my wife and I visited Bologna. As a first step, I walked past the Marescalchi Palace on Via IV Novembre where Marconi was born. Then we proceeded to the Villa Grifone which was his boyhood home and where he conducted his first experiments. While we were viewing the mausoleum at the foot of the hill near the road, a caretaker informed our taxi driver that the house was undergoing repairs and visitors were not permitted to enter. The taxi driver did not know what to do with this information since he was no more able to speak English than was the caretaker. When I addressed the caretaker in her own language, she beamed at us and suggested that we drive to the top of the hill to visit the house and take coffee with her. This we did and we found the house being completely refurbished, with a large meeting room being prepared for technical conferences and a laboratory being re-established on the top floor. It is a magnificent building with high ceilings, marble floors and huge fireplaces. The fields around, on a high plateau, fade off in the distance to a series of rolling hills, affording an excellent location for radio-propagation experiments.
A marble commemorative tablet on the front wall of the house, facing the village of Pontecchio, is inscribed:

> Onore al merito di Guglielmo Marconi il quale in questa casa facendo le prime prove ancora giovanetto col suo ingegno e collo studio invento il telegrafo senza filo nell'anno 1895 ammirato dall'Italia e dall'Europa.

That is to say, "Honor to the achievement of the young man who, making the first tests in this house and inventing wireless telegraphy in 1895, is admired by Italy and Europe."

Early radio patents

I have read a copy of Marconi's original and basic British Patent 12,039 which issued on July 2, 1897, exactly thirteen months after the original application. At that early date, the inventor showed an oscillation producer mounted in the focal line of a cylindrical parabolic reflector and a receiving device similarly placed.
Then came the famous British Patent No. 7,777, granted on April 13, 1901. It soon became known as the "four-circuit" tuning patent, with two circuits at the transmitter and two at the receiver, which overcame the weak spot in wireless transmission by allowing more than one station to send messages at the same time. These two patents, together with a few other supporting patents put Marconi's Wireless Telegraph Company, Ltd., in the forefront of the infant industry which was destined to grow almost beyond comprehension. The company continued under this name until 1963 and is now known as The Marconi Company, Ltd.
Marconi's Wireless Telegraph Company developed many associated and subsidiary companies, including the American Marconi Company, Ltd. , which became RCA Communications, Inc., in 1919 and is now known as RCA Global Communications, Inc.

From its very beginning, Marconi's Wireless Telegraph Company devoted large sums to research and development to make it one of the most prestigious engineering companies in the world. It became known for the quality and quantity of radio transmitters, for broadcast and for point-to-point service, as well as for receiving stations for a variety of services. It was Marconi which provided the basic equipment for the first regularly scheduled television station in the world at Alexandra Palace in 1936.

Prelude to radar

At a joint meeting of the Institute of Radio Engineers and the American Institute of Electrical Engineers in New York on June 20, 1922, Signore Marconi made the following revealing statements:

> "As was first shown by Hertz, electric waves can be completely reflected by conducting bodies. In some of my tests I have noticed the effects of reflection and deflection of these waves by metallic objects miles away.
>
> "It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beam of these rays in any desired direction, which rays, if coming across a metallic object such as another steamer or ship, would be reflected back to a receiver screened from the local transmitter on the sending ship and thereby immediately reveal the presence and bearing of the other ship in fog or thick weather.
>
> "One further great advantage of such an arrangement would be that it would be able to give warning of the presence and bearing of ships, even should these ships be unprovided with any kind of radio."

These thoughts were but a prelude to the development of radar in which the Marconi Company played a leading role during the war in the production of airborne and ground radars, countermeasure devices and direction-finding devices. Radar and its associated systems now provide navigational aids to ships at sea, together with collision-avoidance devices, weather observations and navigational aids for aircraft over the whole world. The applications of the principles of radar are now being actively investigated to bring safety on our highways.

Radio vacuum tubes

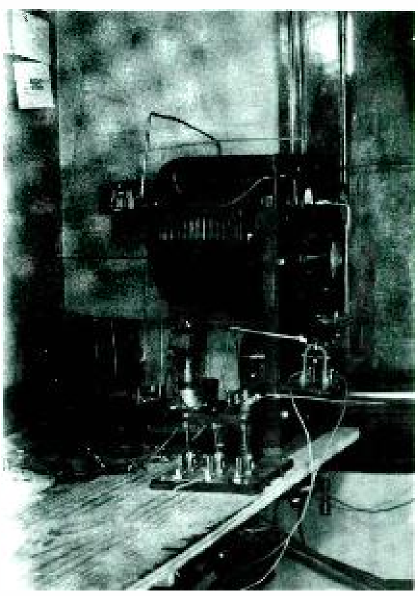
The research and development of radio devices soon began to take us into realms which were seemingly unrelated to the problems of radio. Vacuum-tube development of course was spurred by the obvious needs of the radio industry as well as the telephone business, in short, by the need to communicate. Electronic data processing was made possible by research on vacuum tubes and magnetic materials as well as by the invention of transistors and integrated circuits. With sales of electronic data processing equipment in the United States growing from \$1.2 billion in 1963 to \$11.5 billion in 1973, some sort of growth record is being made. Total sales of electronic equipment in the United States were said to be $18 billion in 1963 and $33 billion in 1973.

Early television

In the fall of 1927, again at a meeting of the Institute of Radio Engineers in New York City, Senatore Marconi predicted that the use of short waves would be necessary to bring about practical television broadcasting. How correct he was in his assessment, for now all television broadcasting in the United States is carried out on wavelenghs between one and six meters.

In his lecture at the Royal Institution on December 2, 1932, he referred to the possibility of using microwave channels for television purposes. At the present time, a large number of television stations commonly use microwave relays to carry the television programs from the studio to the transmitter and microwave relays carry television programs across the entire country. In addition, microwave signals carry television programs between continents by means of orbiting satellites.

Because of my personal involvement with television broadcasting, it is to me the most dramatic of the many consequences of Marconi's invention of wireless telegraphy. The industry has grown to an extent which exceeded by far the prognostications of its most imaginative prophets. Since the inception of black-and-white broadcasting on a commercial scale in 1946, over ninety-five million black-and-white television receivers have been scrapped.



Radio equipment — 1920's vintage.

Color television in the "fifties"

The prophets had even more trouble with color television. The Federal Communications Commission adopted standards for color-television broadcasting late in December, 1953. Many of us who had participated in the development of the systems and had helped to formulate the standards believed that public would clamor for color-television receivers immediately. Yet in 1959, six years after standards were adopted for color-television broadcasting in the United States, only a few hundred thousand color-television receivers were in use in the entire country.

We kept a stiff upper lip as we said "Color is coming along wonderfully." The reasons for the small number of sets in use were many and complex. Some companies which had endorsed the standards in 1953 still failed to offer color sets for sale, some motivated perhaps by black-and-white sets in inventory, some perhaps in a sincere belief that color was not yet ready. Except for programs of the National Broadcasting Company, there was not much color broadcasting. But at least, standards had been agreed upon completely so that if at any moment the fickle public decided that color television was the thing dearest to its heart, the industry could meet the demand without waiting for a decision on standardization.

Then a few years later, something happened. I do not think the change could be attributed to any one factor. There were a few more programs in color, receiver prices came down a few dollars, a couple of small companies announced that they had now perfected color television, which in turn frightened some of the reluctant larger companies into announcing that they, too, had perfected color television. And these very announcements induced people to start buying the RCA sets that had been available for them for many years.

Soon all the major companies were offering color-television receivers. This started the ball rolling, with a good deal of healthy competition between receiver manufacturers, between color picture-tube manufacturers, and between engineering designers. Fortunately, the industry did not have to wait for standards to be set. The standards had been established for years, everyone knew what the rules were, and the industry could move immediately to the task in hand.

Color tv receivers by the millions

By January 1, 1964, there were 1.4 million color-television sets in use in the United States. Then a pattern was established. In 1964, the industry sold 1.4 million additional color-television receivers, just as many as had been sold in all the previous history of color television. So we marched up to January 1, 1965, with 2.8 million sets in use.

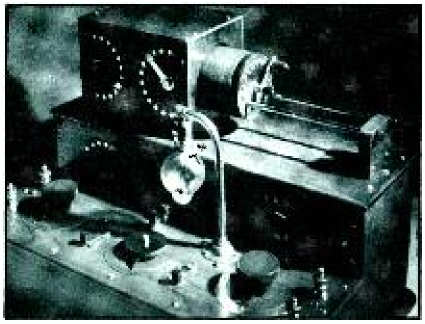
In 1965, the industry sold 2.7 million sets, so we could say "This is getting to be a habit." There were now 5.5 million sets in use as of January 1, 1966. They were probably not all turned on at the same time but they were there.

The pattern persisted. Another 5.5 million sets were sold in 1966, so there were 11 million sets in use by the end of the year. Each year, we had followed the pattern — that the number sold in the year equalled all the sets sold previously. There was something wrong with regarding this pattern as immutable, since it was hardly imaginable that it could keep going from 11 million to 22 million to 44 million to 88 million — it would be ridiculous. We knew that the rule had to fail sometime. After all, if one thinks about the beginning when there were zero sets in use, one could double every year and yet never have a single set in the public domain.

The results have, however, been very gratifying. Color-television receiver sales in 1963, in the United States alone, amounted to 200 million dollars, rising to 2.6 billion dollars in 1973, with over 50 million sets in use at the end of 1973.

Amateur radio activities

I should now like to turn to another area influenced by Marconi, the realm of amateur radio. Wireless fired the imaginations of many who were not professionals but who could, by hard work and experimentation, communicate with each other and share a common adventure. The Senatore was always sympathetic to radio amateurs and interested in their experiments. So great was the spread of enthusiasm among amateur radio operators that the American Radio Relay League was founded in 1914. The



Early radio set-up (1920's)

radio amateurs shared with Marconi an interest and a conviction that short waves would bring exciting new results. While Marconi, together with his professional colleagues, was exploring the vagaries of transmission in the shortwave region, the American Radio Relay League decided to sponsor a trans-atlantic test of transmission on wavelengths of the order of 200 meters, short waves for that day. Paul Forman Godley was selected to undertake the mission. He was probably the foremost receiving expert in America at the time and was the designer of the famous Paragon receiver.

Many years ago, Paul Godley told me of this adventure. He departed from New York on the Aquitania on November15, 1921, carrying two receivers, one a regenerative set with two stages of audio amplification and the other a ten-tube superheterodyne set built especially for the tests. He told me that when he boarded the Aquitania, he had not yet settled in his mind as to the type of receiving antenna to be used. Sailing on the Aquitania was Harold H. Beverage, who at that time was a research engineer in charge of communication receiver development for RCA Communications, Inc. Beverage had just completed his researches on a system of wave antennas for which he was later awarded the Morris Liebmann Memorial Prize of the Institute of Radio Engineers. Naturally, Beverage and Godley talked a great deal about their mutual interests.

On December 8, 1921, at Ardrossan, Scotland, near the Firth of Clyde, Paul Godley used the superheterodyne receiver and a Beverage wave antenna to receive more than thirty American amateur stations on a wavelength in the neighborhood of 200 meters. This feat, together with other contributions to the radio art, was recognized by the Veteran Wireless Operators Association by awarding him, in 1947, the Marconi Memorial Gold Medal.

The human side of Marconi

I take you now to July 24, 1937, four days after the death of Senatore Marconi. I was occupied in the task of installing a directional antenna system for Radio Station WSMB in New Orleans. I was sitting beside a road many miles from tlhe transmitter, with a receiver equipped for measuring the strength of the radio signal and a pair of headphones. Suddenly I heard an announcement of a program to be broadcast — The Human Side of Marconi — followed by the voices of a number of my friends and professional associates, among them Paul Godley and Harold Beverage. This summer, after I had received an invitation to deliver this lecture, I wrote to Paul Godley and to Harold Beverage to learn further details concerning this very moving and dramatic broadcast. To my surprise and gratification, Dr. Beverage supplied me with a recording of the 1937 broadcast, which I should like to share with you. The program was broadcast on the Red Network of the National Broadcasting Company and the announcer was Gene Hamilton. Mr. Hamilton adequately identifies the five participants.

A Transcript of "The Human Side of Marconi—Broadcast on July 24, 1937.

Announcer: Guglielmo Marconi - during the past few days several programs have been broadcast in memory of this great man, one of the greatest inventors of all times. In this program this evening, men who knew Senatore Marconi intimately and who worked with and for him will give us some little-known incidents in the life of the inventor which show him to us not so much as a great genius but as a great and warm-hearted human being.

For the beginning of our story, let us go back to the beginning of Marconi's experiment. Let us listen to a reproduction of the electrical sounds which first proved to the young inventor that success was to be his. (sound effects) Three buzzes and a distant pistol shot which announced success of the first wireless message ever sent in the world and its acknowledgment. That message was sent by the hand of young Guglielmo Marconi from his crude boyish apparatus set up on his father's farm in Bologna, Italy, in 1895. Marconi was but a lad of twenty-one at the time and was trying out his new invention from one building to another on the estate. The sound you hear, like that produced on that historic day in 1895, was the striking of a trembler on Marconi's detector, which was a glass tube filled with filings, known as a coherer. His father's gardener was at the receiver waiting for the signal. Three short dots from Marconi's hand at the key. The message was in code. The three dots meant "If you hear the trembler make three buzzes, fire a shot from your revolver." Now the distant shot you heard a moment ago was a replica of this acknowledgment of the first wireless message.

Marchese Guglielmo Marconi, Senator of Italy, President of the Royal Academy of Italy and of the Italian National Council of Research, intimate friend of rulers, of the highest church dignitaries, of executives and engineers in all countries, is no more. Cut off from his labors while he was in the midst of his latest and perhaps his most sensational experimentation in the field of ultra short waves, he leaves behind a new tool in the hands of mankind — radio. Rarely has there been a more fitting tribute to any inventor than that the art he created should serve to glorify his passing.

Of his greatness, of his great friends, the world has heard much during the past days, but there is another, an intensely human side, to Marconi which was hidden from all but a very few of his intimate friends. Of this human side of his nature, of his associations with the fellowmen, with his fellow workers, this program will tell you a little.

Wireless was first introduced to this country by Mr. Marconi who came here with a set of instruments in 1899 to report the International Yacht Race. His eagerness to get his apparatus set up was balked by the formalities of the Customs Office, and after Marconi had climbed up and down the steep steps of the Customs House a half dozen times, he said with a weary smile, "When does the next boat leave for Liverpool? This is too much of a rush for me." But eventually he got his trunks released and the races were reported with great success. Marconi was his own operator, although a poor one, and while sending a message with the letter "J" he had to look up the telegraphic characters on a card. "Why wasn't he named Robert," he said with a chuckle, "instead of John?"

After the races, a group of reporters and yachtsmen met in the saloon of the Yacht Ponce used as a transmitting booth and spent an hour or two in comradeship with Senatore Marconi, as he was then known in America. Marconi, the report runs, sat at the piano and played for an hour, running the range between popular songs of the day and light opera. He was voted by those gathered around as a prince of a good fellow.

After the races, Mr. Marconi directed the formation of the Marconi Wireless Telegraph Company of America, which continued in operation until 1919 when it became the Radio Corporation of America. There are few left of the little band who formed the personnel of that first American wireless concern. The oldest operator living who served in those days is John Cowden, now Assistant Traffic Superintendent for RCA Communications, one of the RCA family. He will speak briefly on the wireless of those early days.

Mr. Crowder: The first wireless station built under Mr. Marconi's direction for the newly-formed American Marconi Company was at Babylon, Long Island. It was a mere shack and was used chiefly for experimental work. Years later it was abandoned and everyone forgot all about it, but in 1931, Edward H. Armstrong, of superheterodyne fame, rediscovered it in use as a paint shop and presented it to RCA. It now stands near a high-power station at Port Jefferson, Long Island, and during the forthcoming World's Fair in New York, it will be completely fitted up with replicas of the original transmitter and receiver used in 1901 and exhibited at the Fair as part of the RCA exhibit as a memorial to Senatore Marconi.

Announcer: Marconi was a hard worker and he required long hours and patient attention to duty from his subordinates, but at the same time he so fired them with zeal reflected from his own tireless efforts that they were an especially loyal group. A typical story of his thoughtfulness for his co-workers will be told by H. E. Hallborg, veteran engineer with RCA Communications.

Mr. Hallborg: In 1912 I was one of a group of American Marconi Engineers sent to England to study the huge Marconi transmitter there, preparatory to installing duplicates in our American high-power station. Day after day while we were in the transatlantic station at Clifden, Ireland, we would see Mr. Marconi come to the station with mysterious packages under his arm. Sometimes these would prove to be a new form of spark gap or a jigger for receiving and the next step would be to try his device out in practice.

One cold rainy night Mr. Marconi came in quite unexpectedly, having walked several miles from the railway station, but carrying the usual package — this time unusually large. Everyone eagerly watched the unwrapping, but it was not a condenser this time or a new magnetic detector, but instead a dozen phonograph records. "I thought you young men from the States might be rather lonely out here," said Mr. Marconi rather shyly, "so I brought you some graphophone records." So saying, he placed the first one on the machine and we homesick Americans thrilled to the strains of "Everybody's Doing It Now."

Announcer: Throughout all the adulation that was heaped upon Senatore Marconi, the honors he received, the incredibly swift growth of the new art of which he was the father, he never lost his sense of humbleness, his heart was always with the young struggler after knowledge — the amateur. He who was amateur number one never got out of touch with those later youthful enthusiasts in the field of radio. One of America's best known early amateurs, Paul Godley, will tell of this from his personal experience.

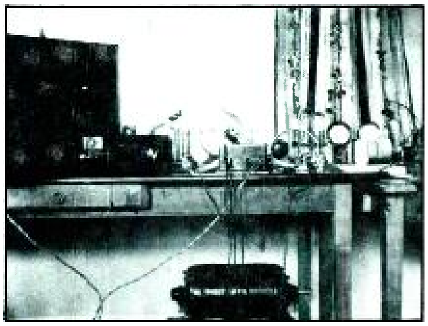
Mr. Godley: In the late fall of 1921, the American Radio Relay League sent me to the British Isles to attempt to receive for the first time the short-wave signals from American amateurs. We were highly successful. Some thirty American amateur stations were clearly received.

While in London I attended a meeting of the Wireless Society of London, and afterwards there was a dinner in honor of the transatlantic test. Of course, I was present. I met Mr. Marconi there and we had a long talk about American amateur activity. He said "I am never so happy as when talking with young men so eagerly working on wireless communications, testing, just as I did. I have never lost touch with that side of my work and never shall." Some years later he again voiced the same opinion when he was the guest of honor at a Century of Progess in Chicago. Two days had been designated as Marconi days and at the close of the program — it was eleven o'clock at night — everyone was tired, but not Marconi. He asked to be taken down to the Palace of Transportation to visit the amateur station there, which had been set up for communication work. When the boys saw their visitor, they were astonished, operating schedules were forgotten and he was shown an entire exhibit. Marconi was intensely interested and asked many questions. As he was about to leave, he noticed a partly built transmitter and said "That is certainly a fine piece of work." "But Mr. Marconi," said the lad, "it can't be very good for I am only an amateur." That may be so," replied the Senatore, "but remember I too am only an amateur."

Announcer: The Institute of Radio Engineers not only owes its existence to the art which Mr. Marconi founded, but also was honored from time to time with scientific contributions from him. One of these was delivered in person in 1920 when Senatore Marconi was the recipient of the Medal of Honor of the Institute. This lecture given before a joint meeting of the Institute of Radio Engineers and the American Institute of Electrical Engineers was on the then new subject of shortwave communications. Mr. Harold Beverage, President of the Institute of Radio Engineers and chief research engineer for RCA Communications, will tell us of Mr. Marconi's reactions toward the institute and America.

Mr. Beverage: In this lecture, Mr. Marconi demonstrated a beam transmitter on a turntable and showed how with waves almost as short as one meter the transmitter could be turned towards the receiver to give a signal or turned a few degrees off in which case nothing would be heard. This lecture was a history-making one in radio circles, and Mr. Marconi was asked why he gave it first to America instead of to London or Rome. "Because I feel under a deep sense of obligation to America," he replied. "When I was unknown in 1901, I was received enthusiastically by American scientists and they tendered me a most unexpected banquet when I received the first signals across the Atlantic. So, today I am giving to America and its two great electrical societies, the first information and the first demonstration of my new beam apparatus."

Announcer: Marconi was the first man to send a wireless message in the world and that caused him to be enrolled during his life as Veteran Number One of the Marconi Pioneers, an organization of England and the Continent. He also sent the first wireless message in America, which qualified him for membership in the Veteran Wireless Operators Association, a group of old-time radio operators and engineers, of which he was honorary president. Mr. George H. Clark, RCA's Historian, former President of the VWOA, and a close friend of Mr. Marconi, will give some instances of Marconi's feelings toward that organization and also other reminiscences of the great inventor.



Equipment used for first short-wave amateur communication across the Atlantic.

Mr. Clark: Although Mr. Marconi was a very busy man, yet he always found time to send a long message of greeting to our annual gathering of old-time radio men of the VWOA, and the message was always warm and real. In December 1931 on the Thirtieth Anniversary of his first wireless conquest of the Atlantic, the VWOA presented him with a special gold medal. He replied, "I am deeply touched at having been conferred such a generous token of appreciation by the Veteran Wireless Operators Association, the component members of which are particularly close to me. I wish to assure you that your valuable gift will be treasured among the most cherished awards I have ever received."

There is a monument in Battery Park, New York City, overlooking the sea, which is dedicated to the memory of wireless operators who have given their lives to saving others. This monument is under the care of the VWOA and from its fund Mr. William McGonigle, President of that organization today, has pledged a donation of one hundred dollars as a first subscription toward a larger, more worthy monument to Marconi. RCA has become second on this list of donors by direction of its president, Mr. Sarnoff, a life member of our Association. What form this monument will take, where it will be located, remains for the future to tell, but without doubt it too will face the sea that Marconi loved.

Announcer: Thank you, Mr. Clark. In this brief program dedicated to the memory of Senatore Guglielmo Marconi, inventor and patriot, friend of the high and of the lowly, we brought you first-hand reminiscences of men who knew and worked with the great inventor and now as we bring the program to a close, let us listen respectfully to the mingling signals of messages from many ships, calling to mind the sea which Senatore Marconi loved so well and on which he spent so many years of his life and to whose mastery he first applied his great discovery of wireless telegraphy. (Sound effects)

This was a Red Network program of the National Broadcasting Company, RCA Building, Radio City.

An evaluation of a resistor composition for the TACTEC® hand-held portable radio

R.W. Grant

Precision resistors (within 1% stability) are critically important to some electronic circuits of mobile communications equipment. The RCA Meadow Lands TACTEC® hand-held portable radio uses thick film resistor compositions in its microelectronic circuits. In this radio, a number of resistors must hold within 1% stability to meet the Federal Communications Commission frequency control requirements. An evaluation conducted by Advanced Development Engineering in Meadow Lands shows that the trim accuracy and stability within 1% can be obtained on the necessary resistor compositions through laser trimming, module assembly, environmental, and reliability stresses. The data from this evaluation is presented as the percent drift for various conditions for four compositions from one vendor (Vendor A) and comparisons are made with two other compositions from a second vendor (Vendor B).

THE major engineering and manufacturing effort for the past several years in the new product area at Meadow Lands has been the design, development, and production of the advanced performance TACTEC® hand-held portable radio (see Fig. 1). Its main advantages of size, power, performance, and reliability can be traced to the partitioning of a number of electronic functions into hybridized microelectronic modules (see Fig. 2). These modules utilize two microelectronic technologies (*i.e.*, hybrid) — beam lead silicon integrated cirucits and thick film substrates — to make thirteen hybrid modules. Fundamentally important to the thick film technology is the capability to produce a wide range of precision resistor values. Typically, resistors with 1% tolerance must be obtained and must be stable after trimming and stressing through module manufacturing processes. The TACTEC radio contains only six 1% resistors but five of them are in the critical temperature com-

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Russell W. Grant, Advanced Development Engineering, Mobile Communications Systems, Commercial Communications Systems Division, Meadow Lands, Pennsylvania, received the BS from Bates College in 1963 and the MA in Organic Chemistry from Boston University in 1968. Between 1967 and 1971, he was involved in microelectronics process development, including the application of photoresist and etch techniques to silicon wafers and thick and thin film materials. He also developed processes and design rules for thick film microelectronic circuits including multilayer, solder, and fine line screening techniques. In 1971 Mr. Grant joined RCA Meadow Lands Manufacturing Engineerin to assist in the training, facilitation, and process development for thick film microelectronics in engineering and then in production. In 1973, he transferred to Advanced Development Engineering and is now investigating advanced materials and processes for hybrid circuit production. He has published previously in the field of organic chemistry and is a member of the American Chemical Society and the Volunteers for International Technical Assistance.

Fig. 1 — TACTEC® hand-held portable radio with microphone.

pensated crystal oscillator (TCXO) trimmed substrate (see Fig. 3).

This study's general parameters are outlined as follows, showing the precise area of concentration.

Resistor compositions:	Vendor A (5 comp.) Vendor B (2 comp.)
Types of trim:	Vernier "L" Double plunge
Resistor sizes:	1.0. 1.5. 2.0. 4.0 squares
Sample categories:	Untrimmed. stressed Trimmed 60% inc. stressed Trimmed 100% inc. unstressed. Trimmed 100% inc. stressed
Test points:	Time increments after trim Process stresses Environmental stresses Reliability stresses

Selection of resistor composition vendor

The decision to use Vendor A's resistor composition for these precision resistors was based on the literature, preliminary tests, and opinions from laser trimmer manufacturers and technical people within RCA. All of the sources indicated that ±1% resistors could be made by laser trimming Vendor A's compositions. Preproduction TACTEC modules also helped demonstrate this capability.

Since none of these inputs had been rigorously documented, it was felt the Advanced Development Engineering Department should evaluate the series and perform such tests which would closely duplicate the existing production processes, environmental stresses, and reliability requirements. This evaluation would verify the resistors could be trimmed with the double plunge and vernier "L" trims, and show if any particular process or condition affected the drift. To trim the resistors, a Teradyne W311 Dynamic Laser Adjust System, as shown in Fig. 4, and a nine-resistor test pattern were used.

Test pattern design

The major interest of the evaluation was in confirming the precision and stability between the vernier "L" and double plunge trims for resistors greater-than-one square. The test pattern in Fig. 5 was used. It is comprised of four doubled resistors, R2 through R9. R1, a five-square resistor, was evaluated but is not included in this report. This test pattern allowed two different trims on each substrate, thus eliminating substrate to substrate variations. As noted above, the two types of trims selected were the double plunge and the vernier "L", also illustrated in Fig. 5. The double plunge trim consists of two consecutive plunge trims into the resistor. The first trims the resistor up 70% of the required amount. The second plunge, a reasonable distance (minimum of 0.010 inch) from the first, trims the resistor up the remaining 30% to obtain the programmed resistor value. The vernier "L" trim begins with a plunge then turns to trim parallel to the current path. The turning point varies with the number of squares (*e.g.*, a 13% increase of the required amount for a four-square resistor and a 60% increase for a one-square resistor). The foot of the "L" trims to 98% of the final value. Then the vernier which is a plunge trim in the shadow of the foot increases the resistor value to 100% above the original value. Thus the "L" plunge trims up 13 to 60%, the "L" foot trims to 98%, and the vernier to 100%. To obtain clean trims the linear energy density was adjusted to 2.65 joules per centimeter, the repetition rate was 3.0 kHz, and the trim speed was 0.962 centimeter per second.

The design of the test pattern was simplified by selecting nine resistors of greater-than-one aspect ratio. The determination of the size of the resistors is calculated from eq. 1.

$$\text{Number of squares} = L/W \qquad (1)$$

where W equals the width (inches) and L equals the length (inches). Since the selected standard resistor width, W, is 0.030 in., eq. 1 rearranges to $L =$ number of squares $\times$ 0.030, and the length of a 1.5-square resistor is 0.045 in.

Selection of trims and stresses

A trimmed resistor evaluation could have been overwhelming if it had not been limited to these two trims and to several resistors above one square. Table I shows generally when the different types of trims are used to trim resistors between 0.2 and 5 squares and 0.030 inch wide. The particular choice is dependent on the required stability and the area of the resistor. The shaded area shows the limited trims and configurations evaluated in this study. There are, of course, other types of trims which have particular advantages in thick film hybrid circuits, but are not included in this table.

Essential to the determination of the stability of resistors for hybrid circuits are the stress and the anticipated environmental conditions which each trimmed substrate will receive through assembly and under which the TACTEC radio is expected to continuously perform. The process steps and stresses to which each trimmed substrate is subjected is given in Table II. The last column of the table shows the simulated stress that the trimmed substrates received in this study.

The environmental and reliability simulated stresses (which cause failures in resistor systems) were selected from Electronics Industry Association (EIA) standards and recognized sources. These are listed in Table III with the requirements for mobile communications equipment. The substrates were subjected to these simulated stresses after the process simulated stresses.

The last stress, long-term stability, will not be concluded until December, 1974. These stresses, coupled with suitable control substrates, give an accurate demonstration of the stability of resistor compositions under our trim, processing, and environmental conditions.

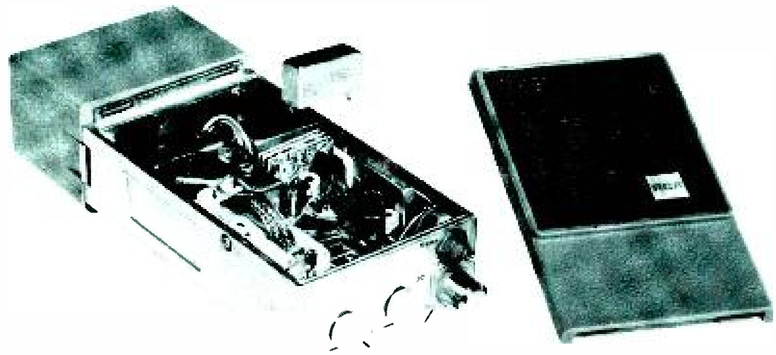

Fig. 2 — TACTEC radio with cover removed, showing three hybrid modules (below the metal shielding can).

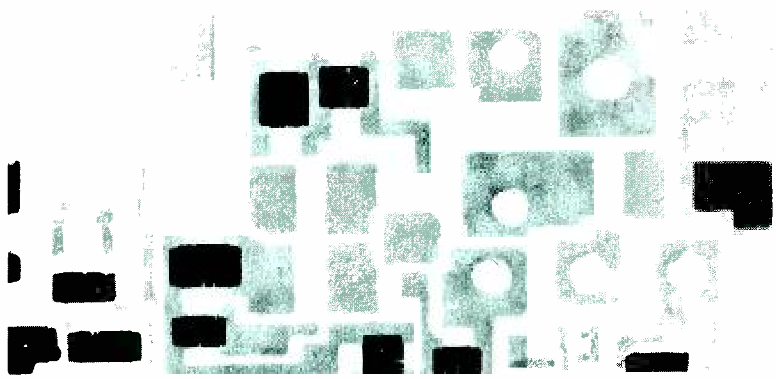

Fig. 3 — Temperature-compensated crystal oscillator (TCXO) trimmed substrate.

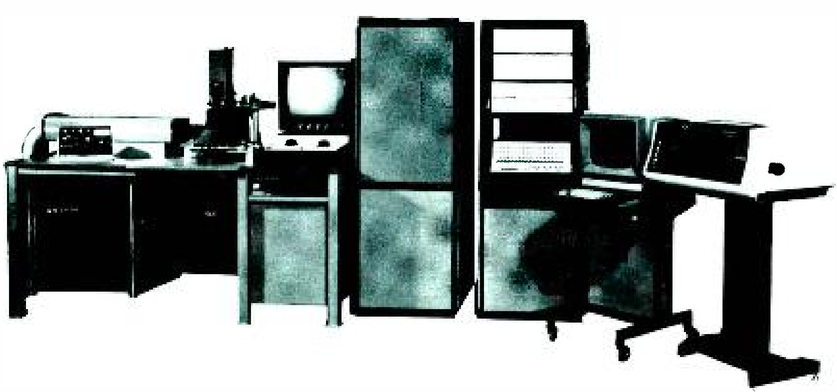

Fig. 4 — Teradyne W311 Dynamic Laser Adjust system. (Photo courtesy of Teradyne, Inc.)

Experimental and trim controls

However, to obtain a more accurate idea of the drift of these resistor compositions, two experimental controls were included, and two compositions from another manufacturer (Vendor B) were evaluated to compare trim accuracy and drift stability.

The first control sample (ten substrates for each resistor composition) was untrimmed but stressed with the evaluation samples. The second control sample (also ten substrates each) was trimmed up to 100% but not stressed. The first evaluation sample (ten substrates) was trimmed to increase the initial median value by 60% and then stressed. The second evaluation sample (ten substrates) was increased 100% and stressed.

The trim distance, fixed by the percent change of resistance and the change of resistance with the distance trimmed across the width of the resistor, was not used as a trim criterion. Manufacturing trims to a value and not to a distance. In addition the untrimmed, unstressed resistor stability was determined and was found to be within 0.05% drift for a one-month period on all compositions.

Worst-case evaluation

At this point it should be emphasized that, within reasonable constraints, the stresses involved are worst-case conditions. The evaluated resistors are similar to the smallest TACTEC radio resistors. The trim distance from the termination was 10 mils, the minimum allowed. The doubling of the initial value is the maximum allowed. These resistors of greater-than-one aspect ratio and 0.030 inch wide left, in some cases, only 0.005 inch of material on the double plunge trim between the laser termination crater and resistor edge. The vernier "L" always left more than 10 mils. The resistors were 10 to 20% thicker than recommended by the manufacturer. The laser trimmer power, speed, and frequency have not been optimized for drift with our conditions. In Table II the simulated stresses are in excess of the process stresses. In Table III this also was the case. The modules, and thus resistors, are internal to the radio and should not experience a thermal shock condition or boiling water stress. Also, the 1000 hours at 85°C condition is a greater-than-normal stress on the radio. This study's conditions are believed to be a harsh and rigorous environment for the resistors when compared to their end use.

Some may question electrical load/life characteristics; but in portable hand-held equipment, the modules operated on less than 10 V. Vendor A's data shows that the 100,000-ohms-per-square composition, trimmed and stressed with 3750 V/in. (166 W/in.^{2}), drifts less than 0.1%. Therefore, voltage stress was not considered to be a necessary test in this study. The TACTEC resistors are conservatively designed with respect to power dissipation.

The methods of sample segregation, laser programing, the types of stresses and limits, and times of testing have biased the results, but because of the judicious selection of these parameters, the results may be directly applied to our production of hybrid circuits.

Discussion of results

The results of this study generally show that ±1% resistors are obtainable under these conditions. Graphs in Fig. 6 through 9 give the percent drift from the trimmed value for the four groups of substrates for the 1.0, 1.5, 2.0, and 4.0 square resistors. The median value for ten samples is valid for small sample sizes. These graphs demonstrate that positive drifts between 0.5 and 1.5% from the trimmed value can be expected.

Vendor A's 100-ohms-per-square resistor compositon

The 100-ohms-per-square composition is exceptional in this respect. Not only does Fig. 6 show excessive drifts for most groups (points which exceeded the graph limits are not included), the 60% trim and stressed sample drift is greater than the 100% trim. The 100% trim stressed drift is less than the unstressed drift. The untrimmed material drift is not as low as desired. Note that the values of the two points for the untrimmed, stressed sample should be identical since they are a pair of equal resistors on the same substrate. The greatest difference is, however, only 0.25%.

It is obvious that this size resistor, extent of trim, and types of trims cannot be used

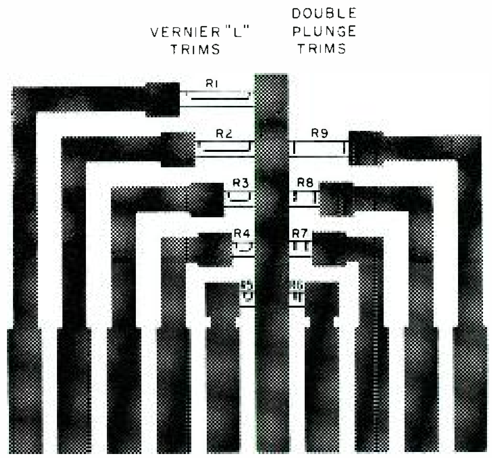

Fig. 5 — Representation of a trimmed test pattern.

Table I — Types of laser trims.

TYPE OF TRIM	CONFIGURATION	NUMBER OF SQUARES 5	4	2	1.5	1	0.75	0.5	0.25	0.2
SINGLE PLUNGE				X	X	X	X	X	X	X
"L"		X	X	X	X					
VERNIER "L"		X	X	X	X					
DOUBLE PLUNGE			X	X	X	X	X			
OPPOSITE DOUBLE PLUNGE		X	X	X	X	X	X			
SERPENTINE		X	X	X						

Table II — Process and simulated stresses.

Process steps	Process stresses	Simulated stresses
Beam lead bond	300°C, 30 seconds (one to four cycles)	300°C, one minute (five cycles)
Reflow	220°C, ten seconds	Omitted
Encapsulation cure	150°C, four hours	150°C, 16 hours
Conductive epoxy cure	140°C, one hour	
Identity (mark) cure	150°C, one hour	

Table III — Environmental and reliability stresses.

Environmental and Reliability Requirements		Simulated stress
Humidity	90-95%, 50°C, 8 hours	One hour in boiling water at pH 4.5
Thermal shock	Operating range: −30 to +60°C	Ten cycles from −40 to +85°C, air-to-air
High-temperature aging	None	One thousand hours at 85°C
Long-term stability	Maximum yearly retuning	One year after trim under ambient conditions

to trim this composition to ±1% tolerance. However, good stability was obtained on the two-and four-square resistors using the vernier "L" and trimming 100%. A 100% trim cannot always be guaranteed and about 13 mils of the resistor was left. A larger resistor (0.040×0.040 inch), fired closer to the target value, could produce 1% resistor with Vendor A's 100-ohms-per-square resistor composition.

Vendor A's 1000-ohms-per-square resistor composition

The 1000-ohms-per-square resistor composition in Fig. 7 shows greater accuracy and consistency. The material drift after stressing is less than 0.15% and both groups agree very closely. The 60% trimmed and stressed sample shows less than 0.5% drift, with the vernier "L" trim, slightly better than the double plunge. In the 100% trimmed but unstressed sample, the drift is 0.5% for the vernier "L", while the double plunge shows twice that drift. The double plunge leaves less resistor material than the vernier "L", which explains the additional drift. The 100% trimmed and stressed sample drift is similar to the unstressed sample. It is interesting to note that the one-square resistors drift more than the longer resistors. This may be explained by the crowding of the laser trims in the resistor area.

Vendor A's 10,000-ohms-per-square resistor composition

There was not a sufficient number of substrates with this composition to carry out all evaluations. Only the 100% trimmed and stressed samples were done. The drift characteristics will be covered in the comparison to Vendor B's resistor composition later.

Vendor A's 100,000-ohms-per-square resistor composition

The 100,000-ohms-per-square resistor composition begins to show the effects of the worst-case conditions. The resistor stability untrimmed but stressed in Fig. 8 is between 0.25 and 0.5% with close agreement for the different number of squares. All groups show the vernier "L" is significantly better than the double plunge. The vernier "L" shows 1% capability except on the one-square resistors, again due to trim crowding. An interesting effect appears in this and, to a lesser extent, in the other compositions. As the length of the resistors increases, and therefore the length of the foot of the "L"; the amount of drift decreases. The amount of resistor remaining is the same for the different number of squares. The data adds support to the theory[1] that the longer the foot of the "L", the more stable the resistor. Thus, the terminal laser crater is the principal source of drift rather than the edge of the trim parallel to the current path.

Vendor A's 1-megohm-per-square resistor composition

The 1-megohm-per-square composition demonstrates a different effect after laser trimming of the resistor with the vernier "L" trim. On several of the longer resistors (longer "L" foot) the value at 300 ns compares well to the other compositions data. At 3.6 s, the second measurement, the value decreased as shown in Fig. 9. It appears that the 1-megohm-per-square composition is thermally affected by the laser beam to give the programmed value which stopped the trimming prematurely. In several seconds, the resistor cools to read a value lower than the programmed value. Drift then occurs slowly upward after this time, similar to the other compositions. This effect is seen in Fig. 9 where the 60% and 100% drift curves for a five-square resistor is given. The former trim shows less thermal effect because it is not

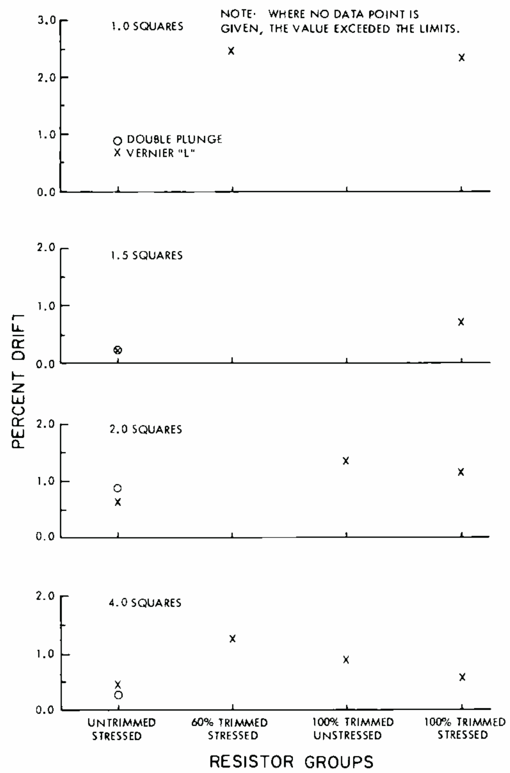

Fig. 6 — Percent drift from trimmed value for 100-ohms/square resistor composition.

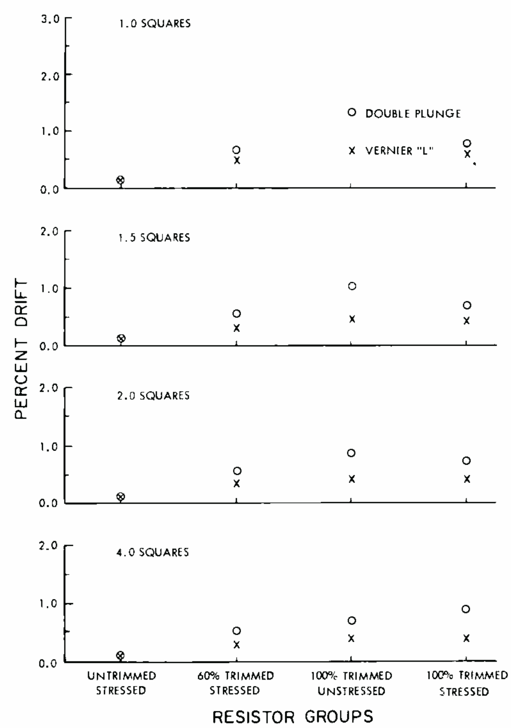

Fig. 7 — Percent drift from trimmed value for 1000-ohms/square resistor composition.

trimmed as far into the resistor. The double plunge trims do not strongly exhibit this effect because of the small amount of trim in the current path. The inversion of the 100% data points in Fig. 10 was caused by a programming error which limited the maximum drift value to 1.034%. The inversion of the 60% points are within experimental accuracy.

The drifts are quite low for the 1-megohm-per-square resistivity. The 60% trim apparently drifts more than the 100% trim. This is a small amount of the relaxation phenomena present in the 100% trim for both the double plunge and vernier "L". However, the material drifts only about 0.25% and the trim drift is only 0.5%.

In summary, Vendor A's resistor compositions demonstrate very good stability under harsh stress conditions. They have performed well under production trimming and assembly conditions, giving 80 to 90% trimmed yields with our most difficult substrate.

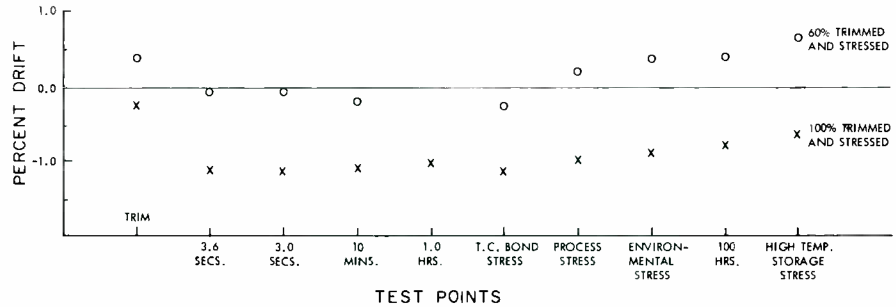

Fig. 9 — Percent drift versus test points (Vendor A resistor composition, five-square resistor).

Comparison of Vendor A and Vendor B

Figs. 11 and 12 present the data for Vendor A and Vendor B as comparative bar graphs. The percent change of resistance is given for the different number of squares and types of trim. Included here is the trim accuracy, which is the difference between the programmed resistor value and the first measured value after trim, and the stability, which is the total drift from the programmed value after stressing.

Fig. 11, for both of the 1000-ohms-per-square compositions, shows that the trim accuracy and stability are good. The trim accuracy for the vernier "L" is 0.1% or less, and for the double plunge 0.5%. The stability is also good even for the double plunge trim which shows about 1% drift or less. Vendor A's composition is only slightly favored in its trim accuracy and stability.

The 10,000-ohms-per-squre compositions in Fig. 12 are similar in trim accuracy. They are both slightly greater than the previous trim accuracy but nearly equivalent. The stability data, however, shows Vendor B's composition has excellent characteristics, but Vendor A's has considerable drift with the double plunge. This indicates that a one-square

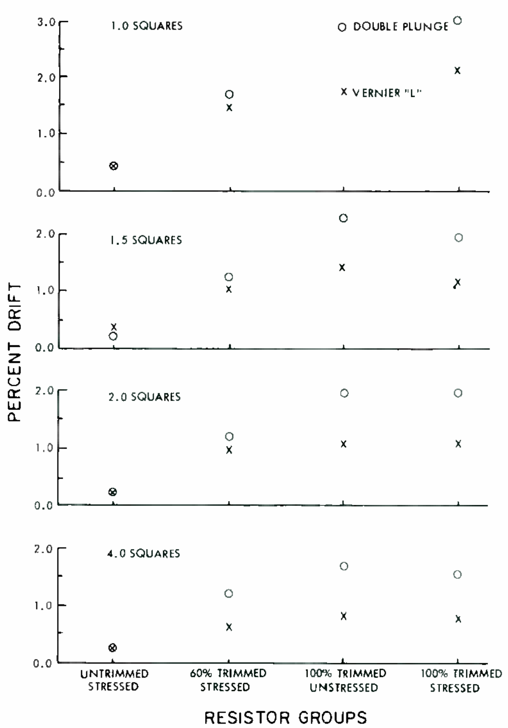

Fig. 8 — Percent drift from trimmed value for 100,000-ohms/square resistor composition.

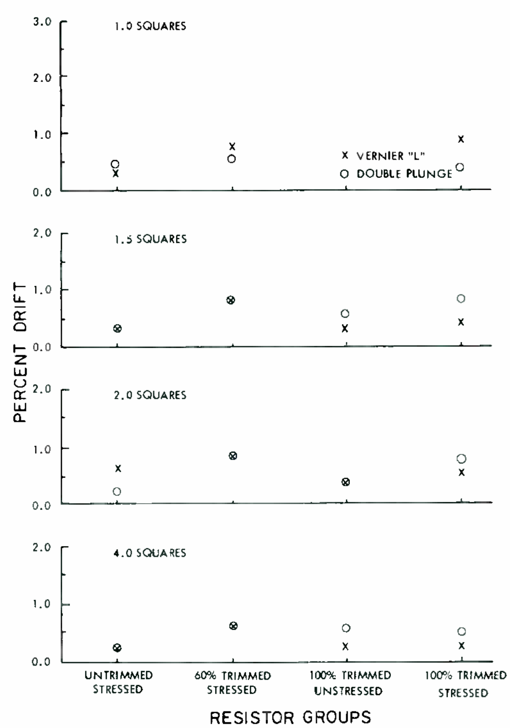

Fig. 10 — Percent drift from trimmed value for 1-megohm/square resistor composition.

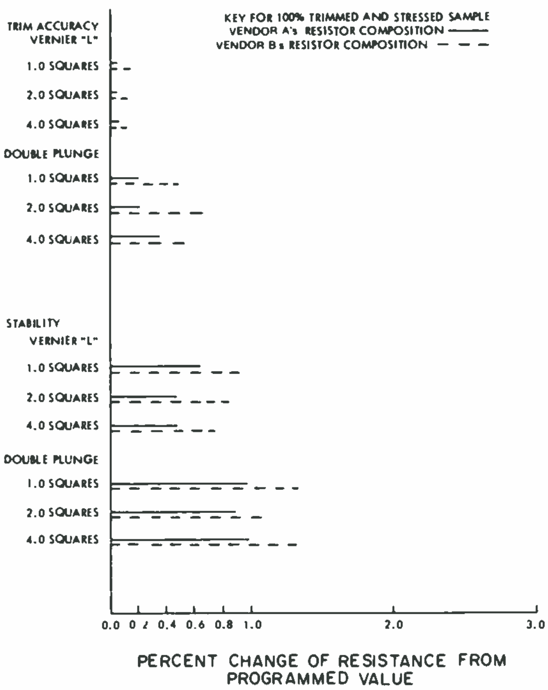

Fig. 11 — Comparison of 1000-ohms/square resistor composition.

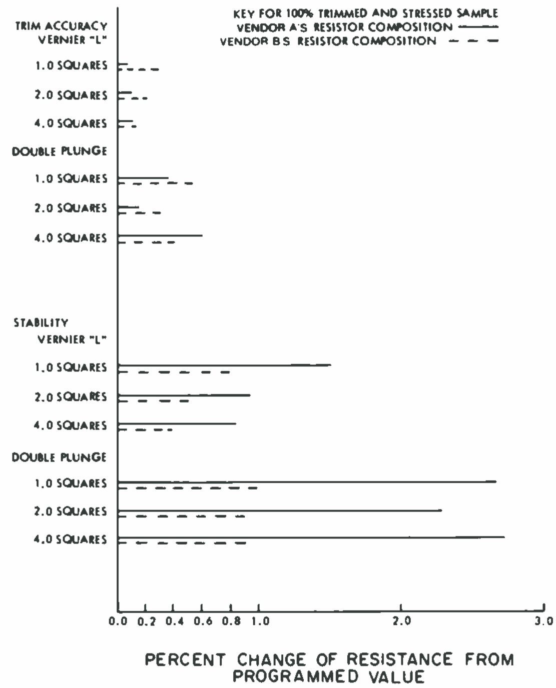

Fig. 12 — Comparison of 10,000-ohms/square resistor composition.

resistor with Vendor A's material should not be trimmed up 100% with a double plunge.

These two graphs in Figs. 11 and 12 show the consistent results of this study and again that ±1% resistors are within the capability of Vendor A's resistor compositions, RCA Meadow Lands equipment, and processes.

Trim anticipation

A reasonable question to ask at this point is: If these resistors drift 1% or more and a distribution exists around that value, how are ±1% tolerance resistors obtained? The ideal composition would trim to the exact resistor value and then would not drift. Few systems behave in this ideal manner. Instead, anticipation of the programmed value is necessary. If a drift after a certain stabilization period is 0.5%, then the trimmer is programmed to trim to −0.5%. At the end of the period, the resistor should be the exact value plus or minus the distribution. Alternately the resistors may be trimmed just above the lowest tolerance (including the distribution) since all drift is positive. Both of these methods allow some extraneous and life-time drift to occur and the resistor will stay within the required tolerance.

Nature of trim drift

As can be seen from Figs. 6 through 9, an interesting effect emerged. Looking at the 100% trimmed samples, trimmed and untrimmed, shows that they drifted the same amount within statistical accuracy. This implies that the resistor drift is less sensitive to these process and environmental stresses than to chronological drift. If this implication is correct, the drift is dependent on the time rather than discrete stresses. As shown in Fig. 10, after 3.6 seconds a gradual increase of drift occurs rather than significant jumps at each stress. Thus, one stress may be insufficient information to discuss the drift of a resistor system. Other data during this investigation show similar results. The significance of this effect is to emphasize the importance of continuous drift measurements with time rather than isolated stress measurements. This effect needs to be confirmed through further study, accelerated aging tests, and more rigorous statistical analysis.

Future work

The results of this study indicate this method of experimentation and analysis provides a valid and important tool for the evaluation of precision resistors. The limited area of this work leaves a substantial amount of investigation to be done. Certainly other types of trims and the less-than-one aspect ratio resistors need evaluation. In addition, large resistors, smaller amounts of trim, and laser trim parameters such as power, pulse frequency, and trim speed are the less obvious areas of improvement. All of these areas should receive attention to improve the scope of the total investigation.

Acknowledgments

The author appreciates the preparation and initial testing of the test patterns by Ms. H.J. Sims and the guidance in laser trim programing by Mr. H. Rashad. Mr. K. R. Bube, DSRC, Princeton, assisted greatly in several technical areas and reviewed the initial technical report and this paper. Mr. A. Missenda, Program Manager, TACTEC Products, provided helpful discussions and directions in the study.

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Design considerations for a-m auto-radio IC's

Dr. A.A. Ahmed

This paper discusses the use of integrated circuits in automobile a-m radios. The particular circuit requirements of automobile radios are described, and the general approach to integrated-circuit auto-radio design is considered. Then, a specific design which meets severe performance and layout requirements is detailed. Finally, future trends in integrated-circuit automobile radios are discussed.

AN AUTOMOBILE radio is called upon to provide a great deal in the way of performance. Traditionally, the radio receiver must overcome the trying conditions in which it must operate. Thus, before attemping to describe the design of new ICs, the general auto-radio requirements are reviewed below.

Auto-radio requirements

Because it operates with a rather inefficient antenna, the rf stage must have high sensitivity and a low-noise figure to produce an intelligible output from signal levels of about 1 microvolt. When subjected to the very high signal levels near a broadcast transmitter tower, however, the rf amplifier must handle the signal without perceptible distortion, and it must handle a weak signal on an adjacent frequency without appreciable cross-modulation from the strong signal. The selectivity characteristic of the receiver should have broad skirts, so that a listener tuning across the dial can easily hear when he begins to tune in a strong station. The agc should maintain a slope, particularly at strong signal levels, so that nearby stations can be distinguished (by loudness) from more distant stations, and the audio output must be as high as seven or eight watts to overcome background noise.

The automobile radio must deliver good performance with high reliability despite a difficult operating environment. Shock and vibration must be tolerated, as well as temperatures from −30 to +75°C. The battery supply voltage may vary between 10 and 17 volts, with occasional large transients, so the radio must provide adequate voltage regulation. Because the regulator operates by dissipation of power, thermal considerations are important.

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The automobile radio must be mass-produced on an assembly line; therefore, its performance must be insensitive to the wide tolerance variation of machine-aligned components.

Automobile-radio performance

The requirements for automobile radio performance that are set forth above conflict with one another. For example, high gain and wide dynamic range in rf amplifiers require an agc that can function with a 1,000,000-to-1 variation of input level. The compromises between characteristics are embodied in the specifications from which the designer works. In the design process, transformer ratios are usually among the last parameters to be fixed; this degree of freedom is retained to set the gain partitioning, impedance levels, agc-to-audio relationship, noise-source impedance, and the like for optimum performance.

Integrated circuits

Integrated circuits offer the circuit designer a number of advantages. The characteristics of components on the same chip match one another, and temperature coefficients are exactly predictable. However, tolerances of component values are poor (although tolerances of component *ratios* are excellent), and crossing of leads entails resistance in one of the leads. Large capacitor values (greater than 30 picofarads) are undesirable because of the large area required; back-biased diodes are used as capacitors, and have low temperature coefficients. Potentials below substrate potential are avoided because they create *forward-biased* parasitic diodes.

IC automobile-radio design

An integrated circuit can be made that contains all of the transistors for an automobile radio. The use of such a device in conjunction with discrete resistors, capacitors, coils, and transformers will improve such factors as size, reliability, and product uniformity, but will *not* necessarily reduce the cost of the radio. The transistors and diodes are among the least expensive components in a discrete circuit, and some of the passive components are costly; therefore, the integrated circuit must replace a number of passive components as well as the active ones if the IC radio is to achieve a cost advantage. However, the discrete resistors, capacitors, and inductors are not directly replaceable by IC components because of the limitations on

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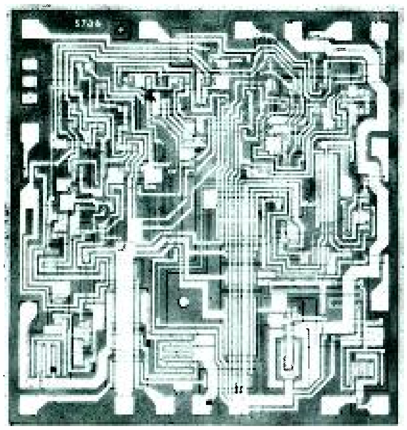

Fig. 1 — RCA automobile-radio chip.

integrated resistor and capacitor values. Therefore, the IC design must use a different circuit arrangement to produce the desired performance. The integrated circuit uses amplifiers whose gain depends on resistor ratios and differential amplifiers where gain control is required, and eliminates capacitors by using more diodes and transistors. Because complexity is not such an important consideration in IC cost, the complex IC can be less expensive than the discrete circuit.

In designing the IC, performance must be calculated carefully because component values cannot be adjusted on the IC. The agc curve, for example, can be calculated and manipulated in the design stage, but the breadboard revisions made with discrete circuits are not possible.

Besides the straight-forward cost comparison, there are other less-readily-assessed savings inherent in the IC radio. In discrete-radio assembly, individual components must be specified, purchased, delivered, sample-tested, stored, distributed, and mounted. When the radio is assembled, a certain amount of on-line fault correction may be required as a result of some defective components. Furthermore, the independent tolerances of individual components affect the uniformity of the final product.

The IC, on the other hand, replaces a large number of assembly and testing operations. Testing is carried out by the IC manufacturer on fast, computer-controlled test sets, and the variability of the final product is reduced as a result of the reproducibility of the IC.

The automobile industry, increasingly concerned with problems of proper maintenance and repair, prefers reliable, trouble-free systems. The reliability of monolithic IC's is well-known. IC's also simplify the stocking of replacement parts because the greater part of servicing becomes the replacement of a faulty device. Moreover, IC's are capable of improved performance.

IC automobile radios that are designed today still use discrete (off-chip) components for filtering and for rf and i.f. coils, and retain the basic superheterodyne receiver system. Future IC radios may have all elements on the same chip, possibly even using thermal time constants for filtering. The circuit design can not yet be predicted, however, nor can the cost. Some little-used receivers, such as the synchrodyne, may become practical with IC's.

The RCA automobile-radio IC

RCA undertook the development of an IC that would reduce the cost, improve the uniformity, and simplify the repair of a typical a-m automobile radio. The functions on the chip were to include the rf amplifier, mixer, i.f. amplifier, detector, and agc circuitry. The design was required to provide performance at least equal to that of a discrete-component model- the IC version actually provides superior performance.

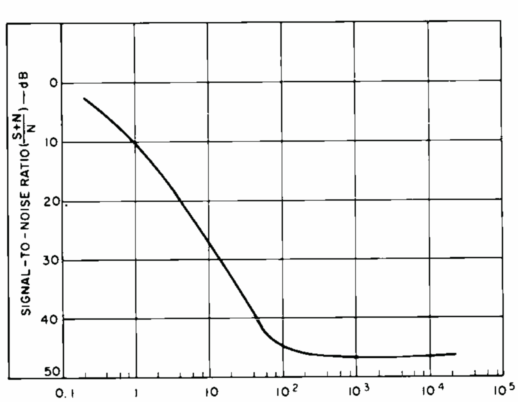

Fig. 4 — Signal-to-noise ratio as a function of input-signal level in the IC.

The large-volume mass production of auto-radio receivers places certain constraints on the design which are not usually associated with IC's. To allow for the possibility of problems in the IC design, it must remain possible in the initial stages to continue to produce the discrete-component set. The IC version was, therefore, required to mount on the same printed circuit board as the components it replaced, and to use the same antenna coils, rf and i.f. transformers, and audio amplifier. Owing to the common use of automatic aligning equipment, the grounded ends, directions of winding, approximate core positions and tapping points of the coils had to be the same as those used in the discrete-component assembly. The pin assignments for the 16-pin dual-in-line package of the IC were specified accordingly. The IC was successfully developed within these engineering constraints.

Fig. 1 is a photograph of the IC and Fig. 2 is a diagram showing the connections of the IC to the other components on the PC board. Fig. 3 shows the IC schematic diagram.

Integrated-circuit design

The IC replaces some of the discrete circuitry in an automobile radio that is typical of present-day design. This radio uses an rf stage followed by an autodyne converter, a single i.f. amplifier with a diode detector, and an audio amplifier. A separate agc detector is used, as usual, from the primary of the i.f. output transformer where a broader selectivity curve can be produced. The rf and mixer stages are controlled by the agc.

The circuit does not incorporate the audio amplifier, but drives the existing thick-film-module audio stage. Also, as has been mentioned, the IC is required to use the discrete radio tuner and transformers, unaltered in any way. This requirement fixes the gain partitioning, impedance levels, agc-to-audio relationship, and noise-source impedance within narrow limits to the values that offered a good compromise with single-transistors stages. Thus, the IC performance, while meeting specifications, is less than could be achieved with complete design freedom.

In the choice of pin assignments for a custom-designed IC, topology, lead

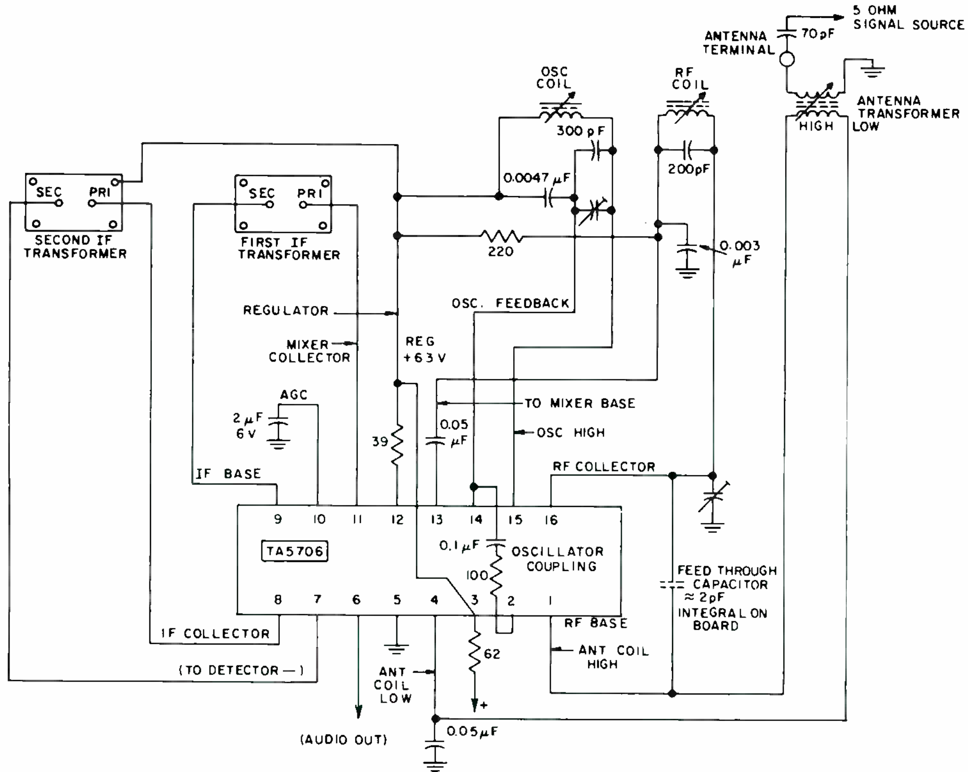

Fig. 2 — Automobile a-m radio showing external circuitry required with the IC.

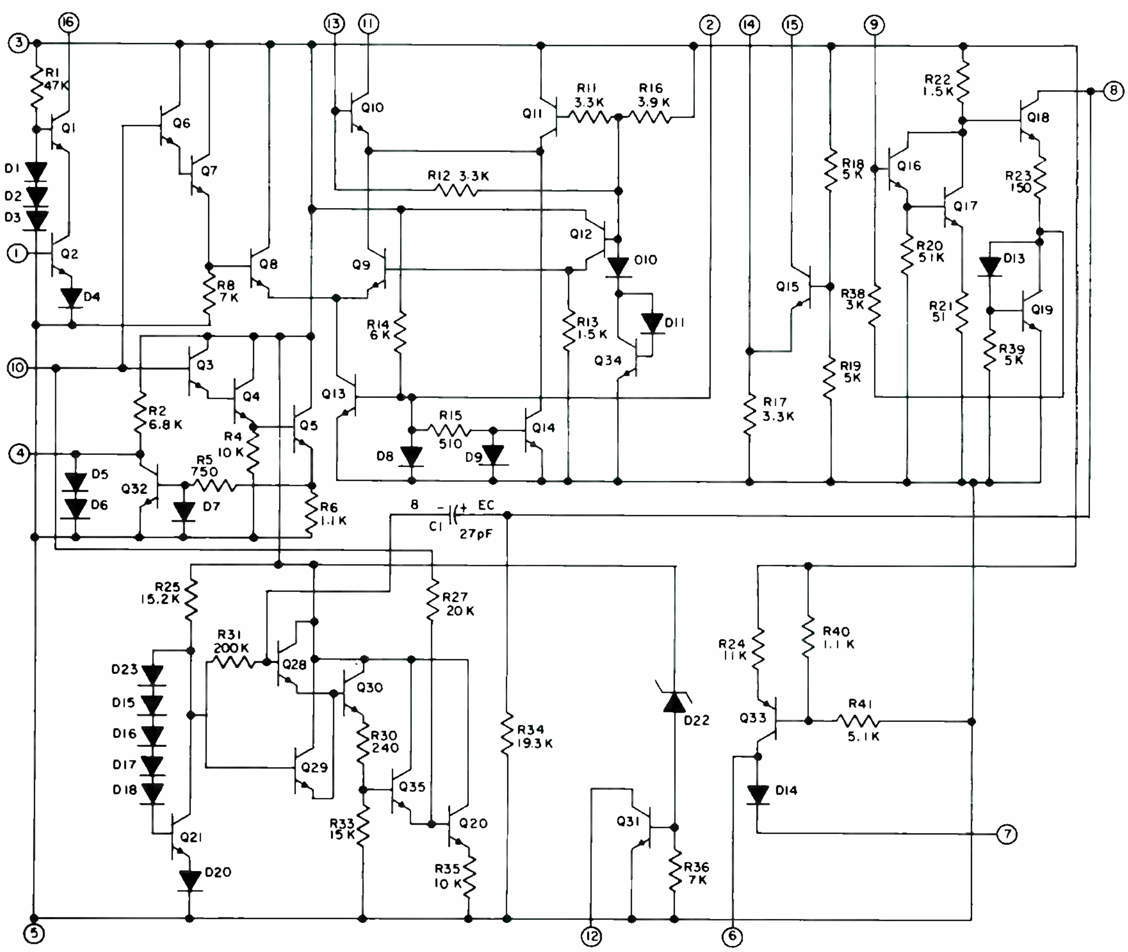

Fig. 3 — Schematic of auto-radio IC.

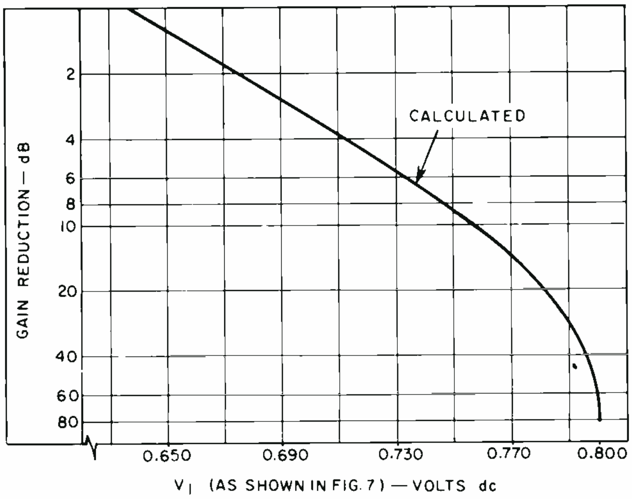

Fig. 5 — Calculated gain-control characteristic for the rf amplifier.

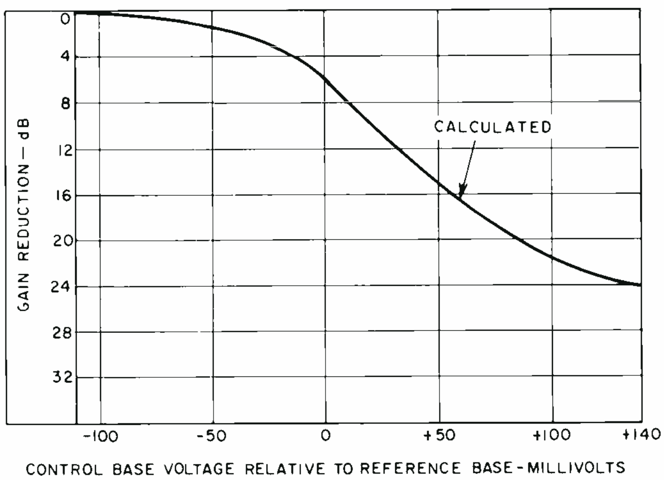

Fig. 6 — Calculated conversion-gain control characteristic for the mixer.

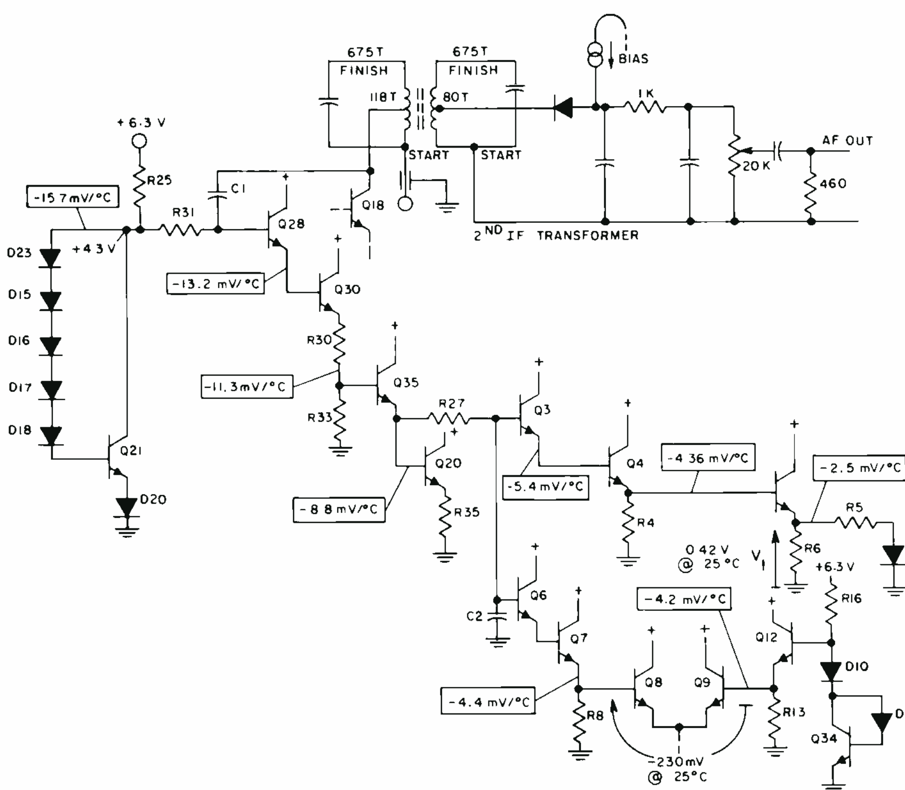

Fig. 7 — AGC derivation and control circuitry relative to quiescent levels.

resistance and PC-board layout are major factors. In the case of the auto-radio IC, however, the compatibility requirements referred to had to take precedence and, as a result, considerable chip area had to be utilized for lead crossings and multiple grounds to achieve the low impedances required for proper operation.

RF amplifier

The cascode rf amplifier consists of transistors Q_1 and Q_2. Diode D_4 permits application of reverse agc bias (approximately 1.5 volts) without additional negative voltages exceeding the substrate potential, and also reduces cross-modulation. This diode does not degrade the signal-to-noise ratio significantly. Fig. 4 shows the signal-to-noise performance of the IC as a function of rf input level.

The rf transistor, which is in the lower left-hand corner of the IC chip in Fig. 1, must be large enough to have high gain and low current density. Base resistance is kept low by the use of narrow emitter fingers with large periphery. Calculations based on the geometry indicate that this transistor provides an optimally-matched noise figure of 1 to 3 dB at 1 MHz, depending on process variations. As a check on the design, to determine whether a larger transistor area would yield a lower noise performance, five of the rf transistors were connected in parallel to simulate a single larger-area transistor. The improvment in signal-to-noise ratio was only 1 dB, which indicates that the rf transistor already has nearly adequate area.

The rf output coil is a pi-section type with a bandpass impedance transformation for the signal and a band-stop characteristic for the image frequency. Maximum voltage gain from the antenna to the mixer input is about 35 dB at a collector current of 7 milliamperes. Because a feedthrough capacitor is used, the cascode feature enables the total feedthrough capacitance to be predictably controlled by the external capacitor, which takes the form of a metal "meander" on the PC board. Fig. 5 shows the calculated rf gain-control characteristic of the amplifier. Although the attenuation appears to increase indefinitely, the feedthrough capacitor takes over at about 80 dB of gain reduction.

Converter

The converter stage uses a differential configuration with gain control obtained by variations of the effective current source. Transistors Q_8 and Q_9 steer current into or away from the mixer, thus varying the conversion transconductance with control voltage, as shown in Fig. 6. If the mixer gain control was not limited in any way, the characteristic would cut off very rapidly at a control voltage of about +100 millivolts. Mixer agc would continue until the rf stage became overloaded. Limiting of the mixer control-voltage by means of voltage clamps would not give consistent performance because the undesirable part of the characteristic is temperature dependent and changes very rapidly within about 20 millivolts of control-signal change. In the actual design, no limit is put on this part of the control system (which can, in fact, cut off entirely). Instead, a novel system is used in which an auxiliary current source, independent of the steering circuit, is connected in parallel. The Q_{14} collector current is an attenuated replica of the Q_{13} collector current; the ratio is temperature-independent because the temperature coefficient of the diffused resistor, $R15$, compensates almost exactly for the changing V_{BE} difference between D_8 and D_9. The conversion gain control, therefore, ceases at about 26 dB of gain reduction independently of temperature.

An additional, related advantage of the gain-control limiting system is that the low-level auxiliary-mixer source retains the sinusoidal local-oscillator-current injection waveform. Voltage gain to the i.f. amplifier input is 24 dB. The separate local Colpitts oscillator is capacitively coupled.

The i.f. amplifier

The i.f. amplifier is a 40-dB two-stage gain block with dc feedback to stabilize the operating point. This circuit was proposed by the customer and calculations showed that it could provide the required gain. The i.f. gain block is not a critical function as long as the required linearity and dynamic range are provided. Detailed stability calculations show that there is no chance of instability as a result of the production variations in the transformers or the IC chips.

Automobile-radio i.f. amplifiers operate at 262.5 kHz, which is about half the frequency used for other a-m radios. At this low frequency it is easier to obtain the required selectivity and gain with discrete components. The same considerations do not apply to an IC radio; as a result, the i.f. should be raised to 455 kHz to improve image response and reduce "tweet". This raised i.f. is one of the constraints considered in this work.

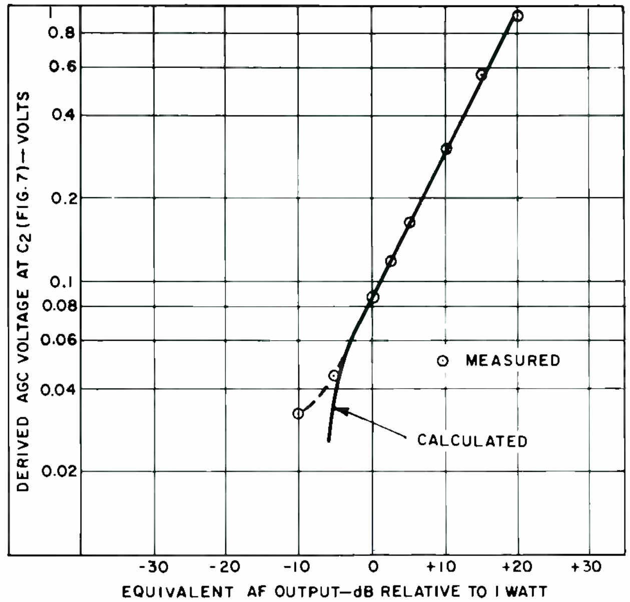

Fig. 8 — Calculated curve with measured points of agc voltage relative to quiescent levels (neglecting noise).

Automatic gain control

The differential amplifier composed of Q_{28} and Q_{29} functions as the agc detector in the novel circuit shown in Fig. 7. The inputs are dc biased to the reference voltage set up by D_{15} to D_{18}, D_{20}, D_{23}, and Q_{21}. The exact value of this reference voltage (in terms of V_{BE}), and its temperature coefficient and dependence on transistor current gain are chosen to maintain constant quiescent level and delay offset in the gain-control elements over the operating-temperature range.

The input to Q_{28} is at a high-impedance level, and a 27-picofarad capacitance is sufficient for C_1. The detected output is taken from the emitter of Q_{30} and, after level shifting and filtering, the agc voltage is applied to the rf and mixer stages. Gain in the rf stage is controlled by the current in R_5. Because the beta of Q_{32} is degenerated to a geometry-dependent value of five, and because R_5 tracks with the gain-setting bias resistor R_2, the agc performance is virtually independent of processing variations and temperature.

The mixer agc voltage is applied to the base of Q_8, while the other input to this differential amplifier is referenced by Q_{12}, Q_{34}, D_{10}, and D_{11} to a suitable voltage

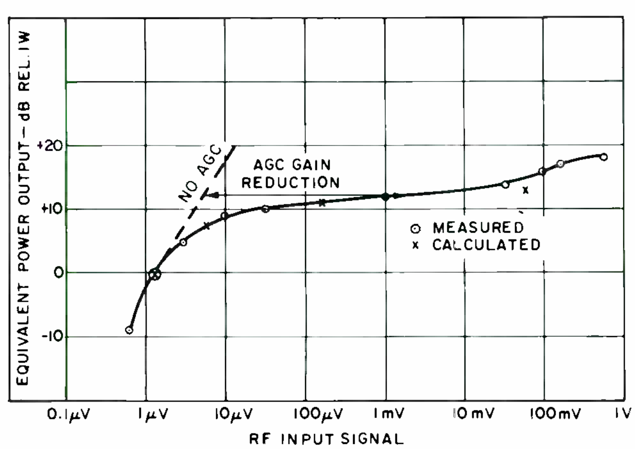

Fig. 9 — Input/output agc characteristics.

Table I — Performance of auto radios using the RCA integrated circuit.

Test No.	*Test Description*	*Results*
1.	Sensitivity for one watt	1.2uV
2.	(Signal + Noise) Noise	
	at 10 μV input	26.5 dB
	100 μV input	45.0 dB
3.	60 − dB bandwidth	30 kHz
4.	IF transmission	3000x
5.	Image response	4000x
6.	Max. power output, 10% distortion	5.8W
7.	Max. power output, 50-mV input	7.0W
8.	Output for 5X sensitivity signal	4.5W
9.	Sensitivity at 10% mod./sens. at 30% modulation	9X
10.	1-W output at 50 mV drops at 30-uV input	0.6W
11.	High-voltage operation, 17V	OK
12.	Low-voltage operation, 9.5V	OK
13.	Cross-modulation 1000, 950 kHz relative to 1W	1.2 mW
14.	Distortion for 30% modulation at 1W	1.2%
	Distortion for 90% modulation at 1W	2.4%
15.	Tweet at 50-mV input	
	3rd IF harmonic	8 mW max.
	4th IF harmonic	8 mW max.
	5th IF harmonic	8 mW max.
	Low-signal tweet	
	3rd IF harmonic	at 4 uV
	4th IF harmonic	no tweet detected
	5th IF harmonic	no tweet detected
16.	High-signal overload	
	30% modulation at 10% distortion at	1 volt
	90% modulation at 10% distortion at	0.9 volt

*All tests except 4, 5, and 15 were performed at 1 MHz under standard conditions.

with the proper temperature coefficient. A small voltage delay allows the mixer agc to operate first, so that it maintains a good signal-to-noise ratio by allowing the rf stage to operate at full gain for as long as possible. This delay is independent of temperature and processing variations (Appendix I). Fig. 8 shows measured values of the agc voltage as a function of the audio-output level superimposed on a curve calculated as in Appendix II. Fig. 9 compares measured agc input/output characteristics with a curve calculated by the method shown in Appendix II.

Detector

The detector is a diode with a suitable biasing circuit. A constant-current source is used because of the unacceptable wide tolerances on pinch resistors.

Regulator

A shunt regulator provides a temperature-stable regulated supply of 6.3 volts. Part of the regulation losses are outside the chip in the 39-ohm resistor shown in Fig. 2. Worst-case chip dissipation (including external resistor tolerances) is about 550 milliwatts.

Design layout

The layout of the integrated circuit involves electrical, thermal, and topological considerations. The input and ground leads to the rf amplifier must be kept short for good noise performance. In addition, common impedance couplings in the B+ and ground lines must be kept low to avoid instability and "tweet" problems.

Bypass points must truly bypass the node in question. For example, at the agc bypass at pin 10 in Fig. 3, a 1-ohm impedance between the pin and the junction node of the bases of Q_3 and Q_6 with R_{27} would cause instability. Because of the pin arrangement, a resistive *tunnel* was necessary, but trouble was avoided by formation of the node at the bond pad. In this case, resistance in the base leads causes no problem. The regulator sensing node must also be referenced to the proper point to provide internal ac bypassing. Dynamic regulation is so good that no bypass capacitor is required on the B+ line.

The greatest amount of heat is dissipated in the regulator transistor, Q_{31}, Fig. 3. The expected isotherms caused by this dissipation were delineated, and the matching components positioned as closely as possible on the same isotherm. Subsequent results showed no thermal problems in the finished chip. The topological considerations were somewhat difficult as a result of the pin problem mentioned in the paragraph above. In several parts of the circuit, multiple *tunnels* were required to avoid undesirable coupling.

Circuit performance

The first sample of IC's performed satisfactorily. Table I summarizes performance data taken with the IC in the receiver for which it was designed.

Test 1, the sensitivity measurement, indicates that the stage gains, the overall gain, and the dc references in the agc are all correct. Incorrect agc references would cause premature agc action and, therefore, poor sensitivity at low signal levels.

Test 2 involves the signal-to-noise ratio. The 10-microvolt measurement shows that agc action at this signal level must occur almost entirely in the mixer, with no significant contribution from rf-amplifier agc. To test this conclusion, the agc was disabled (i.e., clamped at the quiescent level); the signal-to-noise ratio remained virtually unchanged. The 100-microvolt measurement is at a level where the mixer agc approaches its limiting value; therefore, for higher signal levels, this magnitude is unlikely to be reduced much.

In Test 3, the bandwidth is mainly a function of the i.f. transformer design, provided that regeneration does not occur; regeneration would narrow the passband. Tests 4 and 5 are also mainly functions of tuner and wave-trap performance. The image is the undesired frequency that will also produce an i.f. component by beating with the local oscillator. In this case, the desired signal frequency is below the local oscillator frequency, while the image frequency is above it.

Tests 8, 9, and 10 relate to the shape of the agc characterisitc, as shown in Fig. 9. Test 13 covers cross-modulation. This cross-modulation is also a function of the tuner design and of the rf stage. The test determines interference caused by a signal in a neighboring channel, though not as closely as under Test-3 conditions.

The "tweet" in Test 15 is a beat tone produced by simultaneous reception of an i.f. harmonic and a desired signal. The i.f. harmonic is usually coupled into the rf and mixer stages through a common impedance. The low-signal "tweet" is the lowest desired signal level at which the whistle interference can still be detected.

Conclusions

The design objectives for the automobile-radio IC have been achieved with the first sample of chips. The performance of an auto-radio employing these chips meets or exceeds that of a radio assembled with discrete components in almost all areas. There is little doubt that variations of performance characteristics required for different customers can be designed into the IC.

In addition to the possible improvements of the present system, future designs will probably attempt to depart from the traditional superheterodyne receiver to various other types of receivers that are becoming economically attractive with the use of integrated circuits.

The achievement of the objectives of this developmental program has contributed to the successful completion of an auto-radio IC, the RCA type CA3123, which is now in mass production.

Appendix I — Temperature tracking of mixer AGC delay

The voltage delay, δv in the applied agc voltage, is a function given by

$$\delta v = C(KT/q)[\ln f(I_a/I_b)] \tag{1}$$

The current, I_m, steered into Q_9, is given by

$$I_m = I_o/1 + \exp(\Delta vq/kT) \tag{2}$$

where Δv is the differential input to the bases of Q_8 and Q_9, k is Boltzmann's constant, T is the absolute temperature, q is the electronic charge, I_0 is the total current into Q_{13}, and C is a constant.

Because $f(I_a/I_b)$ is a function of resistor and beta ratios, it is practically a constant. Substitution of δv for Δv into Eq. 2 produces the following expression

$$I_m = I_o/\{1 + [f(I_a/I_b)]C\} \tag{3}$$

The conversion gain is directly proportional to I_m. Therefore, virtually perfect tracking is assured because the right-hand side of Eq. 3 is independent of temperature and processing variations. Similar considerations apply to the rf-amplifier agc delay.

Appendix II — AGC input/output characteristics

This section compares a somewhat simplified calculation of the agc characteristics with measured results taken from the complete receiver (Fig. 7).

The characteristics of the audio amplifier are such that a 60-millivolt peak-to-peak audio signal is required at the top of the volume control to produce a one-watt equivalent output with the control turned down by a specified amount. For the agc curve measurement, the detector operation and the second i.f. transformer damping are, therefore, different from the conditions for full sensitivity where the volume control is at a maximum setting. This point is mentioned because the agc operation is also checked under this condition, although this part of the detailed analysis will be omitted.

The audio output voltage from the detector-filter and the signal at the i.f. primary are related by

$$E_{pri} = E_{out}(N_p/N_s)(R_p/R_s)^{1/2}[1/K(Q_pQ_s)^{1/2}]$$
$$(1/\eta m)[(R_{ac} + R_d)/(R_{ac} - R_f)] \tag{4}$$

where N_p and N_s are the turns from start to tap (both windings have the same total number of turns), R_p and R_s are the total parallel damping resistance, k is the coupling factor (not to be confused with kT/q), Q_p and Q_s are the loaded Q's, η is the detection efficiency, m is the degree of modulation, R_{ac} is the detector ac load resistance, and R_d is the equivalent detector diode resistance.

The values are:

N_p = 118 turns	k = 0.025
N_s = 80 turns	Q_p = 30
R_p = 150 kilohms	Q_s = 40 with volume control retarded
R_s = 200 kilohms with volume control retarded.	
η = 1	R_{ac} = 17 kilohms
m = 30 percent	$R_d = R_f$ = 1 kilohm

Substitution of these values into the Eq. 4 produces the following:

$$E_{pri} = (5.5)(E_{out}) = 330 \text{ mV peak-to-peak}$$

Because of the reactance of C_1 and the resistance present at the base of Q_{28}, this voltage is reduced to

$$330 \times 0.88 = 290 \text{ mV peak-to-peak}$$

On positive half-cycles of the i.f. signal, transistor Q_{28} will conduct and cause C_2 to charge (Fig. 7), but there will be some reduction of the input peak amplitude as a result of the differential-amplifier characteristic. This error is small for small amplitudes; however, as the input is increased, the error will also increase and will level off at $0.7\,kT/q$ for inputs greater than about $2\,kT/q$[52 millivolts at 25°C]. The performance of a half-wave rectifier can be predicted from published rectifier curves. The total charging resistance is $R_{27} + 1/g_m(Q_{35}) = 25$ kilohms. The discharging resistance if $\beta \times R_{35}$, giving a source-to-load ratio of approximately 3.6 percent. From the curves, the following ratio is obtained:

$$V_{dc}/V_{ac\ peak} = 0.8$$

Because transistor Q_{35} will conduct heavily on the voltage peaks, the applied peak voltage must be reduced by

$$(kT/q)\ln[(I_{peak} + I_{quiescent})/I_{quiescent}]$$

For the values used, the rectifier curves give $I_{peak} = 6\ 5 \times I_{quiescent}$ (dc). Therefore, the above expression becomes

$$(kT/q)(\ln 7.5) = 2kT/q$$

If the previously-derived correction of $0.7\,kT/q$ is included, the peak signal must be reduced by a total of $2.7\,kT/q$ or 70 millivolts at 25°C. Therefore, the derived dc voltage will be

$$V_{agc} = 0.8[0.88\ E_{pri}/2 - 70 \text{ millivolts}]$$

for $E_{pri}/2$ greater than $2\,kT/q$ or 50 millivolts at 25°C. At lower levels, as the correction becomes smaller, the voltage will tend more to

$$V_{agc} = 0.8\,[0.88\ E_{pri}/2 - 50 \text{ millivolts}]$$

Fig. 8 shows the curve of derived agc voltage calculated as described above toegether with measured points. In this case the agreement is close except at very low levels where the effects of noise have been left out of the calculation. The agc does not operate in this region.

Next, the gain control characteristics of the rf amplifier and converter stage together with the control elements must be calculated. This calculation is a straightforward application of basic equations; the results are shown in Figs. 5 and 6.

The derived agc voltage of Fig. 8 is then superimposed on the quiescent levels developed by the dc reference shown in Fig. 7. These dc levels and their temperature coefficients are also obtained in a straightforward manner.

For a direct comparison of calculated and measured results, the sensitivity is taken to be the sensitivity of the particular set measured, in this case 1.2 microvolts for a 1-watt output. From this point, a line is drawn on Fig. 9 at a slope of 20 dB per decade. This slope is the input/output characteristic without agc. For any given output level, the total gain reduction can be obtained from the graphs of Fig. 5, 6, and 8. The input, as required on the "no-agc" line, is then augmented by this amount to give the overall input/output curve, as shown in Fig. 9. The measured values are shown on the same graph. At about 100 millivolts of input signal, the "feedthrough" capacitor causes the measured and calculated points to the diverge because the agc can no longer increase the attenuation. A receiver of different sensitivity would show a characteristic that is displaced from this one but of the same shape.

On the distribution of patents among patentees

M.S. Winters

Based on an examination of RCA patents issued from 1958 through 1972, an expression has been developed for the probability that a patentee selected at random in a given population has a given number of patents. This expression could have some relationship to the distribution of highly creative people among a creative population.

DATA collected for RCA patentees indicate that for a fixed period of years, the number of patents issued to each patentee follows the exponential law $p(n) = (1/\sigma) \exp(-n/\sigma)$ where $p(n)$ represents the probability of finding a patentee selected at random with exactly n patents, and σ is the standard deviation.

Such a distribution might arise from an assumption that, in the selected population, the number of patentees found in the interval n to $(n + \Delta n)$ is proportional to the number found in the group having n patents. Accordingly

$$p(n + \Delta n) - p(n) = K_1 \, p(n) \, \Delta n \qquad (1)$$

in which K is a positive constant.

We have then the simple differential equation:

$$dp(n)/dn = K_1 \, p(n) \qquad (2)$$

where K_1 is positive.

The constants are readily evaluated. The standard deviation σ and the average a are equal, and

$$\begin{aligned} p(n) &= (1/\sigma) \exp(-n/\sigma) \\ &= (1/a) \exp(-n/a) \end{aligned} \qquad (3)$$

which is the exponential probability curve. The suggestion that the curve might apply to the data is due to Dr. Dwight O. North, Fellow, RCA Laboratories.

If we adopted a somewhat different assumption, namely that the ratio of the rate of change of $p(n + \Delta n)$ to $p(n)$ is proportional to n, we would have;

$$\frac{dp(n)/dn}{p(n)} = -Kn \qquad (4)$$

From this latter equation, taken over the range of zero to infinity, we would derive the positive abscissa portion of the so-called normal curve, normalized for one half its usual range.

$$p(n) = [2^{1/2}/(\pi^{1/2}\sigma)] \exp(-n^2/2\sigma^2) \quad ,n \geqslant 0 \qquad (5)$$

The 2,292 patents issued to 1,207 RCA patentees in the five-year period 1968 through 1972 are plotted in Fig. 1. Each patent counts once for each coinventor named. Thus a patent naming two coinventors is in fact counted as two patents. The probabilities that a patentee is found with exactly 1, 2, 3, *etc.* patents are obtained respectively by dividing the number of patentees who have exactly one patent by the total number of patentees, the number who have exactly two patents by the total number of patentees, *etc.* The probabilities are plotted as ordinates on a logarithmic scale, against the number of patents as abscissas on a linear scale. Two straight lines correspond to the function $p(n) = (1/n) \exp(-n/k)$ for k equal to the standard deviation $\sigma = 1.83$ and for k equal to the average $a = 1.90$ calculated from the data. For comparison, there is shown the corresponding curve for Eq. 5 using $\sigma = 1.83$. Also shown in Fig. 1 for

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comparison is a Poisson distribution in which the probability $p(n)$ of finding exactly 0, 1, 2, *etc.* patents follows the respective values of the expression $\exp(-a)a_n/n!$ for respective values of n of 0,1,2, *etc.* where a is the average 1.90.

Similar plots for the ten-year period 1963 to 1972 are shown in Fig. 2. The data points are calculated from the 4,082 patents issued to 1,786 RCA patentees. The two straight lines represent the function $p(n) = (1/k)\exp(-n/k)$ for k equal to the standard deviation 2.50 and the average 2.29, respectively, calculated from the data.

In Fig. 3 are shown the plots for the twenty-year period 1953 to 1972 inclusive. Here the data are for 8,830 patents issued to 2,834 patentees. The abscissa scale is smaller by a ratio of two-to-one in this Figure. The average number of patents per inventor here is 3.12 and the standard deviation is 4.63 calculated from the data. Naturally the average and standard deviation are functions of the time span over which the sample extends.

On the basis of the exponential Eq. 3 we would suppose that the probability that a patentee selected at random in the given population has more than n patents is:

$$\frac{1}{\sigma}\int_n^\infty \exp(-n/\sigma)\,dn = \exp(-n/\sigma)$$

The prediction on this theoretical basis is too small for n equal to 1 or 2 because the number of patentees having only one patent is greater than that predicted from the postulated distribution. As n increases the prediction is improved.

We may at some future time examine data relating to applications. Another interesting project would be to compare statistics drawn from the Patent Office to ascertain whether or not they exhibit similar characteristics and trends, and how national or international samples compare with the smaller samples studied here.

The results are tentative. They show a possible distribution of highly creative people among a creative population. It is hoped that this work will stimulate interest in further statistical investigations which may lead to a better understanding of creative processes.

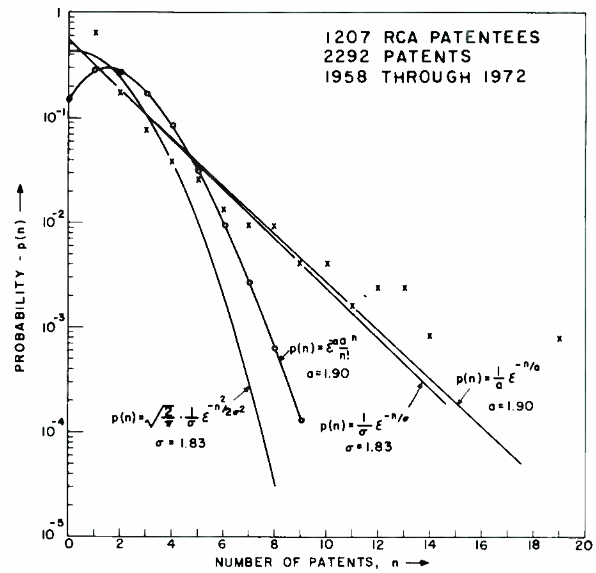

Fig. 1 — Patents issued over a five-year period.

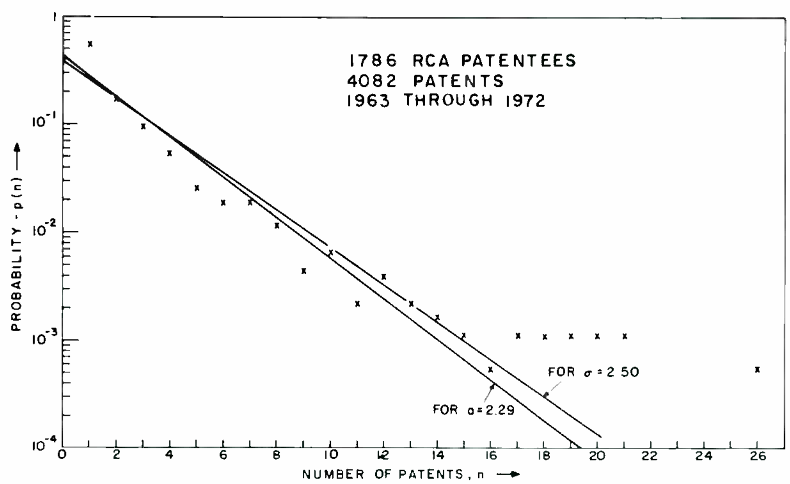

Fig. 2 — Patents issued over a ten-year period.

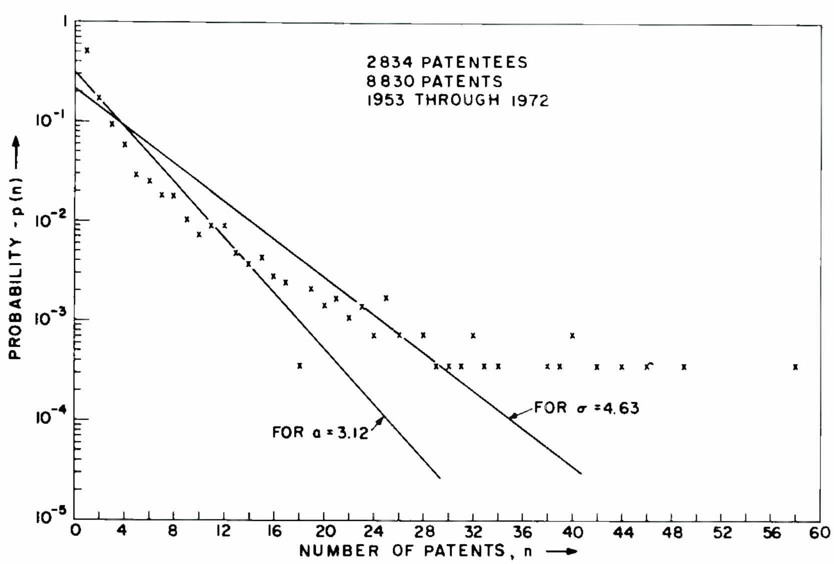

Fig. 3 — Patents issued over a twenty-year period.

Observing integrated-circuit operation with liquid crystals

Dr. D.J. Channin

A non-destructive technique has been developed that enables both the electric fields and temperature distributions at the surface of an operating integrated circuit to be viewed with conventional optical microscopes. Packaged chips or unscribed wafers are coated with a nematic liquid-crystal layer and operated in their normal fashion. Practical preparation and observation procedures have been developed.

A SERIOUS difficulty in development and manufacture of integrated circuits is the inability to easily observe or measure the internal functioning of the circuit. Complex circuits with 10^2 to 10^4 transistors and corresponding numbers of interconnects and crossovers must be tested by examining the output of 16 or so terminals. The engineer is obviously handicapped when he tries to diagnose the fault location and failure mechanism of an improperly operating device. Even very simple circuits do not permit probing of fields and currents within individual transistors or other structures. The value of practical techniques for making visible the electric fields, currents, and temperature patterns at the surface of operating integrated circuits is quite apparent.

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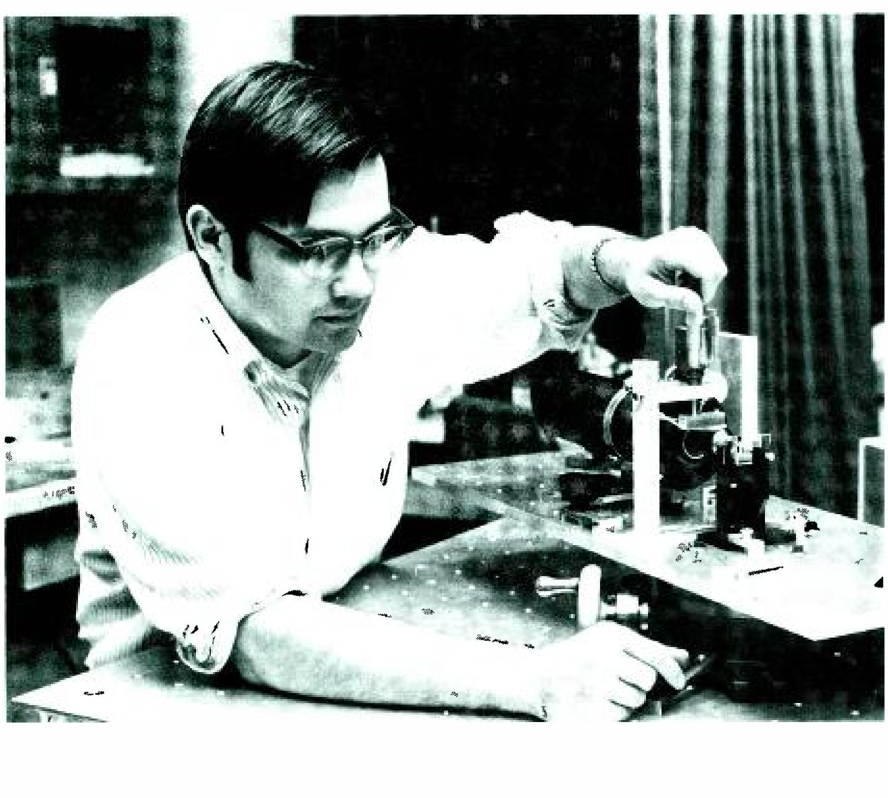


An IC observation technique

A technique has been developed that uses liquid crystals to achieve the desired visualization. A well-aligned nematic liquid-crystal layer is prepared on the active area of the circuit. The device is then operated in its usual fashion and observed under a conventional metallurgical microscope with polarized light. In pulsed or ac operation the regions on the circuit where the potentials are modulated appear bright against a dark background. When the pulse frequency is slowed down to visual rates the propagation of bits through a complex circuit can be followed. The operation of individual transistors and the continuity of various connections may be inspected.

The same setup also makes visible regions of local heating. Depending on the specific liquid-crystal material used, temperature rises of about 10°C cause a transition between the nematic and isotropic phases. *Hot spots* on individual transistors and the uniformity of conduction across long junction strips can be observed. Finally, regions of conduction through the insulating oxide layer over the circuit may be seen as bright areas in dc operation.

Background

Various liquid-crystal techniques for studying semiconductor devices have been reported.[1-4] They all rely on observing a change in the color or opacity of the liquid crystal. Temperature changes cause coloration effects in cholesteric materials[5] and electrical conduction in nematics produces a turbulence phenomenon known as dynamic scattering.[6] In contrast, the technique discussed here uses optical refraction changes in clear nematic liquid-crystal material. Such changes are produced by electric fields in the absence of current flow, though current itself will cause similar effects. They also occur at a thermally induced nematic-isotropic transition. Though a more subtle effect than scattering or color changes, they can be made visible with suitable optics and give a bright presentation of circuit fields and local heating against a dark background. Especially important is the sensitivity of these optical phase effects to a variety of phenomena in normal and defective circuits. This enables them to be the basis of a process that allows examination of integrated devices of all kinds in their normal production form.

Integrated circuits in their usual configurations impose a number of constraints that limit or prevent the use of previous liquid crystal testing techniques. Completed devices usually have insulting layers that prevent access of liquid-crystal material to current carrying junctions and connectors. This prevents the use of dynamic scattering techniques unless the circuits can be specially processed to expose the desired conducting regions. Scattering techniques that involve conduction through the liquid-crystal layer to a conducting cover plate are limited in resolution to the thickness of this layer, which is hard to control below about 10 microns. Integrated circuits, tiny in themselves, have very little clearance between their contact pads and their active regions, yet the liquid crystal must usually have a properly treated cover plate to confine it to a thin, optically clear layer. This cover plate must not interfere with the access of leads to the contact pads, both on unscribed wafers and with mounted chips.

Finally, many circuits in normal operation, particularly COS/MOS, draw very little power. On such circuits purely thermal techniques are limited to observing localized defects drawing abnormal currents. The technique discussed here is designed to cope with these constraints and remain straightforward enough to be of practical use in an integrated-circuit laboratory.

Liquid-crystal optics

A nematic liquid crystal is composed of rod-like organic molecules which act on each other to force themselves to align in the same direction. In bulk or in an unprepared layer, different microscopic regions will be aligned in different directions as in polycrystalline solids. If the walls bounding a thin layer are suitably treated, however, they will force the molecules adjacent to the walls to be aligned in a particular way, such as standing perpendicular to the wall. The liquid-crystal ordering tendency then causes the rest of the molecules to follow suit and point in the same direction. What results is a single domain which will still flow as a liquid having characteristic optical, electrical, thermal, and mechanical properties.

Most important are the electro-optic and thermo-optic properties. The materials of greatest usefulness are strongly birefringent, that is, their refractive index changes with direction. When electrical fields or currents cause local distortion of the molecular ordering, the refractive index is correspondingly changed. Similarly, when local heating in the circuit causes an adjacent region of the liquid crystal to pass from the nematic to the isotropic (normal liquid) state there is also an index distortion. There is no fundamental resolution limit for these phenomena down to optical wavelength dimensions. Threshold voltages for electrical effects are around 8 volts or less, and temperatures for nematic-isotropic transitions can be about 10°C above room temperature, with the transition region a fraction of a degree. Response times depend on geometry and field strength, but are usually on the order of milliseconds.

As a result of these properties a refractive index pattern is produced in the liquid crystal which mirrors the pattern of electric fields at the surface of the integrated circuit. Various optical methods can be used to make this pattern visible. The easiest is to view the operating circuit in a conventional metallurgical microscope with a linear polarizer in the illumination beam and a crossed polarizer in the ocular system. The image is formed of light passed through the liquid-crystal layer—and reflected from the integrated circuit surface. Undistorted regions appear dark because their light is not passed by the second polarizer. Regions in the liquid crystal, where circuit operation has distorted the refractive index, rotate the polarization of the light that passes through them. The rotated light is passed by the second polarizer to give a bright image of the operating parts of the circuit.

The torque exerted on the liquid-crystal molecules by an electric field is proportional to the square of this field. Therefore, a field that is turned *on-and-off* at a rate exceeding the liquid-crystal response time will produce a non-zero average response and will appear as a steady brightness in the optical system. However, a dc field applied to a liquid crystal by insulated conductors will be cancelled by charging of the insulator surfaces with typical charging times of about 10^{-1} seconds. The response to a pulsed voltage of duration exceeding this charging time is simply flashes at the start and end of the pulse.

Critical voltages of three to ten volts are required to initiate the optical effects with the liquid-crystal materials we have used so far. The optical effects saturate at several times the critical voltage. Between these extremes the brightness is a measure of the magnitude of the surface fields.

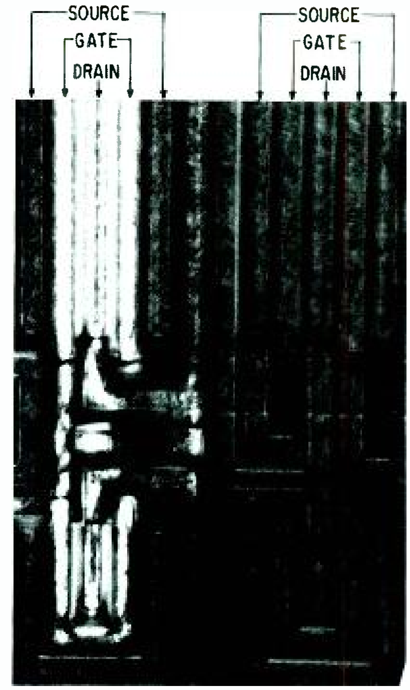


Fig. 1 — Operation of COS/MOS circuit with left transistor pair functioning and right transistor pair quiescent. Location of source, gate, and drain electrodes that constitute a MOS transistor are indicated.

A picture of the resulting effect is shown in Fig. 1. A commercial RCA CD-4007 COS/MOS integrated circuit consisting of three independent transistor pairs is operated as an inverter with the gates of one pair of transistors pulsed at about 1000 cycles/s while the other gates are grounded. Alternating fields at the gates and drains of the operating transistors appear brightly. Constant fields at the source are not made visible, because charge accumulation on the capping SiO_2 layer covering the circuit produces a self-cancelling field.

The liquid crystal used in this work, commercially available *n-(p-methoxybenzylidene)-p-butylaniline* or "MBBA", has negative dielectric anisotropy which causes the molecules to rotate to align themselves perpendicular to an electric field. Therefore, the liquid crystal responds to the component of the electric field that is perpendicular to the integrated circuit surface. Other materials with positive dielectric anisotropy will respond to the parallel field component.

Liquid-crystal layer

The development of a practical means of

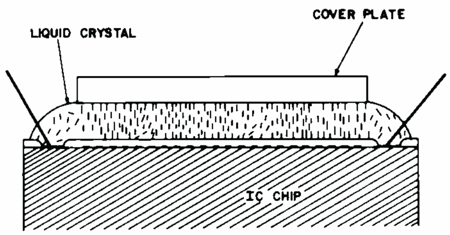


Fig. 2 — Structure of liquid crystal assembly, showing integrated circuit chip, liquid crystal layer, and transparent cover plate. Surfactant coatings on circuit and cover plate promote molecular alignment of liquid crystal. Regions of alignment distortion shown here are response of liquid crystal to circuit operation.

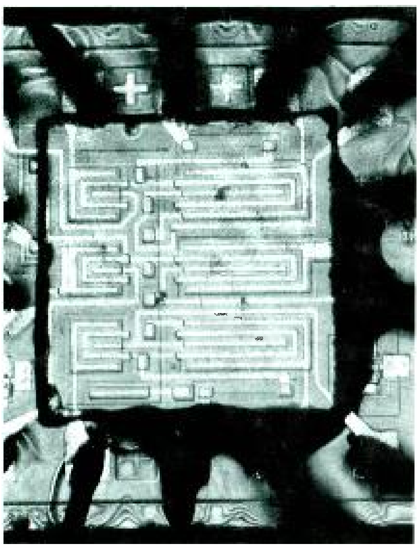
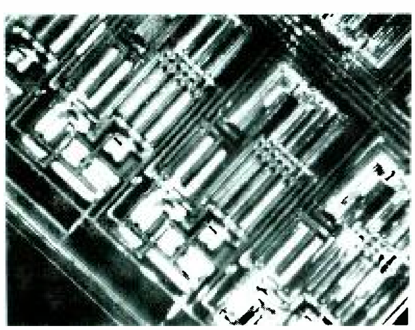
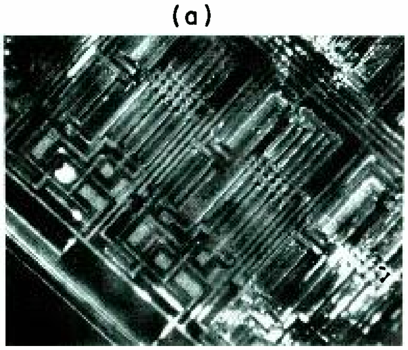


Fig. 3 — Liquid crystal assembly on a packaged integrated circuit.



(a)



(b)

Fig. 4 — SOS 7-stage counter in operation (a), and with dc bias (b).

creating a well-aligned liquid-crystal layer on an integrated-circuit chip or wafer is central to this process. Regions of misalignment due to poor preparation will show up as brightly as circuit effects. Achieving this alignment is made difficult by the textured surface of the circuit and the tiny chip size. Nevertheless, a satisfactory method has been developed.

Fig. 2 shows the assembly on a single chip. The circuit is first spin-coated with a surfactant solution that promotes liquid-crystal molecular alignment perpendicular to the surface. This may be easily done for packaged devices as well as wafers. A drop of liquid-crystal material is then placed on the chip. A thin glass cover plate, scribed to the chip size and also treated with surfactant solution is lowered onto the drop. Surface adhesion holds the cover plate down and forces the liquid crystal into a uniform layer. The cover plate is supported by the liquid in the manner of a contact lens on an eyeball, and it in turn provides the alignment and uniformity of the liquid-crystal layer.

The assembly is performed with standard micropositioners, hypodermic syringes, and vacuum lifters for the cover plate.[7] Fixtures for prepositioning the pieces facilitate preparation of a large number of circuits at once, after which they may be observed at leisure.

With this assembly one achieves a well-aligned liquid crystal without interfering with access to the contact pads; Fig. 3 shows this structure on a packaged circuit. Viscosity prevents the cover plate from moving around, though it may be pushed with micropositioners if a new placement is needed. Alternative arrangements such as a large cover plate with holes pre-etched to match the contact pads are also possible.

Integrated-circuit examination

A variety of integrated circuits were studied with the liquid-crystal technique, including both commercial RCA COS/MOS inverters and counters and RCA silicon-on-sapphire circuits.[7] Some circuits which had been identified electronically as malfunctioning were examined and the location of the defects were found.

The operation of a commercial COS/MOS inverter is shown in Fig. 1 and has been discussed earlier in the article. Only the electric fields associated with ac operation are involved in creating the visible pattern; no conduction or heating is involved.

Fig. 4 shows the operation of the SOS 7-stage counter circuit. Figure 4a shows the counter operating with an input pulse rate exceeding the response rate of the liquid crystal, to give a steady picture of the ac fields on the transistors and other circuit elements. Three counter stages are running side-by-side in the picture. In Fig. 4b the input pulses are not applied but the dc bias voltages are still on. Most of the optical effects are gone, but there is a bright area in the lower-right counter stage due to conduction through porous areas in the passivation oxide layer.

One stage of an improperly operating counter is shown in Fig. 5. No output is observed from this stage, yet the downstream stages function properly. Examination by the liquid-crystal technique shows that the output transistors of the defective stage are not running, though the rest of the circuit functions. On turning up the voltages a point of local heating in the bad area has been observed, which further pinpoints the fault.

Another counter fault is seen in Fig. 6. Here all the transistors of the middle stage are functioning, yet no output is received from this stage. Examination shows an anomaly in the bright region at a crossover of the output conductor (6a, arrow) compared to the same crossover

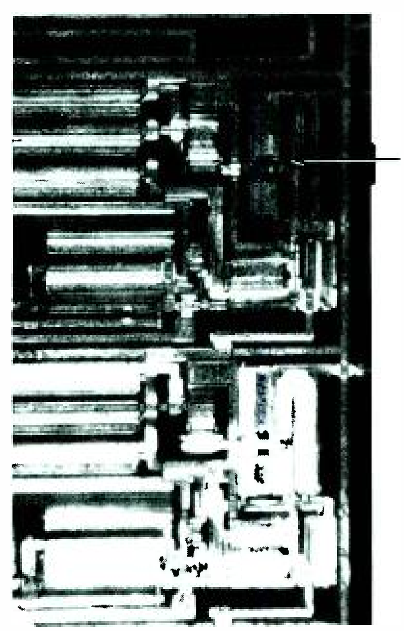


Fig. 5 — Counter stage with non-operating output transistors (arrow).

on the properly outputting stages. Examination at higher power shows a flawed area in this part of the device (6b).

Conduction at a breakdown in the gate insulation of a MOS transistor is identified by local heating in Fig. 7. In this case a properly operating transistor was damaged in a controlled fashion by connecting a charged capacitor to the gate pin while grounding all the other pins. The devices are then operated, and the location of the breakdown is identified by the bright region associated with local heating at the conducting path. Threshold currents for seeing the effect (Fig. 7b) are about 2 mA, and larger currents show the greater area that has been warmed above the nematic-isotropic liquid-crystal transition temperature.

Conclusions

A technique for using conventional optical microscopes to observe the electric fields, currents, and temperatures at the surface of operating integrated circuits has been demonstrated. The display of these effects is clear and vivid at high magnifications. The process is non-destructive and involves no special preparation of the circuits other than the application of a liquid-crystal layer which may be easily removed. The circuits are operated in their usual fashion and within their voltage and current specifications. At low-repetition rates the propagation of pulses through complicated counter and logic circuits may be observed. COS/MOS and SOS circuits have been investigated so far, but the technique should be applicable to many kinds of integrated circuits and other semiconductor devices.

The ability of the technique to locate and study circuit defects and weaknesses has also been confirmed. In addition to the identification of working and non-working areas, one may also view the uniformity of fields and currents along device junctions to search for hot spots and high field concentrations in functioning devices.

Some of the capabilities of this process parallel those of other testing techniques. Local heating at insulated gate breakdown has been observed with infrared microscopy. Electric potentials above operating circuits can be observed with a scanning electron microscope in the voltage contrast mode. Both of these are effective testing tools and have good resolution, but they require expensive specialized equipment—and each accomplishes only one task. The infrared microscopy appears to require higher current density for a visual effect than does the liquid crystal. Observation time on scanning electron microscopy is sometimes limited by surface charge accumulation on the circuit.

In contrast, the liquid-crystal process requires only conventional microscopes and electronics of the types that are generally used in integrated-circuit development laboratories. The coating of the liquid-crystal layer uses spin-coaters or spin dryers and micropositioners which are also typical tools in IC development. Packaged circuits or unscribed wafers may be coated in batches and then observed at convenient times in numerous locations. Previously examined circuits may be stored, re-examined and compared with the most recent devices. By manipulating the driver voltages and repetition rates a circuit can be observed in slow-motion operation and then examined in detail for field uniformity at various places in the circuit, and for local heating.

Further development directed toward increased sensitivity will involve using the wide variety of liquid-crystal materials now available. Improvements in processing of the liquid-crystal layer are also under study.

Acknowledgments

I am grateful for the excellent technical work of G.E. Nostrand, and for encouragement and valuable discussions with R. Williams, J.C. Sarace, and A.C. Ipri. SOS circuits were supplied by J.C. Sarace, and by G. Caswell, IC Technology Center, Somerville.

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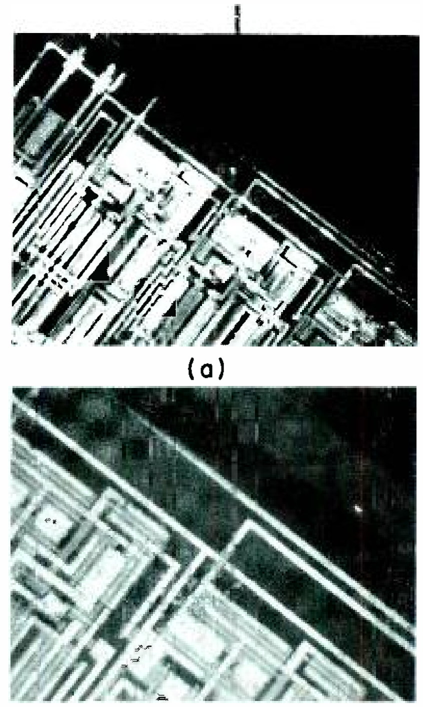
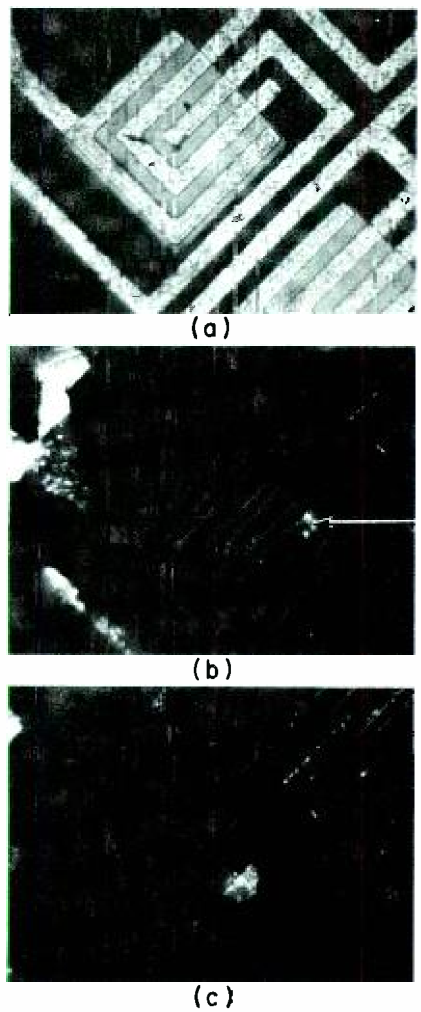


(a)

(b)

Fig. 6 — (a) Counter stage with anomaly at output lead crossover (arrow). (b) Magnified view of defect at crossover.



(a)

(b)

(c)

Fig. 7 — SOS transistor (a) with heating at breakdown of gate insulation (b). Increasing current causes greater heating (c).

Operational requirements for a ship transponder system

E. Jellinek

Operational requirements and signal format requirements for a ship transponder system have been developed by analyzing the operational problems. Conventional and discrete address signal formats were analyzed and found not to meet these requirements. A new generalized signal format called Range Division Mulitple Access (RDMA) was developed to meet these requirements. The basic parameters of RDMA described in this paper may be used as a foundation for further study and optimization; alternative requirements and formats should also be considered. Hopefully, this paper provides a basis for further discussion and eventual agreement on operational requirements, on signal format requirements, and on an international standardized signal format.

COLLISON-AVOIDANCE navigation has evolved from visual detection and prediction with whistle communication to radar detection, computerized prediction, and bridge-to-bridge radio communication. Each evolutionary step was taken to overcome earlier deficiencies. However, there are still fundamental problems to be overcome.

Every vessel must navigate so as to avoid collisions with other vessels regardless of what the other vessel is doing. To do this it follows the *Rules of the Road* and also performs the functions of detecting the other vessel, predicting the collision potential, and making the proper maneuver. In general, these functions can be performed unilaterally, and communication is not needed. Since the other vessel is performing the same functions and since the view from each vessel is complementary, a complementary maneuver and safe passage should result.

However, even with radar, disaster-causing deviations from this ideal occur. Errors in radar plotting can cause failure to recognize that a threat exists; consequently a proper maneuver is not made or is incorrect. Improved plotting techniques or the use of an automated collision-avoidance system (CAS) can overcome this type of error. With either of these, a collision prediction is based on a linear projection of the other vessel's observed course and speed. However, the prediction will be in error when the vessel maneuvers, as the maneuver will not be observed for some time. This type of error can be eliminated by requiring every vessel to communicate its intention to change course or speed.

Intention communication between CAS-equipped vessels is particularly essential. When a CAS causes a maneuver, it must inform other vessels immediately. Maneuver decisions made unilaterally by the vessels in a conflict may be non-

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complementary due to differences in the threat criteria and maneuver decision algorithms of their CAS, and the error characteristics of their radars and trackers. However, if all intentions were communicated, the effect of these differences would be overcome. Even if the maneuver decision is incorrect, knowledge of each vessel's intentions can be used by other vessels for taking proper evasive action.

The need for communication of intentions is satisfied to some extent by the whistle signals specified in the *Rules of the Road.* Bridge-to-bridge radio provides greater reliability and flexibility for the communication of intentions and acknowledgments. Bridge-to-bridge communications for collision avoidance are primarily broadcast announcements by maneuvering vessels, not addressed to any other vessel. There is no need for any vessel to acknowledge a broadcast except when the announced maneuver affects it. In that case, it broadcasts its acceptance or rejection plus its own intention and also indicates the identity of the vessel whose maneuver was accepted or rejected. All broadcasts also include the identity of the broadcasting vessel and a geographic reference that permits receiving vessels to locate it on their radar scope. The direction of flow of collison-avoidance information is from each vessel to all other vessels.

Deficiencies of bridge-to-bridge radio

Implementation of the Bridge-to-Bridge Radiotelephone Act can overcome the significant deficiencies of the typical unilateral collision-avoidance process by requiring a vessel to provide course-projection information to all other vessels which they could not obtain by extrapolation. However, even with this improvement, the following deficiencies permit error:

a) *Incorrect association between the vessel's broadcast and its radar blip.* In performing collision-avoidance navigation, the radar watch officer studies the radar blips on the scope to estimate the collision threat. As he hears each bridge-to-bridge transmission, he must immediately make a mental association between the transmission and one of the blips on the radar scope. For various reasons, he may incorrectly associate the transmission with the radar blip of another vessel. This would cause an error in his course projections for both that vessel and the transmitting vessel. Automatic correlation between each transmission and the radar blip is needed to prevent this error.

b) *Delays and interference due to busy channel.* When the channel is busy, announcements are delayed until a quiet time is found. Then, if two or more vessels were waiting, they would both transmit when the other transmission ends with the result that neither announcement is heard because of their interference. A high-capacity random-access capability is needed to provide immediate access to the channel without interference.

c) *Error in understanding or remembering the broadcast information.* The information may be heard incorrectly, written down incorrectly, or if not written, remembered incorrectly. Digital communication, storage, and display are needed to prevent this error.

d) *Error in providing the automatic collision-avoidance computer with the broadcast information.* If a collision-avoidance computer is used, as is becoming common, it should be given the broadcast information. Errors could occur if manual entry is used. Digital communication directly from the transmitting vessel to the computer is needed to prevent this error.

e) *Failure to receive the broadcast information.* Shadowing, interference, or other reasons may prevent the broadcast from being received by some vessels. Frequent repetition of the information is needed to assure its receipt.

f) *Failure to transmit information often enough on situations that continue over long periods.* Information is also needed by other vessels that a particular vessel is anchored, fishing, dredging or maintaining course and speed. Even though the information is broadcast at the start of the condition, frequent repetition is needed to assure that it is received by other vessels as the condition continues.

Requirements for improved collision-avoidance communication

Based on the communication needed for successful collision avoidance and the deficiencies (listed above) that exist if it is done by bridge-to-bridge radio, the functions required for optimal collision-avoidance communication were derived; these are summarized as follows:

Function 1: Provide identity and other appropriate information from each vessel to all other vessels...

...Function 2: in a way that permits receiving vessels to correlate the information with the originating vessel's radar blip (deficiency a),

...Function 3: on a high capacity random-access channel (deficiency b),

...Function 4: in a digital form (deficiencies c and d),

Function 5: with frequent repetition (deficiencies e and f).

Analysis of these requirements indicates that, except for function 2, all five could be satisfied by a one-way random-access digital-data-link communication system, and there would be no requirements for a transponder system. Vessels could transmit their information omnidirectionally in a short burst at frequent random intervals without knowing whether anyone is receiving. The message format and timing could be designed to provide highly reliable reception in the densest possible traffic.

However, to satisfy the requirement for function 2, the one-way data-link system must be augmented by giving receivers the ability to determine the relative position of each transmitter. This ability could be partially achieved without a transponder system by providing an automatic direction finder on receiving vessels. Then the relative bearing of the source of each transmission could be determined. In many situations this would satisfactorily identify the vessel on the radar scope. However, to prevent ambiguity in situations where more than one vessel is at a particular relative bearing, the relative range of the transmitting vessel must also be determined. The range could be found without transponding, using time synchronization techniques for one-way ranging. With direction finding and one-way ranging, information will flow from each vessel to all other vessels without constraint, in accordance with the requirements.

However, for cost-effectiveness, it would be better to use the radar antenna for direction finding and to use transponding for range determination. But care must be taken that these replacements do not inhibit the required information flow! In transponding, the information receiver determines the sender's range by measuring the time elapsing between his interrogation and the receipt of the reply. The interrogation merely provides a time tag for the sender's transmission. The sender, who would otherwise be broadcasting his information, must wait for the time tag interrogation to arrive before he can transmit. Thus, in a transponding system, the required free flow of information from senders to receivers is throttled when the receiver fails to interrogate.

This rather elementary development of

the issue was done to emphasize the point that basic collision-avoidance communication requires only a one-way random-access digital-data link from senders to all receivers and that transponding is added to the data link solely to permit information receivers to measure the range to the information sender. Again, transponding must not be allowed to inhibit the required information flow! Therefore it is essential that all receivers interrogate continuously, nonselectively, and frequently.

The information-rate requirement for the signal format can be based on the needs of an automatic-tracking CAS. Since this is the most demanding of the functional uses of the transponder system, the format will be compatible with all lesser functional uses. To maintain association of identity tags obtained from the transponder system with target blips on the radar, the update rate of the transponder system should be the same as that of the radar. Therefore, the transponder system should be capable of providing one message plus range and bearing for each target for each rotation of the radar antenna, usually 2 to 3 seconds.

Interrogations should then have a characteristic and a rate that satisfies these requirements. Replies should have a characteristic that is compatible and which also assures reliable message transfer without saturation, synchronous garble, mutual interference and multipath interference. Information in a reply must include vessel identification. It is desirable to include maneuver intention, and possibly maneuver acceptance/rejection.

Selection of a suitable system of identification codes presents a significant problem in signal-format design. If the transponder reply contains the full name of the vessel, identification for communication purposes would be complete and unambiguous worldwide. This also would not require any assignment of a special identity code on either a global or a local basis. However, this approach is not a desirable format for data-link communications.

The most desirable format, for simplicity of coding and decoding circuitry and for communication reliability, would be very short and have a fixed length. Obviously such a format would not identify a vessel uniquely as a particular vessel of the worlds's population. However, in a collision-avoidance communication situation, the need is only to identify a vessel as a particular one within the radio/radar horizon. This need can be filled by an approach that uses a short fixed-length identity code which will not require a special assignment to each vessel.

One possible approach is based on random selection of a code number by each vessel. For example, if the maximum number of vessels expected to be within line of sight is 30 and the system provides 1000 codes, the probability that two vessels choose the same code is less than one in a thousand. If two vessels happen to choose the same code, it would be seen by other vessels and short voice communication would request them to change. To implement this identity format, twelve binary bits (3 binary-coded-decimal digits) would be used in the message and the equipment would have knobs to set each of the three digits. Possibly only a two-digit code would be needed. When using voice communication, the vessel would be referred to by its selected number which would be visible to both the sender and the receiver. Names would not be necessary.

Intentions are amenable to digital communication when they can be communicated by a small set of standard maneuvers, each of which can be represented by a simple symbol. These could include "Maintaining Course and Speed", "Turning Right", "Turning Left", "Reversing Engines", "Anchoring", *etc.* It is undesirable to include other types of messages because their complexity may make manual composition difficult and voice communication would be faster. Four message bits would permit a choice among sixteen possible symbols.

Some provision is needed for communicating acceptance or rejection of another vessel's stated maneuver and identification of the vessel to which it applies. This could be provided by including appropriate symbols in the transponder reply if the identification of the other vessel can be easily inserted. Otherwise this function should be performed by voice communication. It should not be performed on the interrogation link because this would not provide correlation with the radar blip of the sending vessel, which is a fundamental operational requirement.

Means must be provided for selecting the maneuver symbol, and possibly the Accept/Reject symbol with the other vessel's identity on the few occasions when it is applicable. Selection may be done manually with a set of simple pushbuttons. However, manual entry of the maneuver symbol presents an opportunity for human error in omitting or delaying entry or removal when it is no longer applicable (the automobile turn-signal problem). To avoid possible delays or errors in the information, which would negate one of the purposes of the transponder, it would be preferable to insert and remove maneuver symbols automatically by sensors and/or by the CAS.

Requirements for range and bearing measurement

The justification for using a transponder system is that it obtains the range and bearing of the source of each collision-avoidance communication. The signal-format requirements for its communication functions were developed in the preceding section. This section develops the signal-format requirements for its range and bearing measurement functions. The objective of measuring range and bearing via the transponder system is to provide an association of the transponder message with the correct target blip on the radar PPI scope. To accomplish this without ambiguity, the resolution of targets and the accuracy of range and bearing measurement must be at least as good as that of the radar. If they were not, incorrect association could occur when targets are closely spaced in either range or bearing.

Providing the required range measurment accuracy is straightforward, with a bandwidth about the same as that of the radar, and a reply signal power greater than that of the radar, random errors will be minimized. Bias errors must be minimized by proper specification of transponder turnaround time.

Providing also that the required bearing measurement is straightforward, radar blips appear on the scope as an arc representing the position of a number of hits on the target as the antenna beam sweeps by. The bearing of the vessel is taken as the center of this arc. Even on a synthesized display, the displayed position of the target is derived the same way by processing the entire arc. To be able to make the bearing measurement with sufficient accuracy to associate the transponder message to the correct radar target, the transponder reply signals also must produce a similar arc. Interrogations and replies must therefore be at the radar PRF to achieve the same number of hits on the target. Acceptable accuracy possibly may be obtained at one half the radar PRF.

Let us consider the desirability of reducing the interrogation and reply rate still further, say to one per target, and accepting some higher probability of ambiguity. For a typical marine radar with a rotating antenna, the antenna beamwidth was designed to provide adequate azimuth resolution of targets and bearing measurement accuracy. The rotation rate of the antenna was designed to provide a sufficiently high update rate on all targets. The PRF was designed so that, with that beamwidth and rotation rate, some minimum number of hits would be obtained on a target to assure detection with a certain reliability and bearing determination with a certain accuracy.

Now if a transponding system were added, operating at the radar PRF and via the radar antenna, about the same number of hits would be obtained, producing an equivalent arc. In its simple free-running operation at the radar PRF, the number of hits on some targets are already at a minimum. To reduce the number of hits to one, a computer would be needed to track targets and to send that one interrogation when at least some part of the antenna beam is on the target. When this occurs, although the reply may be received, the transponder system is not measuring the bearing (unless a sophisticated monopulse antenna and receiver is used). The bearing information comes from the computer whose source of data is the radar. Thus, the desired association of the transponder message to the correct radar blip is not achieved.

Ironically, lowering the PRF to produce one hit per target requires a more complex system and results in zero bearing-measurement capability. By running at the radar PRF, a computer is not required and an accurate bearing measurement can be made.

Table I — Summary of signal format requirements.

Characteristic	*Communication*		*Range and bearing measurement*
Interrogation type	Continuous Non-selective		
Reply type	Minimum Blocking, Synchronous Garble, Mutual Interference, and Multipath Interference		
Reply rate	One Message per Vessel per Antenna Rotation		At radar PRF
Reply content		*Bits*	
	3 BCD Identity	12	
	1/16 Maneuver	4	One pulse
	3 BCD Optional		
	Other Vessel Ident	(12)	
	Overhead (Approx)	19(32)	
	Total	35(60)	

To provide reply signals that are equivalent in format to those of the radar, transponder replies should be single pulses which are received at the same range and bearing as the corresponding radar returns and have the same resolution (freedom from synchronous garble) and number of hits on each target. To maintain registration between transponder information and radar blips, replies from all targets must be obtained during each rotation of the antenna. To produce such radar-like replies from transponders, radar-like interrogations are required. Such interrogations must therefore be continuous, non-selective, and at the radar PRF.

The type of reply described will have greater signal strength and position stability than the radar returns. Fed directly to the radar scope, the reply signals would produce a similar arc which would improve visual detection of weak targets and accurate measurement of their range and bearing. Fed to the CAS in parallel with (or in place of) radar returns, they could be handled by the existing tracking circuits. The signals would also be compatible with the input circuits of synthesized video displays. Measurement accuracy is improved because of higher signal power and freedom from clutter and glint.

Signal format requirements

The primary purpose of the analysis of operational requirements is to develop their impact on the signal format. Development and international standardization of a signal format is the ultimate goal. In the preceding sections signal format requirements were developed separately for the communication aspects and for range and bearing measurement aspects of the transponder system. These requirements are summarized in Table I. The selected signal format must satisfy all of these requirements. It must permit single-mode operation with continuous, non-selective interrogations. The reply format must minimize blocking, synchronous garble, mutual interference, and multipath interference. For range and bearing measurement purposes, replies must be at the radar PRF but each reply need be only a single pulse. For communication purposes, only one message (of up to 60 bits) is needed per ship every two seconds.

In our studies, two basic transponding signal formats—conventional and discrete address—were carefully examined against these requirements and found to be unsatisfactory. A new format, called

Range Division Multiply Access (RDMA) had to be developed to satisfy the requirements.

Conventional transponding

Conventional transponding, as exemplified by the Air Traffic Control Radar Beacon System (ATCRBS), provides for interrogations and replies that satisfy the basic requirements for continuous identity determination, message communication, and radar-compatible signals for range and bearing measurement. However, it has certain well known problems that cause it to be unacceptable.

Conventional transponding is able to satisfy the basic requirements by utilizing nonselective interrogations that are synchronized with the radar and transmitted via an antenna mounted on the radar pedestal. In reply to each interrogation, transponders emit both the single pulse needed for range and bearing measurement and the message containing its identification. Thus, each reply is at the radar pulse rate and has a fairly long duration. The actual duration is determined by the product of the number of bits in the message and the duration of a single bit which itself is defined by the bandwidth available.

In a single-interrogator environment, such as a traffic surveillance system, this conventional transponding technique is satisfactory except for limitations of synchronous garble and multipath interference. Synchronous garble occurs when two or more transponders are simultaneously within the interrogator beam and have range separations which are so small that their reply messages overlap and can not be decoded by the interrogator. For example, if the reply message length is 12 μs, messages from transponders separated less than a mile can not be resolved. Multipath interference occurs when a reply message is propagated to the receiver over one or more additional paths due to reflecting surfaces. If a reflected message partially overlaps the direct path message, it causes interference which may prevent decoding. The longer the message, the greater the opportunity for overlaps.

In an environment containing many interrogators, there are additional problems—blocking and mutual interference. With many sites interrogating, the probability is much greater that a transponder is blocked and fails to reply because it is in the process of replying to another interrogation. Again, the longer the message length, the greater is this probability. Also, because of the greater number of interrogations, the number of replies propagating at any time will be greater. This increases the probability that unwanted replies called fruit will also be received. Complex defruiting circuitry is needed to extract wanted replies. If the fruit overlaps wanted replies, the wanted replies may be lost.

Discrete-address transponding

The discrete-address interrogation approach was investigated because of its resistance to most of the problems of conventional transponding. However, it was complex to operate and did not meet the operational requirements for providing timely identification, communication, and suitable signals for accurate range and bearing measurement. Although discrete-address transponding is useful in centralized surveillance systems, such as the FAA Air Traffic Control System, it is not appropriate for ship-to-ship service which has much different operational requirements. In addition, certain characteristics generally attributed to discrete address transpond ing were found to be fallacious.

In discrete-address transponding, interrogations contain the address or identity code of the transponder from which a reply is desired, and only the addressed transponder will reply. The primary objective is to eliminate the problems of conventional transponding. In addition, it is often proposed that the addressed interrogation carry a data-link message from the interrogating vessel to the addressed vessel. Synchronous garble is prevented by timing the individual interrogations to closely spaced transponders so that the resulting replies do not overlap. Blocking and mutual interference are reduced because, for each interrogation, only one ship will reply instead of all those illuminated by the antenna. On the other hand, susceptibility to multipath and mutual interference is increased in the interrogation link because interrogations are lengthened to contain addresses and messages, and would be more frequent in order to address all ships separately within the same time. Replies would also be lengthened to contain the interrogator's address.

A basic problem of discrete-address transponding is that it must alternate between two modes of operation which presents difficulties to the operator. Because it must determine the address codes of surrounding vessels before it can operate in the discrete-address mode, the discrete-address interrogator must first be switched to the "all-call" mode. This mode utilizes the conventional transponding technique which has the problems discussed above. These problems may prevent addresses from being determined and thus prevent switching to the discrete-address mode. It must be switched to the discrete-address mode to eliminate synchronous garble and to reduce blocking and mutual interference. But it can't get to this mode without first operating successfully in the all-call mode. Switching back and forth will be complicated and frustrating to the operator as it will be time consuming and provide no indication of what is wrong. Most importantly, he will not have the information he needs when he needs it because of the delays.

When he gets to the discrete-address mode, data will be received only from ships that he chooses to interrogate and data from ships that were not seen, identified, or chosen would not be received. Since the steps involved are many, and depend in some cases on human action, the desired certainty of identifying a voice-communicating vessel or of timely receipt of digital messages is not achieved. Thus, the discrete-address mode does not satisfy the basic system requirement to provide timely communication of identity and maneuver data from the sender to all potential users. If it operates by interrogating a vessel only once as the antenna sweeps by, it will require a tracking computer and will not obtain a bearing measurement, as discussed previously. To avoid this, it must interrogate repeatedly at the radar PRF over an azimuth angle wider than the radar arc. In doing this, interference on the interrogation link is substantially increased, and the reply data rate is decreased because other vessels cannot be interrogated at that time.

There is some interest in using discrete-address transponding for ship-to-ship service, possibly because of the FAA plan to use it for Air Traffic Control (ATC) under their Discrete Address Beacon System (DABS) program. However, it is important to understand the differences between ATC and ship-to-ship (s-s) operation that invalidate an assumption that a DABS type of transponder is also optimal for ship-to-ship service. The differences are:

a) In ATC, the required primary flow of information is from one ground-based interrogator to many airborne transponders as a data link to convey computer-generated commands. This flow is unimpeded because the computer controls the link. Required information in the reverse direction is limited to acknowledgements, and it flows because the computer is certain to interrogate all aircraft within a short time cycle. In s-s, the required flow of information is from the transponder to the interrogator but it would be impeded since there is no assurance that a particular interrogator will interrogate a particular sender within a short period.

b) In ATC, a large number of aircraft are interfaced by a single interrogator, which controls all transmissions and prevents interference. ATC does have problems in areas where there is overlapping coverage by more than one interrogator. These problems are being reduced by minimizing overlapping coverage and by synchronizing the interrogators' pulses and antenna rotation. In s-s, since transponding vessels are also interrogators, these minimizing techniques are not applicable. The result will be much greater probability of blocking and interference on the interrogation and reply channels.

c) In ATC, a large sophisticated computer is used to project the track for each aircraft, and it can easily control the interrogation to the approximate time when the antenna points to the aircraft being addressed. The measurement of the aircraft's relative bearing is accomplished by monopulse techniques on the received reply. In s-s, one of the objectives of the interrogation is to determine the bearing of the other ship, because it is not known in advance. The track-prediction computer (required for operating the interrogator) and the monopulse antenna and the receiver (required for bearing measurement) are considered to be too sophisticated for this service. Also, since the shipboard antenna is not on a steady land-based platform, timing of the interrogation would have to be compensated for yaw, pitch, and roll of the ship. To overcome these difficulties, interrogations would have to be sent with each radar pulse as the antenna rotates through a broad enough azimuth angle to be assured of covering the desired ship with enough hits to make a bearing determination. This would substantially increase interference in the interrogation and reply links.

d) In ATC, every transponder is interrogated during each antenna rotation to achieve the required data rate equivalent to that of the radar. To maintain this data rate and yet prevent synchronous garbles, all transponders within the antenna beam are individually interrogated during each radar pulse period resulting in an interrogation rate much higher than the radar pulse rate. In s-s, because of the greater number of interrogators, and because of the greater computer sophistication that would be required, the higher interrogation rate is undesirable. To offset this, interrogations to potential synchronous-garble-producing ships could be spaced by a complete antenna rotation. However, many rotations would be required to obtain a single data set and the data rate would then be far lower than that of the radar, which is obviously undesirable. The data rate would be even lower if the spacing operation were done manually.

e) In ATC, the requirement for continuously determining the identity of aircraft not previously identified is fulfilled by providing full-time continuous interrogations in the all-call (or ATCRBS) mode interspersed with DABS mode interrogations. The basic problems of the "all-call" mode will exist but are minimized by remote-control switching of the transponder. Once the interrogator obtains the identity of a transponder using the all-call mode, it commands it not to reply to all-call interrogations but only to discrete-address interrogations. After having switched, the transponder's identity can not be determined by any other interrogator. In ATC, this causes no problem because at any time only one control site is responsible for a particular aircraft. The address is passed along from site to site as the aircraft crosses the boundary. In s-s, because all vessels are interrogators that need to receive identification and communication, transponders would have to reply to interrogations of either mode at any time. Interrogators would have to intersperse all-call with discrete-address interrogations in order to identify newly encountered vessels. If they were to be 100% interspersed as in DABS, all of the all-call problems will exist, and there will be no benefit from discrete addressing. If they were to be less than 100% interspersed, the all-call problems would be reduced but there would be a delay in receiving identification and communication from newly encountered vessels.

Several other concepts about discrete addressing were found to be fallacious for the reasons given below:

Fallacy 1 — It will provide a two-way data link for all types of messages between interrogators and transponders.

A data link is merely a communication pipeline between a message generator at one end and a message user at the other. Its value must be considered in terms of the efficiency of the total process. The efficiency is high when the message generator is a computer or a digitizing instrument and the message user is a computer. However, when the message generator and user are people, the efficiency is very low because they can talk faster than they can compose digital messages. Therefore, the data-link capability of the transponder is useful only for messages that can be composed easily. In the reply link, examples of useful messages include the identity code of the vessel and a pushbutton-selectable maneuver symbol. Insertion of an identity code of another vessel causes operating complications as it would have to be quickly composed, inserted, and removed in successive messages. Composition of other messages is still more difficult. It may be more practical to communicate these by voice. Also, any lengthening of a message will decrease the probability of its being received correctly.

It is especially undesirable to include a message in the interrogation as this would not provide the receiver of this information with the relative position of the sender, and this violates the fundamental operational requirement of the transponder system. Only by interrogating can a vessel correlate a received message with the relative position of its source. This correlation requirement is the basic justification for using a transponder system. To satisfy this requirement, information must flow only from the transponder to the interrogator. A reply message can include any information that would be considered for inclusion in an interrogation.

Fallacy 2—It does not have interference on the interrogation channel because interrogations are addressed.

The type of address coding required in this service does not permit the use of anti-jam correlation techniques. Interference will occur when a part of one transmission overlaps a part of another with the result that the address is not properly decoded and a reply is not sent. The probability of interference is actually much greater than in conventional transponding due to the long length of interrogations (since they contain addresses of both sender and receiver plus a message) and also due to the broad azimuth angle over which interrogations must be sent.

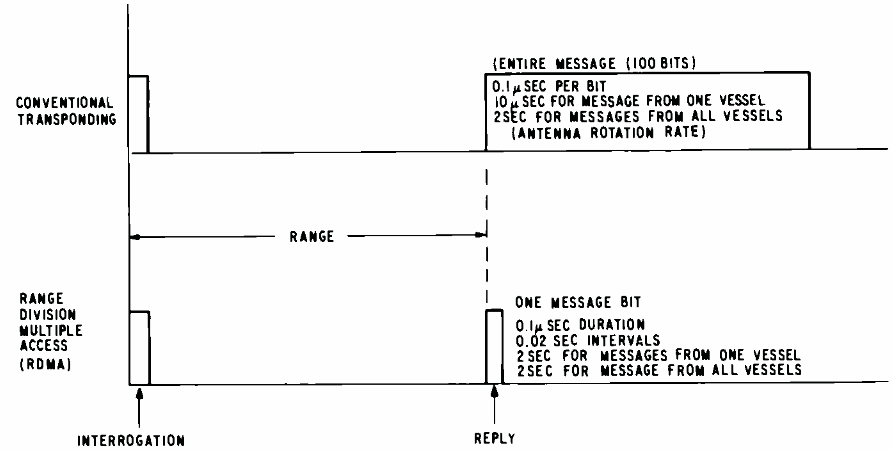

Fig. 1 — Comparison of conventional and RDMA signal formats.

Fallacy 3—It does not have fruit in the reply channel because replies contain the address of the interrogator.

This is true only in the sense that the interrogator will not accept replies that do not contain its address. But these unwanted or fruit replies cause rf interference which can prevent properly addressed messages from being received. The greater length of replies also increases this probability.

Fallacy 4—It can provide enhancement of targets on the radar scope.

Enhancement means to make targets more detectable than they would be by radar alone. Proper enhancement would provide replies from all targets, with greater signal strength than radar returns but at the same PRF. This is needed to permit range and bearing measurements to be made on all targets and to permit the CAS to detect and track transponder replies in the same way as radar returns, and with equal or better accuracy. Discrete addressing does not provide such enhancement, it can enhance only the radar blip of the particular vessel being addressed. It would be more correct to call this process target identification because it simply allows the operator to see a selected vessel.

To summarize, discrete address transponding was found to be unsatisfactory because the desired smooth flow of data from all sources occurs only at the discretion of the user with many operational complexities, delays, and opportunities for error. Its intended virtue is to overcome the blocking, synchronous garble, and mutual interference of the conventional or all-call mode, but it must first operate successfully in that mode in order to work at all. If it does operate successfully in the all-call mode, the discrete-address mode would not be needed because the all-call mode would furnish all of the necessary data transfer, whereas the discrete-address mode does not.

Range division multiple access (RDMA)

Because it was found that neither conventional transponding nor discrete-address transponding would meet the requirements for systems where large numbers of users must continuously transpond among each other to determine relative positions and to receive identification and other communication, RCA developed a unique random-access signalling technique called Range Division Multiple Access (RDMA). It meets all of the signal-format requirements identified earlier in this paper. RDMA permits highly reliable continuous transponding, and thus insures that data made available for communication by any vessel is immediately received by all nearby equipped vessels. The RDMA signal format eliminates the problems of synchronous garble, blocking, mutual interference, and multipath interference which occur with conventional transponder formats. It also eliminates the mode-switching operations, potential delays and errors, and other disadvantages of the discrete-address transponder format.

The performance of RDMA has been evaluated in high density traffic situations by extensive computer simulations and hardware tests since 1967. Its basic elements have been incorporated, in different forms, into two hardware programs which have been undergoing tests. The SECANT (SEparation Control of Aircraft by Non-synchronous Techniques) airborne collision avoidance system has recently successfully completed flight tests by the U.S. Navy. This system also has been tested in a simulated environment with 800 aircraft in view. The HATRIC (HArbor Traffic Ranging, Identification, and Communication) System provides precision navigation and surveillance in harbors, including two-way identification and communication. Development of its navigation function has been underway since July 1972 under the U.S. Coast Guard RIver and Harbor Aid to Navigation System (RIHANS) program.

Rather than discuss the specific RDMA parameters that were selected for the SECANT and RIHANS systems, the general characteristics of RDMA will be described. It is expected that specific parameters to optimize RDMA for ship-transponder service would be developed by a national and/or international standards committee.

RDMA is similar to conventional transponding in that it has a single mode with continuous all-call interrogations. The basic difference in RDMA transponding compared to conventional transponding is simply that the reply, instead of being a continuous burst of all the bits of the message, is only one message bit. Thus, the complete message is spread out with only one bit sent at a time and with a relatively long time between bits. The duration of a bit is based on the available bandwidth, which is assumed to be the same for any type of transponder and for the radar. The allowable time to which the message is spread is determined by the data rate required, which for ship-to-ship service, could be time for one antenna rotation, two to three seconds. A comparison of signal formats is shown in Fig. 1.

For example, consider a message of 100 bits and a bit duration of 0.1 μs. For a 2-s message period, the bit rate would be 50 bits/s, resulting in a spacing of 20,000 μs between bits and an occupancy ratio of 1:200,000 for each bit. In conventional transponding, the same message would occupy 10 μs and would cause synchronous garble on replies from two vessels separated by any distance up to almost a mile, which is intolerable. The RDMA reply, occupying only 0.1 μs, reduces vessel separations susceptible to synchronous garble to one one-hundredth of this. With the pulsewidth about the same as that of the radar, message resolution is as good as target resolution. Similarly, the probability of transponder blocking, mutual interference, and multipath interference, which are affected by the duration of the reply, would also be reduced two orders of magnitude.

Since the time required to obtain the message is about the same as the time for one rotation of the radar antenna, interrogations and replies for message exchange are transmitted and received omni-directionally. Because interrogation is non-selective, replies are received from all vessels within the radio horizon, and these are separated by the respective range of the vessels—hence the name Range Division Multiple Access. Reply signals are very narrow pulses and are scattered in the time domain on a basis which is as random as their relative distances. Further scattering results from the randomness of timing and position of interrogators. Due to the random position and motion of vessels, the probability of signal overlap caused by equal ranges is very low. The message from each transponding vessel is accumulated by decoding the data bit contained in each pulse coming through range gates which are automatically set on each target. Messages from all vessels are accumulated simultaneously. Several forms of bit coding are suitable including pulse-position modulation, pulse-amplitude modulation, phase-shift keying, and frequency-shift keying.

The range gates provide the range of each target with high accuracy. Since an independent range measurement is made on each message bit, integration reduces the random error to one tenth that of the other techniques where one measurement is made on the entire 100-bit message. Determination of target bearing is done via the radar antenna. For this reason, the system should operate at X-bands (9300-9500 MHz)) as these signals can generally be handled by the radar antenna whether X- or S-band (2900-3100 MHz). In this directional channel, interrogation and replies are the same as in the omni channel, except that the PRF is the same as the radar pulses. The range and bearing resolution is the same as that of the radar, but the measurement accuracy will be better because of the greater strength and stability of the signals. These signals can be tracked by the CAS and, on the radar scope, will present a target display similar to but stronger than that produced by radar returns. It is believed that the greater accuracy provided by these signals will eventually be found to be necessary to improve the reliability of CAS systems. The range and bearing of each target whose identification and maneuver message is received in the omni channel is determined by detecting the coincidence of arrival of pulses in both channels. Messages are received in the omni channel without bearing discrimination and pulses are received in the directional channel without a message. Coincidence in both channels provides the correlation between message, range, and bearing. A block diagram is shown in Fig. 2.

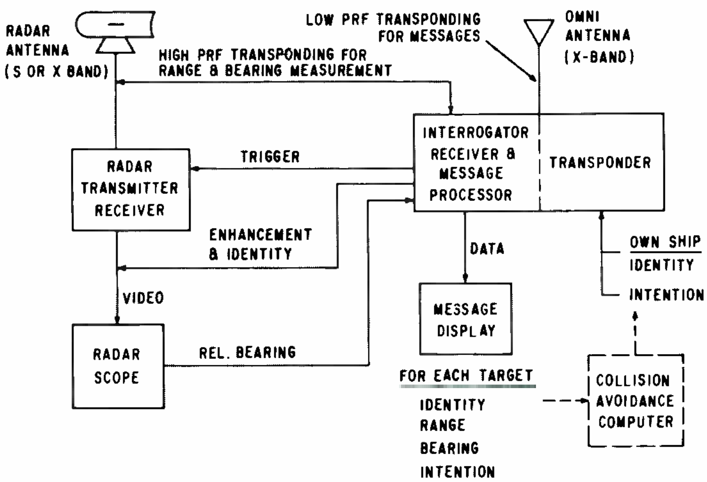

Fig. 2 — Ship transponder system block diagram.

The RDMA format provides the equivalent all-call interrogation capability of conventional transponding, which was shown to be essential to a successful collision-avoidance system. However, it eliminates the problems of conventional transponding, namely synchronous garble, blocking, mutual interfernce, and multipath interference. It receives the same number of message bits from all the targets in the same period as conventional transponding. However, in conventional transponding, the bits are compacted into tight message bundles which is the cause of the problems; in RDMA, the bits are spread out in time and thereby reduce the problems to an insignificant level.

Conclusions

Careful, objective analysis demonstrates that a ship-to-ship transponder system is essential for overcoming the deficiencies of present collison-avoidance navigation and communication. Implementation of the system would require national and international standardization of its signal format so that equipment on all vessels would operate compatibly.

Design of a suitable signal format must be based on satisfying specified operational requirements. In turn, operational requirements must be specified to provide the needed improvements in collision-avoidance navigation and communication, with reliability, simplicity, and ease of operation. Thus, to move toward the goal of international standardization, agreements must be reached on a specification of operational requirements and on a specification of a suitable signal format.

Closer look at electro-optic modulators for lasers

A. Waksberg

To determine whether external or internal amplitude modulation is advantageous in a particular situation, a detailed quantitative analysis has been conducted. The results of this analysis are presented in brief form in this paper; reference 4 contains a more comprehensive treatment.

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EXTERNAL amplitude modulation of a laser using electro-optic modulators has been with us almost since the beginning of the laser itself. More recently, a number of workers have demonstrated that internal modulation of a laser can be an appealing alternative to the more established external modulation techniques.[1,2,3]

Conceptually, this type of modulation acts on the field *inside* the laser cavity. Since this field is larger than the external field, a potentially smaller drive voltage would be required to produce the same modulated laser output. Unfortunately, the introduction of a modulator inside the laser cavity may have a large effect on the laser field both inside and outside the laser. Depending on the laser gain, it is not obvious whether the losses due to the insertion of the crystal will be more than offset by this theoretically more efficient method of modulation.

It might be noted that other modulation techniques such as those using acousto-optics have now come of age and can be attractive alternatives for moderate bandwidth systems. At this stage, however, the electro-optic modulator still provides the widest possible bandwidth capabilities leading into the GHz region.

Electro-optic modulation techniques

Basically, electro-optic modulation makes use of optical phase shifts produced along the electro-optic axes of the crystal as a result of an electric field applied across it. If the optical beam is passing through the crystal with its **E** field along one such axis, pure phase modulation is produced. If the optical field has its polarization at an angle with respect to the electro-optic axis of the crystal, then the beam may be thought as being resolv-

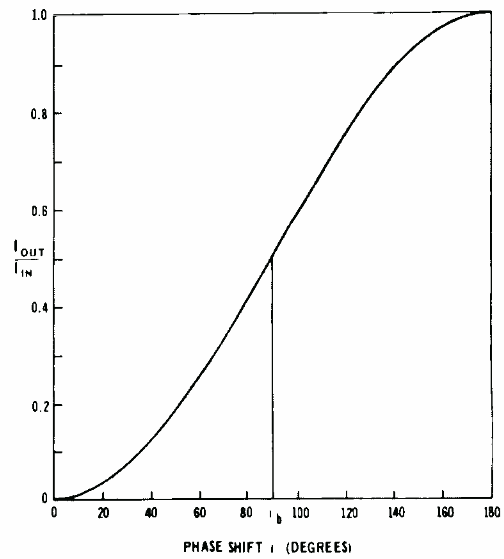

Fig. 1 — Laser output as a function of phase shift in an external amplitude modulator.

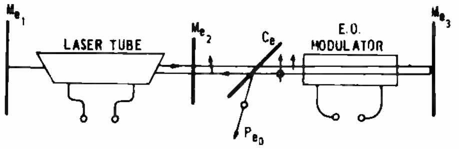

Fig. 2 — External amplitude modulation for a double-pass system.

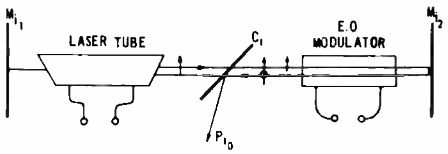

Fig. 3 — Internal amplitude modulation.

ed along the two axes as it passes through the crystal. Each component will travel at a different speed dictated by the crystal and the modulation field. The total phase shift between the two beams is given by

$$\Gamma = kVL \qquad (1)$$

where k is a constant which depends on the electro-optic coefficient as well as the geometry, V is the field applied, and L is the length of the crystal. At the output of the crystal, the two optical components then recombine and, because of their respective phase shift, will generally produce an elliptically polarized beam. Using this effect for amplitude modulation, typically the optical beam is launched with its polarization at 45° to the electro-optic axis and then the beam is analyzed with a polarizer at 90° to its original polarization. With no modulation field applied, no relative phase shift is produced between the two components, and hence no perpendicular component of the field is created. All the laser output would be absorbed by the polarizer, and the effective output of the modulation is zero. As the field is increased, the phase shift would cause an increasing amount of polarization along the polarizer with a resulting higher output — up to the point where a relative phase shift of 180° would result in a total rotation of the field of 90°, and this would result in maximum output. The output intensity of such a modulator is of the form.

$$I = I_o \sin^2\Gamma/2 \qquad (2)$$

Pure phase shifts can be used in other systems, such as fm or phase modulation, but these require sophisticated heterodyne techniques and have more restricted uses. This paper, therefore, concentrates on amplitude modulation because of its simplicity and versatility. For example, amplitude modulation lends itself to subcarrier techniques using formats such as a.m.-a.m., a.m.-f.m., a.m.-pcm. Also, these modulation schemes can be detected either by envelope detection or heterodyne systems depending on the sensitivity required. Finally, both external or internal amplitude modulations are possible.

Two main classes of electro-optic amplitude modulators can be recognized: One producing the modulation outside the laser itself; the other, internal to the laser cavity.

External amplitude modulation

This type of modulator causes a $\sin^2$ dependence of the output with respect to phase (Eq. 2), as shown in Fig. 1. As with any other non-linear device (including the vacuum tube and the transistor), the laser output can be modulated to obtain linearity if the proper bias is applied and the signal is not too large. Obviously, the best biasing condition is that shown in Fig. 1 as Γ_b. This half-way mark in the modulation curve is the inflection point where both linearity and maximum slope can be achieved. At this point, the phase shift $\Gamma_b = \pi/2$. The biasing condition can be obtained either by applying a bias voltage or an optical bias by introducing a birefringent material in "series" with the electro-optic modulator. To maximize the electro-optic effect and thus minimize the drive power requirement, the system can be arranged so that the laser beam is made to pass twice through the crystal by means of a mirror $M_{e(3)}$ (see Fig. 2). The output P_{eo} is then coupled out by means of a polarization coupler C_e. In that case, the actual signal output at the fundamental modulating frequency and optimum bias is given by

$$P_e(\omega) = P_e J_1(2\Gamma_m) \cos \omega t$$

where $P_e(\omega)$ is the modulated output beam power; P_e is the laser output power; J_1 is the first-order Bessel function of the first type; Γ_m is the amplitude of the modulated phase; and ω is its frequency.

It has been assumed here that the optical components have no loss. Full treatment for a lossy system can be found in Ref. 4. The maximum signal obtainable can be seen to occur for that value of Γ_m that will make the Bessel function a maximum or

$$P_{e(max)}(\omega) = 0.5819\ P_e \cos\omega t$$

Internal polarization modulation

The system is shown schematically in Fig. 3. The polarized beam leaving the laser tube, with its field in the plane of the paper, passes through a polarization coupler C_i unaltered, into an electro-optic modulator. After being reflected by the cavity mirror $M_{i(2)}$ it makes a second pass through the electro-optic modulator and finally strikes the polarization coupler. With the proper orientation of the electro-optic crystal, a voltage applied to it will produce a perpendicular component which is then coupled out by the polarization coupler C_i. Since the energy coupled out is a very small fraction of the internal energy in the cavity, it can be regarded as producing only a small perturbation of the field. High frequency response is therefore possible since the laser mechanism does not have to take part directly in the modulation process.

The output power $P_{i(o)}(\omega)$ at the modulated frequency is now a very complex function of, not only the modulator characteristics, but also the laser mechanism itself. The exact functional

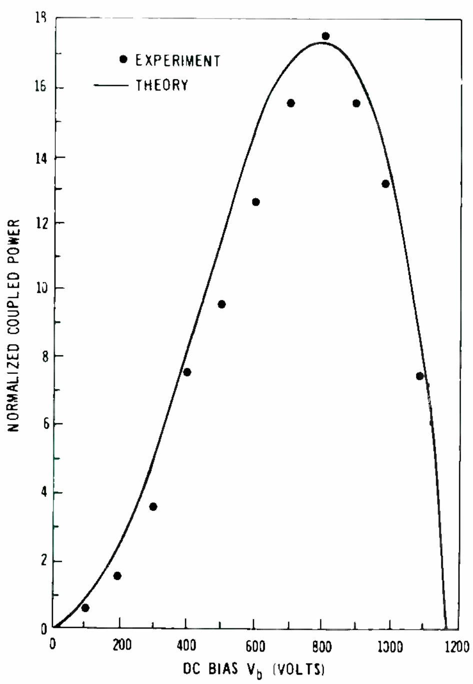

Fig. 4 — Comparison between theory and experiment for output power vs crystal bias.

relation is not given here explicitly, but the interested reader should see Ref. 4. However, a qualitative derivation can be stated: When the average power coupled out of the laser is zero (by producing no phase shift in the modulator) the output signal is obviously zero; as the coupled power is increased, the output signal will increase until the optimum coupling is reached. As the coupling is further increased, the output signal will quickly fall until the laser becomes overcoupled and the lasing action stops. The typical coupled output characteristic, obtained by increasing the bias applied to the crystal, is shown in Fig. 4 for the case of a CO_2 laser-modulation experiment in which the solid line represents the predicted theoretical results; while the experimental results performed in our lab with a *GaAs* modulator 3×3×30 mm are shown on the same graph. Fig. 5 is the actual setup used in this experiment. The laser discharge tube can easily be observed as the main element in the picture. The modulator is enclosed in a cylindrical holder which can be seen to the right, just in front of the laser mirror. The output is coupled out of the right Brewster window of the laser tube, although separate germanium coupling plates have also been used.

Comparison of internal and external amplitude modulation

Internal and external amplitude modulation for realistic modulator losses have been compared by calculating, for each case, the maximum laser signal power output for some small fixed drive voltage and the required optimized bias conditions. The calculations were performed as a function of the laser-gain parameters and modulator losses. We shall denote external polarization modulation by EPM and internal modulation by IPM.

The results are given in detail in Ref. 4. Here we shall summarize some of the findings by presenting some typical results.

The ratio R of the maximum output power retrievable using IPM to that using EPM is plotted as a function of the total gain per pass (g_oL) for various amounts of total fractional loss per pass γ_x of the modulating crystal.

The ratio, R, in Fig. 6 gives a direct comparison between EPM and IPM for small signals. Note that R is the ratio of the maximum laser signal power that can be obtained for IPM and EPM with $\Gamma_m = 1°$. It is therefore evident that this ratio tells us which of the two systems will provide larger laser signals for the same drive voltage. A ratio greater than one means that IPM is advantageous, while a ratio smaller than one implies the converse.

As shown in Fig. 6, for large laser gains, g_oL, IPM always wins. The advantage drops quickly, however, as the modulator loss increases. The largest variation between the two systems occur for lower laser gains. Here, it is found that the modulator losses have the greatest effects. For example, at $g_oL = 0.1$, the IPM is much better than the EPM for low losses while it is infinitely worse for a loss of $\gamma_x = 0.1$ as the IPM laser will not even oscillate under this condition. The reason for this high sensitivity at low g_oL, becomes evident if one recalls that, as the losses approach g_oL, the laser output power quickly drops to zero. As g_oL is decreased, this condition will be approached first by the IPM which has the extra loss of the modulator to cope with inside the cavity.

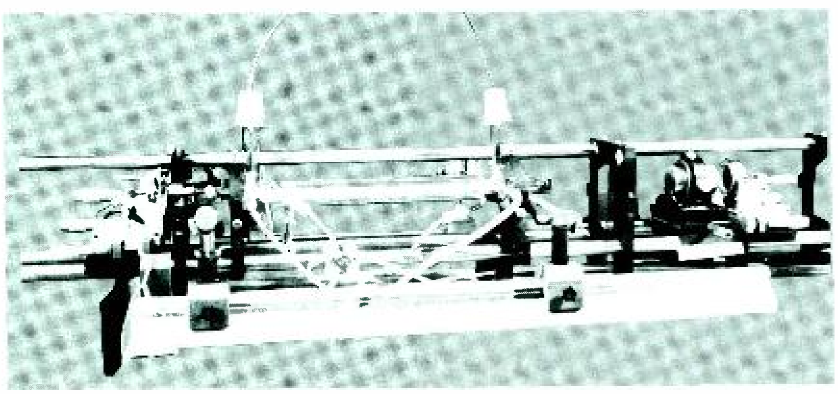

Fig. 5 — Experimental setup.

A special case (labeled S.C. in Fig. 6) has also been calculated for which the crystal is lossless, and the polarization coupler is 100% efficient. The mirrors have been allowed a nominal fractional loss of 0.5% each, and $\Gamma_m = 1°$. Although these parameters cannot be realized in practice, these calculations were done nevertheless to obtain the upper limits of performance of the EPM and IPM systems and for comparison.

From Fig. 6, it is seen that for this special case, the advantage of the IPM over the EPM increases as the value of g_oL decreases and reaches about 35 at $g_oL = 0.01$. This effect is true down to the laser threshold conditions, as in this case the modulator crystal is assumed lossless and both systems have exactly the same total internal loss of 1%.

Signal-to-noise ratio considerations

Another parameter of great importance for signal recovery in a communication system is the signal-to-noise ratio available at the receiving end after detection. Two cases will be considered here. These are the heterodyne and square-law detection systems. The former is superior and can provide much better S/N than the latter. This is obtained, however, at the expense of a more sophisticated system.

Optimization of a signal power for both the IPM and EPM system requires a certain amount of optical bias. The resulting amount of non-modulated intensity will thus contribute to shot noise in the detector.

To bring out the worst possible effect that this and other extraneous "dc" signals might have on the S/N, we shall assume that the detector used is of high quality and is, in effect, background limited. In addition, the receiver has a very narrow field of view, such that the noise is essentially the shot noise produced by the total dc contribution of the received signal P_{ST}. For the square-law detector, the power (S/N) under these conditions can be expressed by[4]:

$$(S/N)_p = \frac{\eta P_s^2(\omega)}{4h\nu\Delta f P_{ST}} \quad (3)$$

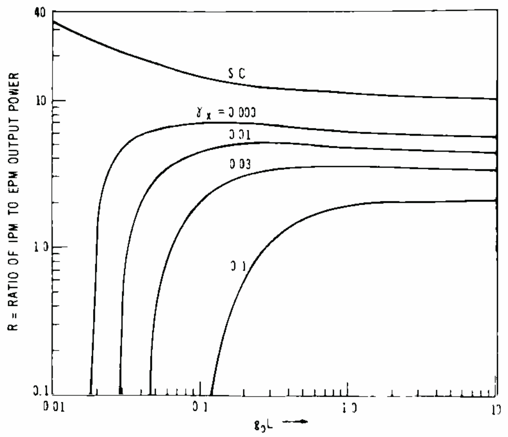

Fig. 6 — Ratio of maximum powers for internal and external modulation and phase shift of 1°.

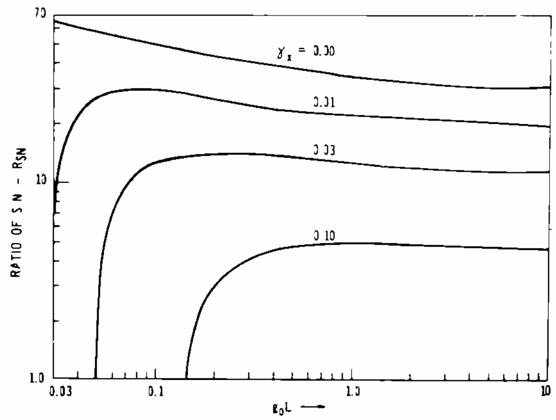

Fig. 7 — Ratio of ***S/N*** **for internal to external modulation and phase shift of 1°.**

where η is the quantum efficiency of the detector and Δf the bandwidth of the receiver.

The (S/N) that can be expected from two identical laser transmitters, one using EPM, the other IPM can now be compared under the condition represented by Eq. 3 — the modulated signal $P_s(\omega)$, having been maximized for each case. The same modulator drive voltage is assumed for both ($\Gamma_m = 1°$).

The ratio of the S/N of EPM to IPM, which will be called *RSN*, is plotted in Fig. 7 as a function of laser gain and crystal losses. It is seen that the advantage of IPM over EPM is substantial for most cases. As an example, it is more than ten times better for the crystal loss $\gamma_x = 0.3$ and g_oL larger than 0.1.

In the case of heterodyne detection, the system is usually run with the L.O. power so large as to make its shot noise larger than all other noise sources. When this is done, the relevant relation is [4]:

$$(S/N)_p = \frac{\eta P_s(\omega)}{2h\nu\Delta f}$$

In this case, P_{ST} does not appear in the expression. This implies that for this particular case, only the modulated part of the received signal $[P_s(\omega)]$ is important in determining the S/N.

A comparison between the S/N's from two identical laser transmitters, one modulated by EPM, the other by IPM. would thus be identical to a comparison between the respective modulated powers, in this case $P_{eo}(\omega)$, independent of their dc content. The ratio of the S/N's is thus equal to R and can be read from Fig. 6.

Drive power requirement

The ratio of the drive-power requirement to the crystal for equal signal output can be shown to be given by:

$$R_p = R^{-2}$$

where R is read from Fig. 6.

As an example, let us take the case of $g_oL = 0.2$. The relative power requirements for equal signal outputs when $\gamma_x = 0, 0.01, 0.03$ and 0.1 are found to be, respectively, 0.02, 0.04, 0.1, 2.8. Because of the square term, the drive power saving can be quite substantial. The maximum saving (from Fig. 6) can be obtained from the special case for $g_oL = 0.01$ where $R_p \approx 0.001$, or a 30 dB saving. This, however, is an upper limit and cannot be achieved in practice. More typical, for $\gamma_x = 0.03$ and $g_oL = 0.3$. R_p = 10 dB, which is still appreciable.

A similar study was made for the case where the drive voltage and bias applied to the modulation crystal were optimized to obtain maximum available laser signal-power output. In this regime, the output usually contains a substantial amount of harmonics. These can, however, be quite acceptable in some modulating systems such as PCM. In this case, the EPM and IPM comparisons were found to be in general accord with the results obtained for small-signal theory, although the actual numbers were different. In general, the improvement of the IPM over EPM, when they occurred, were less important than in the small-signal regime of operation.

Summary of results

Detailed calculations have been made of optimized signal output power of lasers resulting from both internal and external polarization modulation. Results have shown that, in general, for high ratios of laser gain to modulator loss (or g_oL/γ_x):

1) IPM can have substantially greater signal output power.
2) IPM can have substantially greater signal-to-noise ratios at the receiver, the improvement depending on type of detection system used.
3) IPM will require less drive power to the modulator for equal signal out — hence it will have greater efficiency.
4) As γ_x approaches g_oL, the converse of 1) through 3) above quickly becomes true.
5) Effects 1) throught 3) are more pronounced for small-signal drive than they are for the mode of operation that maximizes the output power.

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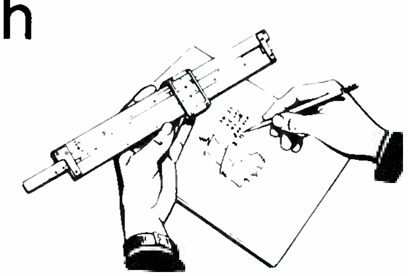
Engineering and Research Notes



Brief Technical Papers
of Current Interest

Divide-by-N circuit with variable pulse-width output

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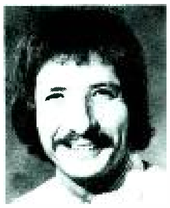

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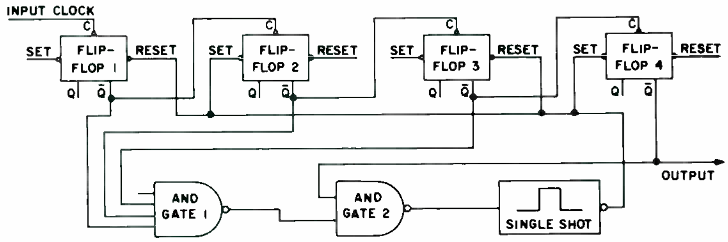

Fig. 1 — Divide-by-N circuit with variable width output pulse capability.

The circuit described divides a train of input clock pulses by N, and also has the capability of varying the width of the output pulses. This circuit is expected to be extremely useful as a timing circuit for solid-state tv camera applications. Fig. 1 shows the circuit using four flip-flops; up to 15 flip-flops can be accommodated.

Using n flip-flops, a single-shot, and two *and* gates, the circuit can divide by an N over the range $2 \leqslant H+L \leqslant 2^n$, where $H+L=N$; H is the number of pulses counted during the high portion of the output and is limited to the range $1 \leqslant H \leqslant 2^{n-1}$; L is the number of pulses counted during the low portion of the output and is limited to the range $1 \leqslant L \leqslant 2^{n-1}$.

The circuit in Fig. 1 is connected to divide by 10 and have an output pulse width H of 7 clock pulses (see Fig. 2). The circuit of Fig. 1 operates as follows. With a train of clock pulses going into the input of flip-flop 1, eventually one of the pulses switches the $\overline{Q}$ output of flip-flop 4 to the high state. This occurs when $\overline{Q}1$, $\overline{Q}2$, and $\overline{Q}3$ all go low (see Fig. 3). For the first six pulses of the input clock (Fig. 3), at least one of $\overline{Q}1$, $\overline{Q}2$, and $\overline{Q}3$ is low. Therefore, the output of *and* gate 1 (input to *and* gate 2) is high. Since the other input to *and* gate 2 ($\overline{Q}4$) is also high, the output of *and* gate 2 is low. When the seventh pulse is put into flip-flop 1, $\overline{Q}1$ goes high, and since $\overline{Q}2$ and $\overline{Q}3$ are already high, the output of *and* gate 1 goes low. This negative-going pulse at the input of *and* gate 2 makes the output go positive, which in turn triggers a pulse from the single shot. In Fig. 1, the output of the single shot is put into the sets of flip-flops 2 and 4, and the resets of flip-flops 1 and 3. The result is that the output states correspond to a count-of-five condition, that is, $\overline{Q}2$ and $\overline{Q}4$ are switched to the low state, while $\overline{Q}1$ and $\overline{Q}3$ remain in the high state. Now, when only three more pulses are counted, $\overline{Q}4$ goes positive, and the circuit is set to start the cycle again. Thus, using $\overline{Q}4$ as the output, the circuit of Fig. 1 divides by 10, and has an output pulse width of 7 clock pulses.

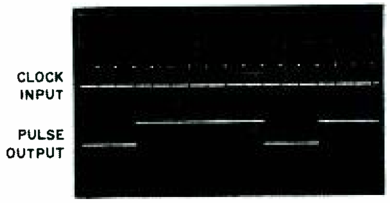

Fig. 2 — Waveforms for divide-by-10 with an output pulse width of 7 clock pulses.

The circuit connections required for division by any number N (= $H+L$) and variable width of the output pulse (H) are given in Tables I and II for the case of four flip-flops in the circuit. These tables are easily extended to n flip-flops by the following simple procedure. Considering Table I first, it is observed that if Q4, $\overline{Q}3$, $\overline{Q}2$ and $\overline{Q}1$ are replaced by 1, then each row of the table gives the binary representation of the number at the left. Thus, a table of binary numbers from 1 to 2^{n-1} can be used to obtain Table I for n flip-flops merely by replacing each 1 by the $\overline{Q}$ of the proper stage. The only exception is for the n^{th} flip-flop, in which case the 1 is replaced by the Q output instead of the $\overline{Q}$ output. To obtain Table II for n flip-flops, a table of binary numbers from $(2^{n-1}-1)$ down to zero is prepared, then *set* replaces each 0, and *reset* replaces each 1. In this case the binary number of the table represents the equivalent number of pulses put into the flip-flops by the pulse from the single shot. The relation between L and the binary number of the table is $L + (binary\ number) = 2^{n-1}$.

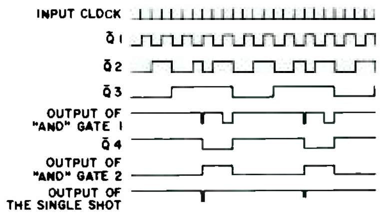

Fig. 3 — Input and output waveforms for circuit shown in Fig. 1.

The scheme of Fig. 1 can be used for up to $n = 15$ flip-flops. This is implemented by using 8-input *and* gates in the following manner. The $\overline{Q}$ outputs required to obtain the desired value of H are obtained from a table such as Table I. The required $\overline{Q}$ outputs from the lower numbered flip-flops ($\overline{Q}1$, $\overline{Q}2$, $\overline{Q}3$, etc.) are connected to the inputs of *and* gate 1. If more than eight $\overline{Q}$ outputs are required, the $\overline{Q}$ outputs from the higher numbered flip-flops ($\overline{Q}9$ through $\overline{Q}14$) are connected to the input of *and* gate 2. This order of lower numbered flip-flops to *and* gate 1, and higher numbered flip-flops to *and* gate 2 must be maintained, otherwise timing will be incorrect for the proper count of H to be obtained. Also, for all values of H, $\overline{Q}n$ is always an input to *and* gate 2; and finally, for the special case of $H = 2^{n-1}$, Qn (not $\overline{Q}n$) is the correct input to *and* gate 1.

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Table I — Circuit connections for output pulse widths (H).

H (No. of pulses)	Input to *and* gate 1 from flip-flop: 4	3	2	1
1	0	0	$\overline{Q}$	
2	0	0	$\overline{Q}$	0
3	0	0	$\overline{Q}$	$\overline{Q}$
4	0	$\overline{Q}$	0	0
5	0	$\overline{Q}$	0	$\overline{Q}$
6	0	$\overline{Q}$	$\overline{Q}$	0
7	0	$\overline{Q}$	$\overline{Q}$	$\overline{Q}$
8	Q	0	0	0

Table II — Circuit connections for spacing between pulses (L).

L (No. of pulses)	Single shot output connection to flip-flop: 4	3	2	1
1	set	reset	reset	reset
2	set	reset	reset	set
3	set	reset	set	reset
4	set	reset	set	set
5	set	set	reset	reset
6	set	set	reset	set
7	set	set	set	reset
8	set	set	set	set

Registers

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There are many uses in computer systems for registers which can accept data signals indicative of bits at some stages without affecting, or while logically manipulating, bits stored at other stages. One example is a queue register for storing interrupt requests from various peripheral devices. Figs. 1 and 2 illustrate improved register stages suitable for this purpose.

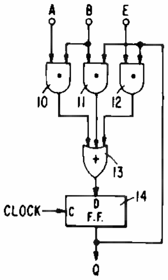

Fig. 1 —Improved three-AND-gate register.

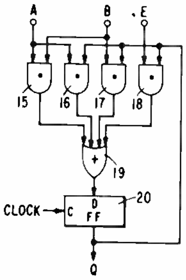

Fig. 2 — Improved four-AND-gate register.

The register stage of Fig. 1 includes three *and* gates connected through an *or* gate to a D-type flip-flop. The output terminal of the flip-flop connects back to two *and* gates. The input signals *A* and *E* can be considered to be control signals while input signal *B* can be considered to be a data signal. The operation of this register stage is summarized below.

A	*E*	*Q*
1	1	$B+q$
0	1	q
1	0	B
0	0	Bq

In this table, *Q* is the present value of the flip-flop output signal and *q* is the previous value of this signal. The present value occurs in response to a clock pulse.

It is clear from the table above that when $A=1$ and $E=0$ a new bit can be inserted into the register stage. If during this period it is desired that another register stage remain undisturbed, its control signal inputs should be $A=0$, $E=1$. Concurrently, still another register stage may be reset by making $E=0$ and $B=0$. The stage is also capable of implementing the OR logic function, as shown.

The register stage of Fig. 2 includes four *and* gates, an *or* gate, and a flip-flop. Here the feedback connection is from the output terminal to three of the *and* gates.

The operation of the register stage of Fig. 2 is given in the truth table below. ϕ in this table means don't care.

A	*E*	*Q*
1	ϕ	$B+q$
0	1	q
0	0	Bq

Fig. 3 illustrates a register which may be made up of the stages shown in Fig. 1 or the stages shown in Fig. 2. It may also be advantageous to have common *A* and *E* controls for the entire register shown in Fig. 3.

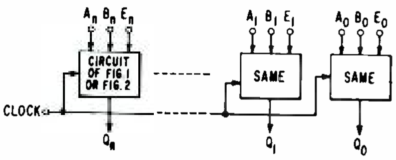

Fig. 3 — Register.

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Crosspoint switch state sensor

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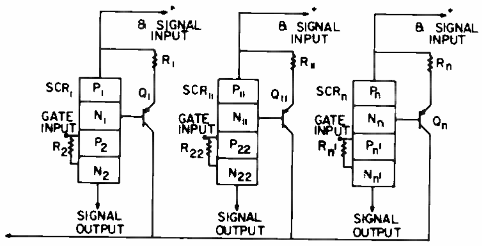

Fig. 1 — Crosspoint switch state sensor.

The circuit shown in Fig. 1 is directed to crosspoint switches and, particularly, to crosspoint switches comprising a silicon controlled rectifier (SCR) formed on a monolithic integrated circuit chip. In a telephone switching system, for example, it is necessary to sense the operating state (*i.e.*, conducting or nonconducting) of a semiconductor device. Moreover, the sensing means should not degrade the performance of the circuit by loading the signal circuit. Fig. 1 illustrates the use of a pnp transistor which is biased by an SCR junction to provide this function. In operation, when any SCR has been triggered into conduction, all other SCR's on the chip are inhibited (*i.e.*, remain nonconducting) as long as the SCR remains in a conducting state.

The floating junction (*i.e.*, P_1N_1) of a silicon controlled rectifier (SCR_1) is used as a bias source for the base-to-emitter junction of a transistor (Q_1). When the SCR is triggered into conduction as a result of the application of a triggering signal to the gate input terminal of the SCR from a triggering circuit (not shown), the transistor is biased into conduction via the drop accross the SCR junction (~0.95V). The collector output of the transistor is transmitted to a sense summing line which in turn operates the readout and inhibit circuitry (not shown). The summing of transistor collector currents constitutes a logic *or* function as required. If the transistor is operated at small currents (in the order of 10 μA), its collector dynamic resistance is very high and negligible loading is introduced into the signal circuit. The voltage drop across the SCR junction (P_1N_1) is substantially independent of current in the conduction mode of the SCR. Consequently, the transistor current is substantially dependent upon the value of the emitter resistor R_1 and relatively independent of the current in the conduction mode of the SCR.

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National Broadcasting Company, Inc.

Meaney MH, Jr, New York City; NY-46233, New York
Polak HL, New York City; NY-42746, New York
Siebert JL (Consultant), New York City, CA-4732EE, California

Patent Operations

Coalter RG, Princeton; TX-304307, Texas
DeCamillis M, Washington; MI-12131, Michigan; NJ-11692; New Jersey

Palm Beach Division

Peters KD, Palm Beach Gardens; NY-43107, New York

Government Plans and Systems Development

Jellinek E, Camden, NY-22650, New York
Keller MA, Camden, NJ-15007, New Jersey
Patterson P, Camden; Ontario
Rose WA, Camden; OH-E022538, Ohio
Shore D, Moorestown; NJ-16176, New Jersey
Wilkinson DA, Washington; DC-2865, Washington, DC

Record Division

Devarajan A, Indianapolis; India-15114
Liddle SW, Indianapolis; IN-7671, Indiana
Nelson G, Indianapolis; IN-15343, Indiana; NJ-19613, New Jersey
Stancel AL (Jr), Indianapolis; AL-5583, Alabama; IN-5583, Indiana

Research and Engineering (Staff)

Dickel FW, Cherry Hill; PA-2868E, Pennsylvania
Widmann F, Princeton, NJ-8131, New Jersey

Solid State Division

Ahmed AA, Somerville; NJ-19596, New Jersey
Baugher D, Somerville; NJ-17921, New Jersey
Bennett WP, Somerville; NJ-18910, New Jersey; PA-9249E, Pennsylvania
Blattner DJ, Somerville; NJ-16183, New Jersey
Czorny BR, Somerville; NJ-13518, New Jersey
Deegan TE, Harrison; NY-37829, New York
DiMauro JA, Mountaintop; NJ-A9989, New Jersey
Fitzgerald WV, Somerville; NJ-16389, New Jersey
Glaser WA, Somerville; MI-8417, Michigan
Goldfarb S, Somerville; NJ-9324, New Jersey
Greenberg LS, Somerville; MA-11061, Massachusetts
Hays JR, Somerville; NJ-13737, New Jersey
Jetter E, Somerville; NY-036913, New York
Keller JP, Somerville; NJ-19400, New Jersey
Lindsley C, Somerville; NJ-13355, New Jersey
Meisel HR, Somerville; NJ-20307, New Jersey
Mendelson R, Somerville; NY-27175, New York
Moyer JH (Jr), Mountaintop; PA-8784E, Pennsylvania
Nash TE, Mountaintop; PA-6951, Pennsylvania
Puotinen DA, Somerville, NJ-14276, New Jersey
Scheline FE, Somerville; NJ-14154, New Jersey
Stern HA, Somerville; OH-E022704, Ohio; PA-008459E, Pennsylvania
Waas GJ, Somerville; NY-31494, New York
Waltke H, Mountaintop; NJ-14483, New Jersey
Wilson RL, Somerville; NJ-12968, New Jersey
Yannotti F, Somerville; NJ-19247, New Jersey

Service Company

Cox HC, Patrick Air Force Base; FL-10778, Florida
Dombrosky RM, Cherry Hill; NJ-14495, New Jersey

Recent books by RCA authors

Presented here are brief descriptions of recent technical books that have been authored, in whole or in part, by RCA scientists and engineers. Readers interested in any of these texts should contact their RCA Technical Library or their usual book supplier. RCA authors who have recently published books and who were not cited in these listings should contact the editors, Bldg. 204-2, Cherry Hill, Ext. PY4256.

Microwave Filters for Communication Systems

C.M. Kudsia M.V. O'Donovan
RCA Limited
Quebec, Canada

The rapid increase over the past five years in the number of microwave communication systems has resulted in congestion of the assigned frequency bands. The need for more efficient use of the available spectrum coupled with the demand for wideband systems with very large information capacities make it essential that overall system requirements are the governing criteria in designing the microwave filters used in these systems.

The book bridges the gap between the communications systems engineer and the microwave filter designer. Classical synthesis techniques are extended to include constraints which enable filters to be designed on the basis of minimizing their contribution to distortion in a communications system. Detailed design examples are included and tables of design data, extensive enough to encompass most practical requirements, are provided. The material presented in this book should be valuable to those engaged in the design of terrestrial and satellite communications systems in the next decade. *(Artech House; 1974; 144 pages; $18.95).*

Chandra M. Kudsia received the BSc with honors in Physics from Delhi University in 1961; BE with distinction in Electrical Communication Engineering from the Indian Institute of Science, Bangalore in 1964; and the M Eng in Electrical Engineering from McMaster University, Hamilton, Ontario in 1966. After a year with Amphenol Canada Limited, Toronto, he joined the Antenna Group of RCA Limited in May 1967. At RCA Limited, he worked on the design of microwave components and subsystems for high quality microwave radio-relay links and ground stations for satellite communications. In 1969, he joined the Aerospace Group where he participated in the conceptual and project definition phase (pdp) of the ANIS Satellite. In 1970, Mr. Kudsia joined, as a Systems Engineering representative from RCA Limited, the combined Government Industry Team working on the definition of the Communications Technology Satellite (CTS). Upon completion of this phase, he participated in the Hardware Development for CTS Transponder and was one of the team to develop Light Weight Multiplexers using graphite fibre epoxy composite (GFEC) material for the U.S. Domestic Communications Satellite (SATCOM). In January 1973, he was appointed to the position of Senior Member of Technical Staff. His present responsibilities include technical direction and participation on SATCOM transponder and future oriented applications for Microwave Technology.

Valentine O'Donovan graduated as an electrical engineer in 1959. He joined RCA Limited in 1963. From 1965 to 1969 he was a Group Leader in charge of a development group responsible for the design of microwave devices and subsystems for Radio Relay and Satellite Earth Terminal products. In 1969 he joined the Aerospace Engineering Department of an engineering group responsible for the design of microwave transponders for communications satellite applications. In 1973 he was appointed Manager, Microwave Engineering in the Aerospace Division. He is currently President of ComDev Limited, a Montreal based company in the business of designing and manufacturing microwave devices and subsystems.

Quality Control Handbook

E.S. Shecter
(Contributor)
G&CS Staff
Moorestown, N.J.

The *Handbook* explains basic quality control methodology, statistical methods, and reliability practices. It also deals with quality assurance in several unique manufacturing areas.

Mr. Shecter contributed chapter 38 which deals with unique quality control practices to be applied in the design and manufacture of electronic components. Such practices as design review, computer-aided design and quality planning are explored in detail. Specific methods of vendor control and process control are explained to the extent that forms are developed and basic logic explained. Reliability, testing, quality control methods in test and final product acceptance are also described. Cost-effective quality trade-offs are explained in the quality analysis and corrective action sections. The theme of quality as a significant contributor to economic design and manufacture is developed throughout with specific case histories cited showing the ways in which quality control and quality assurance help identify areas and manage programs to achieve yield enhancement and product performance improvements. *(McGraw-Hill Book Co.; 1974; approx. 1500 pages; $32.50.)*

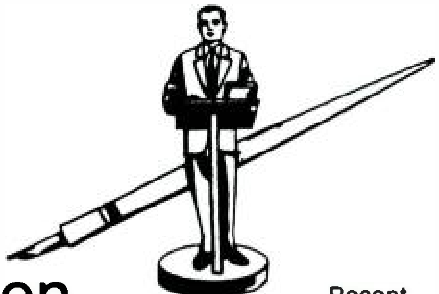
Edwin Shecter received the BSEE from the City College of New York in 1949. He attended Columbia University and completed course credit requirements leading to the MS in Industrial Engineering in 1950. He received the MS in Applied Statistics from Rutgers University in 1962. Mr. Shecter is presently Manager, G&CS Government Product Assurance, RCA Government and Commercial Systems, responsible for establishing Product Assurance Policy for all Divisions of G&CS. He chairs the G&CS Product Assurance Management Council and Materials Quality Assurance Committee. He represents Product Assurance on the G&CS Microelectronics Council and chairs the Quality Engineering Council and Process Quality Assurance Council and the Calibration Committee. He was formerly Manager, G&CS Quality Assurance. He also served as Manager of Quality Assurance Engineering for the Astro-Electronics Divison, responsible for advanced quality planning, personnel and process certification, statistical techniques, the Division Standards Program and the Division Zero Defects Program. Mr. Shecter is a Fellow of the American Society for Quality Control and has served in various section and national offices. He has chaired many conferences of both local and national interest as well as delivering over fifty papers on various subjects in quality and product assurance throughout the country.

Vision: Human and Electronic

Albert Rose
Physical Electronics
Research Laboratory
RCA Laboratories
Princeton, N.J.

The sensitivity performance of the human eye, photographic film and a variety of electronic systems is analysed and compared on an absolute scale of quantum efficiency. The electronic systems include television camera tubes, light amplifiers, optical display systems and electrophotographic arrangements. Emphasis throughout is placed on an examination of the fundamental limitations to and the future possibilities of improved performance. Considerable attention is paid to the information content of a finite number of photons, the visual aspects of photon noise and the viewer's sensitivity to the signal-to-noise ratios of picture displays. These considerations lead to the conclusion that electronic systems will offer increasingly strong competition to the conventional silver halide systems in meeting the demands of the human eye. *(Plenum Press, New York; 1973; 200 pages; $15)*

Dr. Albert Rose received the PhD in Physics at Cornell University in 1935 and has been a member of the research staff of RCA since. His early work in the field of television led to the television camera tubes, the Orthicon and the Image Orthicon. A small group under his direction developed the family of Vidicon (photoconductive) camera tubes. From 1955 to 1958, he inititated and directed Laboratories RCA Ltd., in Zurich, Switzerland. His publications have been in the fields of television camera tubes, electron optics, vision, photoconductivity, electrophotography and electronic transport in solids. He is the author of the book *Concepts in Photoconductivity.* The work on camera tubes was cited by the IEEE Liebman Award, the Sarnoff Gold Medal, and the Television Broadcast Association; the work on vision by the SMPTE Journal Award. He is a Fellow of the APS and the IEEE and a member of the Swiss Physical Society.



Pen and Podium

Recent RCA technical papers and presentations

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 Technical Communications, Bldg. 204-2, Cherry Hill, N.J. (Ext. PC-4256).**

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Subject index categories are based upon standard announcement categories used by Technical Information Systems, Bldg. 204-2, Cherry Hill, N.J.

Subject Index

Titles of papers are permuted where necessary to bring significant keywords(s) to the left for easier scanning. Author's' division appears parenthetically after his name.

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organic, inorganic, and physical.

CONVECTIVE EFFECTS, An investigation of — J.P. Dismukes, B.J. Curtis (Labs,Pr) Chemical vapor disposition, Fourth Int'l Conf., Boston; 10/73

120 Life Sciences and Medicine

biology, physiology, psychology, medical sciences.

PHOTOMULTIPLIER TUBES in nuclear medicine, The role of — D.E. Persyk, W.D. Lindley (EC,Har) Soc. of Nuclear Medicine 12th Int'l Annual Mtg., Munich, Germany; 9/11-14/74

125 Physics

electromagnetic field theory, quantum mechanics, basic particles, plasmas, solid state, optics, thermodynamics, solid mechanics, fluid mechanics, acoustics.

CONFIGURATIONAL COORDINATE MODEL, Condon moments for the — C.W. Struck, W.H. Fonger (Labs,Pr) *J. of Chem. Physics*, Vol. 60, No. 5; 3/1/74

CONFIGURATIONAL COORDINATE MODEL for equal force constants, Recursion analysis of the — C.W. Struck, W.H. Fonger (Labs,Pr) *J. of Chemical Physics*, Vol. 60, No. 5, 3/1/74

TURBULENT AIR, Strong irradiance fluctuations in. III. Diffraction cutoff — D.A. deWolf (Labs,Pr) *J. of the Optical Soc. of America*, Vol. 64, No. 3;3/74

160 Laboratory Techniques and Equipment

experimental methods and equipment, lab facilities, testing, data measurement, spectroscopy, electron microscopy, dosimeters.

RAPID ORIENTATION of back-reflection laue x-ray photographs for zinc, A method for the — T.T. Hitch, J.J. Nunes (Labs,Pr) *J. of Appl. Crystallography*, Vol. 7, Part 1; 2/74

ULTRASONIC EXPERIMENTS, The study of structural phase transitions by means of — W. Rehwald (Labs,Pr) *Advanced in Physics*, Vol. 22, No. 6; 11/73

170 Manufacturing and Fabrication

production techniques for materials, devices and equipment.

CATHODOLUMINESCENT PHOSPHOR LAYERS, Chemical vapor deposition of — J.P. Dismukes, J. Kane, B. Binggeli, H.P. Schweizer (Labs,Pr) Chemical vapor disposition, Fourth Int'l Conf., Boston; 10/73

HETEROEPITAXIAL GROWTH, on insulating substrates, Materials integration through — G.W. Cullen, M.T. Duffy, C.C. Wang (Labs,Pr) Chemical Vapor Disposition, Fourth Int'l Conf., Boston; 10/73

INTERCONNECTIONS — B.R. Schwartz (MSRD,Mrstn) *Electromechanical Design*; 3/74, 5/74, 6/74

MULTILEVEL METALLIZATION, Process for — J.L. Vossen, G.L. Schnable, W. Kern (Labs,Pr) *J. Vac. Sci. & Tech.*, Vol. 11, No. 1; 1-2/74

PHOTOLITHOGRAPHY, The capabilities and limitations of — H.O. Hook (Labs,Pr) *J. Vac. Sci. Tech.*, Vol. 11, No. 1; 1-2/74

RF BIAS EVAPORATION (Ion plating) of nonmetal thin films — J.G. Davy, J.J. Hanak (Labs,Pr) *J. Vac. Sci. & Tech.*, Vol. 11, No. 1; 1-2/74

RF SPUTTERING of ZnO films — H.W. Lehmann, R. Widmer (Labs,Pr) *J. Vac. Sci. & Tech.*, Vol. 11, No. 1; 1-2/74

175 Reliability, Quality Control and Standardization

value analysis, reliability analysis, standards for design and production.

CRITICAL SHIPPING PROBLEM, A planned approach to a — J.R. Van Horn (MSRD,Mrstn) Soc. of Packaging and Handling Engineers, Denver AFB, 5/28/74

ELECTRONIC COMPONENTS — E.S. Shecter (G&CS,Mrstn) *Quality Control Handbook*—Third Edition; 6/74

FMECA (failure modes, effects, and criticality analysis) — F.E. Oliveto (MSRD,Mrstn) American Soc. for Quality Control Fifth Annaul Reliability Technology Seminar, Penn State Annex; 6/6/74

MANDATORY STANDARDS, statistical overview is necessary — E.S. Shecter (G&CS,Mrstn) *ASTM Standardization News*; 4/74

MICROELECTRONIC PACKAGING for cost, maintenance and reliability — B R. Schwartz (MSRD,Mrstn) Int'l Soc. for Hybrid Microelectronics (Fourth Annual Symp. on Hybrid Microelectronics, the Baltimore Hilton, Baltimore, Maryland; 5/1/74

RELIABILITY PREDICTION techniques — R.E. Killion (MSRD,Mrstn) American Society for quality control Fifth Annual Reliability Technology Seminar, Penn State Annex; 6/6/74

180 Management and Business Operations

organization, scheduling, marketing, personnel.

MANAGEMENT: Tasks, responsibilities, practices, (Panel discussion on P.J. Drucker's book) — J.A Lyons, Jr. (EC,Har) Seton Hall Univ., WSOU-FM, South Orange, N.J.; 5/10/74

SERIES 200 MATERIALS, DEVICES, & COMPONENTS

205 Materials (Electronic)

preparation and properties of conductors, semi-conductors, dielectrics, magnetic, electro-optical, recording, and electro-magnetic materials

ACID- AND BASE-SENSITIVE OXIDES, Chemical etchants for the fabrication of thin film patterns of silver on — F. Okamoto (Labs,Pr) Letter to the Editor; *Japanese Journal of Applied Physics*, Vol. 13, No. 2; 1974

AIN, SAPPHIRE, AND SILICON, Thermal expansion of — W.M. Yim, R.J. Paff (Labs,Pr) *J. of Applied Physics*, Vol. 45, No. 3; 3/74

BISMUTH ORTHOSILICATE *Bi*, **Crystal growth and elastic, piezoelectric, and ultrasonic properties of** — W. Rehwald, R. Widmer (Labs,Pr) *J. of the Physics and Chemistry of Solids*, Vol. 34, No. 12; 2/5/74

GaAs on magnesium aluminate spinel, Epitaxial growth and properties of — C.C. Wang, F.C. Dougherty, P.J. Zanzucchi, S.H. McFarlane III (Labs,Pr) *J. of the Electro-Chemical Soc.*, Vol. 121, No. 4; 4/74

INTERFACE between an insulator and a semiconductor, Image force interactions at the — R. Williams (Labs,Pr) *J. of Applied Physics*, Vol. 45, No. 3; 3/74

InGaAs **Alloys, Electron mobility in** — M. Glicksman, R.E. Enstrom, S.A. Mittleman, J.R. Appert (Labs,Pr) *Physical Review*, Vol. 9, No. 4, pp. 1621-1626; 2/15/74

THICK-FILM CONDUCTORS, Adhesion, phase morphology, and bondability of reactively bonded and frit-bonded gold and silver — T.T. Hitch (Labs,Pr) *J. of Electronic Materials*, Vol. 3, No. 2, pp. 552-577; 1974

Zn-DOPED GaN, Properties of: I. Photoluminescence — J.I. Pankove, J.E. Berkeyheiser, E.A. Miller (Labs,Pr) *J. of Applied Physics*, Vol. 45, No. 3; 3/74

210 Circuit Devices and Microcircuits

electron tubes and solid-state devices (active and passive); integrated, array and hybrid microcircuits, field-effect devices, resistors and capacitors, modular and printed circuits, circuit interconnection, waveguides and transmission lines.

CMOS on atmosphere explorer and problems of hardness assurance — G. Brucker (AED,Pr) IEEE Nuclear and Space Radiation Effects Conf., Ft. Collins, Col.; 7/15-18/74

IMPATT diodes, Performance of p-type epitaxial silicon millimeter-wave — G.A. Swartz, Y. Chiang, C.P. Wen, A. Gonzalez (Labs,Pr) *IEEE Trans. on Electron Devices*, Vol. ED-21, No. 2; 2/74

MNOS MEMORY DEVICES, Interaction of nuclear environment with — G. Brucker (AED,Pr) IEEE Nuclear and Space Radiation Effects Conf., Ft. Collins, Col.; 7/15-18/74

215 Circuit and Network Designs

analog and digital functions in electronic equipment; amplifiers, filters, modulators, microwave circuits, A-D converters, encoders, oscillators, switches, masers, logic networks, timing and control functions, fluidic circuits.

CMOS CIRCUITS, EMP hardened — D. Hampel, R.G. Stewart (GCASD,Cam)

Government Microcircuit Applications Conf. (GOMAC) Boulder, Colo., GOMAC Digest of Papers; 6/74

CMOS PROCESSOR, Survivable — S. Teitelbaum (AED,Pr) Hardened guidance and weapon delivery technology mtg., Culver City, Calif.; 3/27/74

CMOS/SOS arithmetic circuits — H.W. Kaiser, W.F. Gehweiler (ATL,Cam) GOMAC; Boulder, Colo.; 6/25-26-27/74

COS/MOS DEVICES, Transient and steady-state radiation response of — G. Brucker (AED,Pr) IEEE Nuclear and Space Radiation Effects Conf., Ft. Collins, Colo; 7/15-18/74

CORRELATOR, CMOS/SOS 32-stage — W. Gehweiler, H.Kaiser, J. Pridgen (ATL,Cam) NAECON, WPAFB, Dayton, Ohio; 5/13-15/74; Proc.

LSI arrays, Electronically programmable — D. Hampel, F.W. Biasco (GCASD,Cam) NAECON, Dayton, Ohio; NAECON '74, *Record*; 5/13/74

MNOS memory devices, The separate and combined effects of aging and irradiation on — G. Brucker (AED,Pr) Int'l Conf. on Evaluation of Space Environment of Materials, Toulouse, France; 6/17-21/74

MOS-preamplifier/CCD multiplexer modules for parallel scan thermal imaging systems, Integrated — D.J. Woywood (ATL,Cam) NAECON, WPAFB, Dayton, Ohio; 5/13-15/74

TRANSISTOR AMPLIFIERS, Fidelity of pulsed microwave — D. Staiman, J. Liston (MSRD,Mrstn) 1974 IEEE-G-MTT Int'l Microwave Symp., Atlanta, Ga.; 6/12-14/74; *Symp. Digest*

TRAPATT diode amplifier, High pulse energy F-band — V.A. Mikenas, A. Schwarzmann, M.E. Breese, J.H. Bowen, M. Weiss (MSRD,Mrstn) 1974 IEEE G-MTT Int'l Microwave Symp., Atlanta, Ga.; 6/12-14/74

225 Antennas and Propagation

antenna design and performance; feeds and couplers, phased arrays; randomes and antenna structures; electromagnetic wave propagation, scatter, effects of noise.

ANTENNA, AN/SPY-1 phased array — R.M. Scudder, W.H. Sheppard (MSRD,Mrstn) *Microwave J.*, 5/74

ANTENNA for satellite communication, An S-band resonant quadrifilar — R.W. Bricker, H.H. Rickert (AED,Pr) 1974 IEEE G-AP Int'l Symp., Atlanta, Ga.; 6/10/74

ANTENNAS, A class of printed circuit — W.C. Wilkinson (MSRD,Mrstn) 1974 IEEE G-AP Int'l Symp., Atlanta, Ga.; 6/10-12/74

ANTENNAS for the Viking lander spacecraft, Two communication — W.C. Wilkinson, O.M. Woodward, W.M. Mulqueen (MSRD,Mrstn) 1974 IEEE G-AP Int'l Symp., Atlanta, Ga.; 6/10-12/74

PHASED ARRAY radar system, Practical aspects of phase shifter and driver design for a tactical multi-function — N.R. Landry, H.C. Goodrich, T.H. Inacker, L.J. Lavedan (MSRD,Mrstn) *IEEE-EMTT Trans.*; 6/74

240 Lasers, Electro-Optical and Optical Devices

design and characteristics of lasers, components used with lasers, electro-optical systems, lenses, etc. (excludes: masers).

EYE, quantum efficiency of the, measured with an I-SIT TV camera — R.W. Engstrom, (EC,Har) Electro-optical systems design conf., San Francisco, Calif.; 11/5-6/74

FE-DOPED $LiNbO_3$ for read-write applications — D.L. Staebler, W. Phillips (Labs,Pr) *Applied Optics*, Vol. 13, No. 4; 4/74

INJECTION LASERS, Spontaneous power and the coherent state of — H.S. Sommers, Jr., D.O. North (Labs,Pr) *J. of Applied Physics, Vol. 45, No. 4; 4/74*

$LiNb_xTa_{1-x}O_3$, Low-loss single-mode optical waveguides and efficient high-speed modulators of — J.M. Hammer, W. Phillips (Labs,Pr) *Applied Physics Letters I*, Vol. 24, No. 11; 6/74

PHOTOELECTRIC SENSORS for colorimetry — R.W. Engstrom (EC,Har) Electro-optical Systems Design Conf., San Francisco, Calif.; 11/5-6/74

245 Displays

equipment for the display of graphic, alphanumeric, and other data in communications, computer, military, and other systems, CRT devices, solid state displays, holographic displays, etc.

COLOR PICTURE TUBES, Three-filter colorimetry of — G.M. Ehemann, Jr. (EC,Har) Electro-chemical Soc., San Francisco, Calif.; 5/12/74

255 Audio Components and Applied Acoustics

microphones, loudspeakers, earphones, etc., sound transmission and control; ultrasonic equipment (excludes: sonar and audio recording).

ACOUSTIC IMAGING with thin annular apertures — D. Vilkomerson (Labs,Pr) *Acoustical Holography*, Vol. 5

280 Thermal Components and Equipment

heating and cooling components and equipment, thermal measurement devices, heat sinks.

COOLING of electronics systems, The role of system architecture in — B. Shelpuk (ATL,Cam) *Electronics*, Vol. 47, No. 13; 6/74

SERIES 300 SYSTEMS, EQUIPMENT, & APPLICATIONS

310 Spacecraft and Ground Support

spacecraft and satellite design, launch vehicles, payloads, space missions, space navigation.

EARTH STATION operations — J. Cuddihy (GlobCom, NY) IEEE, Domestic Satellite Lecture, Engineers' Club, NY; 4/23/74

312 Land and Water Transportation

navigation systems, automotive electronics, etc.

AUTOMATION, New ship — J. Lidiak, J.J. Dor (GCASD,Burl) ASNE Day, DC; ASNE J.; 5/3/74

320 Radar, Sonar, and Tracking

microwave, optical, and other systems for detection, acquisition, tracking, and position indication.

DIGITAL INTERPOLATION for reducing straddling and granularity losses — H. Urkowitz, R.P. Perry, L. Weinberg (MSRD,Mrstn) USNC/URSI Mtg., Atlanta, Ga.; 6/10-13/74

THERMAL IMAGING systems, Integrated MOS-preamplifier/CCD multiplexer modules for parallel scan — D.J. Woywood (ATL,Cam) NAECON, WPAFB, Dayton, Ohio; 5/15/74

325 Checkout, Maintenance, and User Support

automatic test equipment, (ATE), maintenance and repair methods.

BUS MAINTENANCE Operations, Application of automatic test equipment to — R. Barry, J. Laskey (GCASD,Burl) Fleet Week 74, Chicago; 6/18/74

340 Communications

industrial, military, commercial systems, telephony, telegraphy and telemetry, (excludes: television, and broadcast radio).

COMMUNICATION CABLE, Simulation of nuclear blast effects on — E. Van Keuren (GCASD,Cam) New Quarterly J., No. 30, 1974, Institute of Post Office Electrical Engineers, London Centre, London, England; 6/74

MSK system, Signal to noise degradation due to amplitude and band limiting in on — M. Hecht (AED,Pr) Int'l Conf. on Communications, Publ. in *Conf. Record*, Minneapolis, Minn.; 6/17-19/74

PSK, The effect of tandem band and amplitude limiting on the performance of — H.R. Mathwich, J.F. Balcewicz (AED,Pr) Int'l Conf. on Communications, Publ. in *Conf. Record*, Minneapolis, Minn.; 6/17-19/74

TELEX switching systems, Current concepts in computer controlled — L.P. Correard (GlobCom,NY) Int'l Conf. on Computer Communications, Stockholm; 8/12-14/74

CIRCUIT CAPACITIES for satellite systems — J. Cuddihy (GlobCom,NY) IEEE, Communications Society, Lecture Series; 4/16/74

360 Computer Equipment

processors, memories, and peripherals.

NEW ALGORITHMS OK new machine OK — A. Merriam, E. Pate, R. Merker, J. Solomon (ATL,Cam) Eighth Annual Simulation Symp., Tampa, Fla.; 3/12-14/75

365 Computer Programming and Applications

languages, software systems, and general applications (excluding: specific programs for scientific use).

INCOMPLETE SPECIFICATIONS and minimum change impact — S.A. Steele (MSRD,Mrstn) Continuing Engineering Studies—Seminar 1974, Computer and Information Sciences one-hour presentation Modern Methods for Design of Real Time Computer Systems; Univ. of Penn.; 6/12/74

SPA — An approach to getting structured programming to the expectant user — J.P. Riley (MSRD,Mrstn) Computer Trio Seminar, Newark College of Engineering; 6/19/74

REAL TIME SYSTEM on a minicomputer, Development of a — S.R. McCammon (MSRD,Mrstn) Continuing Engineering Studies — Summer 1974, Computer and Information Sciences one-hour presentation — Modern Methods for Design of Real Time Computer Systems; Univ. of Penn.; 6/12/74

TESTING LEVELS in large scale real time software development — J.C. Kulp (MSRD,Mrstn) Continuing Engineering Studies-Summer 1974, Computer and Information Sciences, one-hour presentation - Modern Methods for Design of Real Time Computer Systems, Univ. of Penn.; 6/12/74

370 Computer Programs (Scientific)

specific programs and techniques for scientific use, computation, simulation, computer aided design.

INTERACTIVE GRAPHIC DESIGN AUTOMATION for thick and thin film hybrids, logic diagrams, printed circuits, and integrated circuits — J.A. Bauer (MSRD,Mrstn) IEEE Philadelphia Chapter on Electron Devices and Parts Materials and Hybrids Group Meeting; 5/23/74

CASPER (Comprehensive APL System for the Preparation and Executive of Reports) — W.A. Rux, E. Baelen (EC,Har) APL 6 Int'l User's Conf., Anaheim, Calif.; 5/14-17/74

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printing, photography, and typesetting; writing, editing, and publishing; information storage, retrieval, and library science.

SCIENTIFIC PERIODICALS in an industrial research library, Selection of — E.F. Hockings (Labs,Pr) *J. of the American Soc. for Information Science*; 3-4/74, Vol. 25, No. 2

TECHNICAL REPORT, Preparing the — D.R. Higgs (MSRD,Mrstn) RPI Technical Writers' Institute, Troy, New York; 6/4-5/74

Author 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.

Patents Granted

to RCA Engineers

Astro-Electronics Division

Passive Cooler — R. J. Williams (AED, Pr) U.S. Pat. 3817320, June 18, 1974

Commercial Communications Systems Division

Broadcast Systems

Balanced, Low Impedance, High Frequency Transmission Line — D. A. McClure, H. C. Nichols (CCSD, Cam.) U.S. Pat. 3815054, June 4, 1974

Electromagnetic and Aviation Systems Division

Digital Interface Circuit for a Random Noise Generator — R. B. Goyer (EASD, Van Nuys) U.S. Pat. 3816765, June 11, 1974

Glitch Free Vector Generation — K. Katagi, W. L. Ross, and J. J. Lyon (EASD, Van Nuys) U.S. Pat. 3821728, June 28, 1974

Government Communications and Automated Systems Division

Flowmeter — R. E. Hartwell (GCASD, Burl.) U.S. Pat. 3820395, June 28, 1974

System for Rapidly Positioning Gimbaled Objects — H. D. Eckhardt (GCASD, Burl.) U.S. Pat. 3795150, March 5, 1974; Assigned to U.S. Government

Missile and Surface Radar Division

High-Speed Logic Circuits — D. D. Freedman (MSRD Mrstn.) U.S. Pat. 3818242, June 18, 1974

Means of Securing Ferrimagnetic Core in a Microwave Phaser (A) — R. J. Mason and L. J. Lavedan, Jr. (MSRD, Mrstn.) U.S. Pat. 3811099, May 14, 1974; Assigned to U.S. Government

Solid State Division

Liquid-Crystal Display Device and Method of Making — H. C. Schindler (SSD, Som.) U.S. Pat. 3814501, June 4, 1974

Current Translating Circuits — C. F. Wheatley, Jr. (SSD, Som.) U.S. Pat. 3815037, June 4, 1974

Comparator Circuitry — A.A.A. Ahmed (SSD, Som.) U.S. Pat. 3816761, June 11, 1974

MOS FET Reference Voltage Supply — R. Feryszka and J. O. Preisig &SSD, Som.) U.S. Pat. 3823332, July 9, 1974

Consumer Electronics

Controlled Oscillator — S. A. Steckler (CE, Som.) U.S. Pat. 3815051, June 4, 1974

Television Receiver Service Adjustment System — D. L. Neal (CE, Indpls.) U.S. Pat. 3820155, June 25, 1974

Film Type Capacitor and Method of Adjustment — J. H. Shelby, F. E. Richter (CE, Indpls.) U.S. Pat. 3821617, June 28, 1974

Apparatus for Providing Individual Adjustment of Movable Multiple Transducers in a Plural Tape Cartridge Player — F. Gordon and D. R. Andrews (CE, Indpls.) U.S. Pat. 3821814, June 28, 1974

Television Automatic Gain Control Circuitry Providing for Compatible Control of VHF Tuner and UHF Tuner — J. G. George (CE, Indpls.) U.S. Pat. 3823379, July 9, 1974

Special Contract

Method of Making Cathode Ray Tube Internal Shields — T. M. Shrader (Special Contract Inv.) U.S. Pat. 3822453, July 9, 1974

Staff

Rotatable Paraboloidal Reservoir Useful in an Ink Jet Printer — R. M. Carrell (Corp. Staff, Cherry Hill) U.S. Pat. 3823409, July 9, 1974

Computer Systems Division

Merchandise Handling and Identifying System — F. X. Beck, Jr. and W. E. Kinslow, Jr. (CSD, Pr.) U.S. Pat. 3819012, June 25, 1974

Laboratories

Cryptographically Coded Cards Employing Synthetic Light Modifying Portion — J. P. Russell and D. L. Greenaway (Labs, Zurich, Switzerland) U.S. Pat. 3814904, June 4, 1974

S-Corrected Waveform Generator — P. E. Haferl (Labs, Zurich, Switzerland) U.S. Pat. 3814980, June 4, 1974

Direct Current Electroluminescent Panel Using Amorphous Semiconductors for Digitally Addressing Alpha-Numeric Displays — A. G. Fischer (Labs, Pr) U.S. Pat. 3807036, April 30, 1974; Assigned to U.S. Government

Pocketable Direct Current Electroluminescent Display Device Addressed by MOS or MNOS Circuitry — A. G. Fischer (Labs, Pr) U.S. Pat. 3807037, April 30, 1974

Novel Electro-Optic Devices — M. T. McCaffrey and J. A. Castellano (Labs, Pr.) U.S. Pat. 3816336, June 11, 1974

Identification Card Decoder — D. L. Greenaway (Labs., Zurich, Switzerland) U.S. Pat. 3819911, June 25, 1974

Color Television — D. H. Pritchard and A. C. Schroeder (Labs, Pr) U.S. Pat. 3820157, June 25, 1974

Method of Epitaxially Depositing a Semiconductor Material on a Substrate — M. Ettenberg (Labs, Pr) U.S. Pat. 3821039, June 28, 1974

Method of Making a Semitransparent Photomask — N. Feldstein and J. A. Weiner (Labs, Pr) U.S. Pat. 3822155, July 2, 1974

Cascode Video Output Feedback Amplifier — P. E. Haferl (Labs, Zurich, Switzerland) U.S. Pat. 3823264, July 9, 1974

Targets for Television Pickup Tubes — S. V. Forgue (Labs, Pr) U.S. Pat. 3818262, July 9, 1974

Electronic Components

Thermo-Electric Modular Structure and Method of Making Same — N. S. Freedman, C. W. Horsting, W. F. Lawrence and J. J. Carrona (EC, Hrsn.) U.S. Pat. 3814633, June 4, 1974; Assigned to U.S. Government

Method of Rebuilding a Cathode-Ray Tube — G. L. Fassett (EC, Lanc.) U.S. Pat. 3816891, June 18, 1974

Thermo-Electric Modular Structure and Method of Making Same — N. S. Freedman, C. W. Horsting, W. F. Lawrence and J. J. Corrona (EC, Hrsn.) U.S. Pat. 3787958, July 9, 1974

Thermoelectric Generator — N. E. Pryslak (EC, Hrsn.) U.S. Pat. 3794526, July 9, 1974

Engineering News and Highlights

Hittinger assumes responsibility for Electronic Components

William C. Hittinger, Executive Vice President, RCA Consumer and Solid State Electronics, has assumed the additional responsibility for the Electronic Components activity, effective July 1, 1974.

Under the new organizational structure, Mr. Hittinger will be responsible for the following activities:

Consumer Electronics, which manufactures and markets a full line of color and black-and-white television receivers and other consumer products. **Roy H. Pollack** has been elected Vice President and General Manager, RCA Consumer Electronics. He previously was Division Vice President and General Manager, RCA Color and Black-and-White Division.

Solid State Electronics, which manufactures and markets integrated circuits, liquid crystals and a wide range of other semiconductor devices for consumer, industrial, commercial and defense applications. **Bernard V. Vonderschmitt** continues as Vice President and General Manager of the division.

Electronic Components, which manufactures and markets electron tubes and devices, including picture tubes, for consumer products and industrial, defense and aerospace markets. Mr. Hittinger will be acting General Manager of the activity. Electronic Components previously reported to Executive Vice President **John B. Farese** who will handle special assignments for Mr. Conrad until his retirement in February 1975.

Mr. Hittinger also announced the appointment of **Harold M. Miller** as Staff Vice President, Business Planning, reporting directly to Mr. Hittinger. Mr. Miller had been Division Vice President, Finance, RCA Consumer Electronics. Succeeding him in that position will be **James M. Alic**, who has been Director, Financial Planning and Analysis, RCA Consumer Electronics, since November 1973.

Mr. Hittinger joined RCA in 1970 as Vice President and General Manager of the Solid State Division. He became an Executive Vice President in December 1972, when he also assumed responsibility for RCA Consumer Electronics.

Before joining RCA, Mr. Hittinger was President of General Instrument Corporation, a post he had held since March 1968. Prior to that, he had held a number of top executive positions with affiliated companies of the Bell Telephone System, which he joined in 1946.

Hittinger

Mr. Hittinger graduated from Lehigh University in 1944 with the BS in Metallurgical Engineering.

Mr. Pollack rejoined RCA in 1973 after two years with Fairchild Camera & Instrument Company, where he was Vice President and General Manager, MOS Products Division. Prior to that he was with RCA from 1950, serving in various engineering and marketing management positions at Somerville, N.J., Mountaintop and Lancaster, Pennsylvania.

He is a graduate of Columbia College and School of Engineering with a degree in mechanical and electrical engineering. He has served on the Professional Task Forces of the Electronic Industries Association, and has been active in the Chamber of Commerce as well as civic organizations.

Mr. Vonderschmitt joined RCA in 1944 as an engineer and was engaged in component design projects at Camden, N.J. After serving as a radar officer in the U.S. Navy, he returned to RCA and worked on deflection system development for monochrome and color receivers. He transferred to the Semiconductor Division in 1959 as Manager of Applications in the MicroElectronics Department and subsequently held engineering management positions of increasing responsibility. In 1973, Mr. Vonderschmitt was named head of the Solid State Division, succeeding Mr. Hittinger.

Mr. Vonderschmitt received the BS in Electrical Engineering from Rose Polytechnic Institute in 1944 and the MS in Electrical Engineering from the University of Pennsylvania in 1956. He holds thirteen patents for his design activities with RCA and is the author of numerous technical papers.

Promotions

Astro-Electronics Division

J. E. Hermann from Sr. Engr. to Mgr., Computer Based Systems (A. S. Baran, AED, Princeton)

Electronic Components

J. T. Coble from Sr. Engr., Product Develop. to Engr. Ldr., Product Development (R. W. Osborne, EC, Marion)

Government Communications and Automated Systems Division (Camden)

J. B. Feller from Ldr., Engr. Staff to Mgr., Signal Processing Sys. (J. Santoro, Camden)

E. Fuzer from Sr., Mbr. Engr. Stf. to Ldr., Engr. Staff (J. A. Clanton, Camden)

J. R. Gizara from Mbr., Engr. Staff to Ldr., Test Engrg. (S. Naspo, Camden)

N. Hovagimyan from Princ., Mbr. Eng. Stf. to Ldr., Engr. Staff (D. A. Tannenbaum, Camden)

R. Klein from Sr., Mbr. Engr. Staf. to Ldr., Engr. Staff (M. Rosenblatt, Camden)

RCA Alaska Communications, Inc.

J. H. Hayes from Sr. Engr. Assoc. to Mrg., Bush Communications (J. E. Wakefield, Anchorage, Alaska)

Awards

Palm Beach Division

The team of **Norm Swales, Randy Rhodes, Pete Hions,** and **Tony Scialdone** received Technical Excellence Awards for the error-free design and layout of the COSMAC microprocessor ALU integrated circuit chip. This is the first integrated circuit chip designed and laid out at Palm Beach Division.

Government Communications and Automated Systems Division (Burlington Operations)

Robin Hulls received a Technical Excellence Engineering Award for his contributions to the Hydraulic Test System.

The Tactical Information Processing Interpretation (TIPI) team has been selected for a Technical Excellence Team Award. The TIPI system is a portable electronic data processing system for use within the Air Force tactical environment. The team members are: **D.F. Behrmann, L.A. Broughton, R.M. Carner, D.J. Casaletto, W.D. Clark, H. Cotterly, Jr., D.A. French, K.L. Friedrich, R.J. Geehan, Jr., J.M. Goode, R.A. Hertrich, G.B. Johnson, L.C. Kaye, M.F. LeVarn, T.W. Liu, J.B. McElroy, J. Munzer, F.H. Paradise, N.N. Reid, P.M. Royce, J. Salvato, L.F. Valentine, and E.D. Veilleux.**

Professional activities

Electronic Components

Willis F. Beltz of Microwave Operations, Harrison, N.J., has been elected Vice President of the Northern New Jersey Chapter of the American Institute of Plant Engineers.

RCA Laboratories

Dr. George H. Heilmeier, formerly Head, Device Concept Research, at RCA Laboratories, has received the Arthur Flemming Award as one of "Ten Outstanding Young Men in Government." Now Assistant Director of Defense Research and Engineering (Electronics and Computer Sciences) in the Department of Defense, he was cited for his restructuring and substantial strengthening of the *DoD's* electronics technology program. Dr. Heilmeier is on leave from RCA Laboratories.

Degrees Granted

Missile and Surface Radar Division

David Staiman of the Systems and Advanced Technology Activity received the PhD in Electrical Engineering from the University of Pennsylvania.

Joseph F. O'Brien, Leader of Engineering Systems Projects in the Systems Engineering Activity received the MSE in Systems Engineering from the University of Pennsylvania.

Adam J. Haraburda of the AEGIS Activity received the MSE in Systems Engineering from the University of Pennsylvania.

Alan E. Matt, Administrator of Compensation and Labor Relations in the Industrial Relations Activity received the MS in Personnel Services and Counseling from Glassboro State College.

Girard V. Goldkrantz of the Signal and Data Processing Engineering Activity received the MSEE from the University of Pennsylvania.

Joan A. Schlindwein of the Advanced Systems and Technology Activity received the BS in Elementary Education from St. Joseph's College.

Mildred Valente, Administrator in the AEGIS Activity, received the BS in Management from Rutgers University.

Staff announcements

Anthony L. Conrad, President and Chief Operating Officer, has announced **William C. Hittinger,** as Executive Vice President, for Electronic Components. In addition, he will continue to be responsible for Consumer Electronics and the Solid State Division.

The organization of the Executive Vice President is as follows: **William C. Hittinger,** Acting General Manager, Electronic Components; **Roy H. Pollack,** Vice President and General Manager, Consumer Electronics; and **Bernard V. Vonderschmitt,** Vice President and General Manager, Solid State Division.

Executive Vice President

William C. Hittinger, Executive Vice President has announced the election of **Roy H. Pollack** as a Vice President of the RCA Corporation and the appointment of **Harold M. Miller** as Staff Vice President, Business Planning.

Electronic Components

William G. Hartzell, Division Vice President, Engineering, has announced the Entertainment Tube Division Engineering organization as follows: **Leonard F. Hopen,** Manager, Picture Tube Product Support Engineering; **Robert J. Konrad,** Manager, Picture Tube Applications & Reliability Engineering; **Harold B. Law,** Director, Material & Display Devices Lab - Princeton; **Edward K. Madenford,** Administrator, Engineering Administration; **C. Phillips Pfleeger,** Manager, Glass Development Programs; **Clifford E. Shedd, Jr.,** Manager, Equipment Design & Development Engineering; **David D. VanOrmer,** Manager, Picture Tube Development Engineering; and **W. Hoyt Warren,** Manager, Receiving Tube Engineering Quality & Reliability Assurance.

Clifford E. Shedd, Jr., Manager, Equipment Design & Development Engineering has announced the appointment of **N. Roger Thornton** as Manager, Engineering Projects - Equipment Design & Development.

Missile and Surface Radar Division

William V. Goodwin, Division Vice President and Program Manager, AEGIS Department has announced the organization of the AEGIS Department as follows: **Charles C. Botkin,** Deputy Program Manager, AEGIS Program; **Frank G. Adams,** Administrator, Program Planning Support; **Donald E. Dalgleish,** Manager, AEGIS Production; **Peter J. Dwyer,** Manager, Program Administration; **Bryce D. Inman,** Manager. Combat System; **Dudley Lesser,** Manager, System Assurance; **Bertram F. Rogers,** Manager, Subcontract Management; **Lawrence J. Schipper,** Manager, AEGIS Development; **Walter H. Smith,** Administrator, Customer Liaison; and **Peter J. Dwyer,** Acting Manager, Contract Administration.

Max Lehrer, Division Vice President and General Manager, has announced the organization of the Missile and Surface Radar Division as follows: **George J. Branin,** Manager, Product Assurance; **Alan J. Cook,** Manager, Industrial Relations; **James J. Dougherty,** Manager, Materials; **James R. Foran,** Manager, Operations Control; **Daniel J. Gillooly, Jr.,** Plant Manager, Moorestown Plant; **William V. Goodwin,** Division Vice President and Program Manager, AEGIS Department; **Charles C. Botkin,** Deputy Program Manager, AEGIS Program; **William L. Hendry,** Manager, Range Instrumentation and Operational Systems Department; **Lewis Nelson,** Manager, Strategic Systems Department; **Edward W. Petrillo,** Manager, Special Projects; **Samuel J. Rabinowitz,** Principal Scientist; **Joseph M. Seligman,** Manager, Tactical Systems Department; **Joseph C. Volpe,** Chief Engineer, Engineering Department; **Andrew L. Warren,** Manager, Ballistic Missile Defense Department; and **Max Lehrer,** Acting Director, Marketing.

William V. Goodwin, Division Vice President and Program Manager, AEGIS Department, has announced the appointment of **Charles C. Botkin** as Deputy Program Manager, AEGIS Program.

Solid State Division

B. A. Jacoby, Division Vice President, Solid State Marketing has announced the appointment of **William J. Dennehy** as Manager, Government Market Development.

James C. Miller, Director, Power Transistor Operations has announced the appointment of **Donald E. Burke** as Manager, Applications Engineering - Power Transistors.

Henry S. Miiller, Director, MOS IC Product Operations has announced the MOS Integrated Circuits Product Operations organization as follows: **Terry G. Athanas,** Manager, Circuit Design and Technology; **Terry G. Athanas,** Acting Leader, Circuit Design; **Terry G. Athanas,** Acting Leader, Technology - N/MOS and SOS; **Michael V. D'Agostino,** Manager, Marketing and Application - Memory and SOS; **Henry S. Miiller,** Acting Manager, Microprocessors; **Vernon E. Hills,** Manager, Applications Engineering - Microprocessors.

Rajesh K. Tandon, Manager, Manufacturing and Engineering Systems has announced the organization of Manufacturing and Engineering Systems as follows: **Clyde F. Seltzer,** Manager, Programming - Mountaintop and **Jerry R. Osborne,** Manager, Programming - Findlay.

Donald R. Carley, Manager, Engineering Support - MOS Integrated Circuits announced the organization of Engineering Support - MOS Integrated Circuits as follows: **Donald R. Carley,** Acting Leader, CAD Technology; **Edward C. Crossley,** Leader, Test Technology - MOS Integrated Circuits; **Walter F. Lawrence,** Project Leader, Assembly Technology & Package Development; **William N. Lewis,** Manager, Model Shop - MOS Integrated Circuits; **Bernard B. Levin,** Leader, Model Shop Engineering; **William N. Lewis,** Acting Leader, Model Shop Production; **Charles P. Shievley,** Administrator, Model Shop Material Control; **Evan P. Zlock,** Manager, Photomask Operations.

Richard L. Sanquini, Director, Linear IC Product Operations has announced the appointment of **Heshmat Khajezadeh** as Manager, Engineering - Linear IC, and his staff as follows: **Merle V. Hoover,** Manager, Applications Linear IC; **Lewis A. Jacobus, Jr.,** Manager, Process and Assembly Technology - Linear IC; **Alfredo S. Sheng,** Manager, Circuit Design and Development - Linear IC; and **Bruno J. Walmsley,** Manager, Linear Testing.

Norman C. Turner, Director, CMOS IC Product Operations has announced the CMOS Integrated Circuits Product Operations organization as follows: **Robert P. Jones,** Manager, Integrated Circuits Manufacturing; **Norman C. Turner,** Acting Manager, Production Control Distribution and Planning; **Loren C. Weber,** Administrator, Production Control; **George J. Waas,** Manager, Standard Circuits Engineering; **Richard E. Funk,** Leader, Applications Engineering; **Robert C. Heuner,** Leader, Standard Circuit Design; **George J. Waas,** Acting Leader, Product Engineering; **William E. Wagner,** Manager, IC Market Planning; **Andrew J. Bosso,** Administrator, Market Planning; **Scott B. Clinton,** Administrator, Product Control; **Russell D. Knapp,** Leader, CMOS IC Systems; **Richard R. Painter,** Administrator, Market Planning; **George A. Riley,** Manager, Product Planning; **Sanford A. Roth,** Administrator, Market Planning; **James H. Smith,** Administrator, Market Planning; **Alexander W. Young,** Manager, Custom Circuits Engineering; **Martin A. Blumenfeld,** Leader, Process Technology; **Julius Litus, Jr.,** Leader, Custom Circuit Design; and **Alexander W. Young,** Acting Leader, Product Engineering.

RCA Global Communications, Inc.

Lee J. Wilson, Director, Computer Systems has announced the changes in position titles as follows: **Russel Blackwell,** Manager, Leased Computer Operations; **Maurice ChaFong,** Manager, Computer Systems Engineering; **Joseph Craven,** Manager, Systems Programming; **Frederick Danziger,** Manager, Computer Systems Customer Services; **Patrick Kielty,** Manager, Computer Systems Marketing; **Peter Theodore,** Manager, Computer Technical Services; and **Samuel Thompson,** Manager, Systems Development.

RCA Records

Robert D. Summer, Division Vice President, RCA Records, International has announced the appointment of **Francois Dacla** as President, RCA S.A. (France).

In addition, **Mr. Dacla** is appointed Managing Director, Record Division.

Parts and Accessories

Paul B. Garver, Division Vice President and General Manager, Parts and Accessories has announced the following appointments in the organization: **Edward A. Boschetti,** Division Vice President, Materials and Computer Systems Support; **Paul R. Slaninka,** Division Vice President, Sales; **Walter A. Smith,** Division Vice President, Manufacturing and Distribution.

Special *RCA Review* issue on liquid crystals

The March 1974 issue of *RCA Review* includes the first six of a series of 18 lectures intended to serve as an introduction to the subject of liquid crystals. These published lectures are the outgrowth of a weekly study seminar conducted at RCA Laboratories over a period of several months. The seminar was initiated to stimulate interaction among individuals from different disciplines who share a common interest in liquid crystals by presenting to them a primer in the science and technology of the materials and devices.

Included in the March issue are an introduction to the basic physics and chemistry of liquid crystals, introductions to the molecular theory of nematics, and a discussion of the experimental determination of the degree of order in nematics. Subsequent lectures, which are currently planned for the September and December 1974 issues of the *Review*, will focus on the phenomenological theories of liquid crystals; their optical, electrical, and electro-optic properties; and the applications of liquid crystals.

Anyone wishing to obtain this series of lectures can do so by subscribing to *RCA Review* (order should specify commencement with the March 1974 issue.) The possibility of combining these lectures in a single publication is also under consideration; those interested are requested to contact the editor, *RCA Review*, RCA Laboratories, Princeton, N.J.

Clip out and mail to Editor, *RCA Engineer*, 204-2, Cherry Hill, N.J.

RCA Engineer

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