RCA ENGINEER

12th ANNIVERSARY ISSUE

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RCA

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OUR COVER

. . . the first issue of the RCA ENGINEER (June-July, 1955) was "an artist's conception showing the wide and varied activities of engineering throughout RCA"; this cover has been repeated for the past eleven "Anniversary" issues. To maintain the spirit of this original theme and, at the same time, symbolize some of the new and interesting activities of engineering and research at RCA, we have modernized the twelfth "Anniversary" cover. Many of the activities shown on this new cover were only embryo ideas when the first cover was drawn—and now we predict that the increasing rate of RCA's technological progress will demand future modernizations at successively shorter periods of time.

Twelfth Anniversary

This issue marks the completion of 12 years of publishing professional papers by RCA engineers and scientists in their journal—the RCA ENGINEER. First published in June 1955 the journal was dedicated to the task of matching the forward-looking interests of its readers. Now, over 70 issues later the Editor of the RCA ENGINEER and his staff are to be congratulated for continuing this dedication of purpose of following the changing engineering and scientific trends at RCA. The RCA ENGINEER began as a 56-page engineering journal; by contrast, today's 96-page issues epitomize the technology explosion and the seriousness of the modern engineer's efforts to keep his associates informed. The papers published in the RCA ENGINEER clearly reveal the interdisciplinary nature of engineering today. The RCA ENGINEER editorial representatives have projected plans for the next two years which promise issues devoted to such themes as medical electronics, space technology, graphic systems, educational electronics, data processing, broadcast and television, and integrated circuits.

The intrinsic value of the published papers that record the engineer's work is impossible to estimate. Management, sales and marketing departments, public relations, and almost every conceivable activity within RCA find the articles of great value. This accounts for the remarkable utilization of reprints of engineering articles from the RCA ENGINEER. Three hundred and forty-five reprints have been made available to date and during this last year, as many as 70 individual reprints were ordered, published, and distributed; these range from individual 4- and 8-page booklets containing 1 or 2 articles to special brochure-type collections of many articles ranging up to 88 pages. Over 100,000 copies of such reprints are fruitfully utilized by RCA in the same one-year period—and represent the annual accomplishments of over 200 engineers.

The Editorial Representatives, the Advisory Board, and the Editorial Staff have met their major objective of publishing in the RCA ENGINEER the finest engineering articles available. Congratulations again on this your twelfth Birthday issue.

D. F. Schmit
Staff Vice President
Product Engineering
Research and Engineering

RCA ENGINEER

VOL. 13, NO. 1
JUN.-JUL., 1967

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DEPARTMENTS

A TECHNICAL JOURNAL PUBLISHED BY **RADIO CORPORATION OF AMERICA,** PRODUCT ENGINEERING 2-8, CAMDEN, N. J.

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

RCA ENGINEER articles are indexed annually in the April-May Issue and in the "Index to RCA Technical Papers."

RADIO CORPORATION OF AMERICA

Part IV—The Years 1962-1966

DR. ELMER W. ENGSTROM

Chairman of the Executive Committee of the Board

Radio Corporation of America

For the Radio Corporation of America, the years from 1962 through 1966 were characterized by vigorous growth and an outward thrust that took the company into new areas of business.

By any measure, the rate of growth was impressive. Total annual sales increased from $1.75 billion in 1962 to $2.5 billion in 1966. During the same period, net profits more than doubled.

RCA's manufacturing capacity was vastly increased as more than $500 million was spent to build new plant facilities and expand existing ones. In 1966 alone, the company undertook the largest domestic capital expenditure in its history, allocating $198 million for the construction of new plants at 11 locations and substantial expansion at 15 other operating facilities. These additions involved such key activities as color television, home instruments, semiconductors, computers, and communications.

By early 1967, total employment had grown to exceed 120,000 people in the United States and abroad, up from approximately 93,000 five years earlier.

During the four-year period, RCA maintained a growth rate that consistently outpaced the average of all American manufacturing enterprises. In 1966, the percentage of sales increase over the previous year was double that of the average for all other manufacturers, and the company's profit increase of 28% contrasted with the average manufacturing rise of 11%.

This outstanding performance reflected many influences—a sustained period of strong consumer demand for RCA home entertainment products; a steady growth in other established areas of business, such as commercial and industrial electronic products, and a vigorous involvement in new ventures, such as publishing, the graphic arts, education, and medical electronics.

Coupled with these trends was a gradual change in the character of the

Final manuscript received May 1, 1967

DR. E. W. ENGSTROM, received the BSEE at the University of Minnesota in 1923. In the early thirties, Dr. Engstrom directed RCA's television research toward a practical service. He was responsible for development and construction of apparatus used in field tests, and in the early planning and coordination of black-and-white television. Dr. Engstrom was a member of the NTSC at the time TV standards for broadcasting were established and a member of the Radio Technical Planning Board. He was a member of the NTSC which developed technical signal specifications for color television transmission, adopted by F.C.C. Dec. 17, 1953. In 1942 when all research activities of RCA were brought together at Princeton, N.J., Dr. Engstrom became Director of General Research. On Dec. 7, 1945, he was elected Vice President in charge of research of the RCA Laboratories Division; on Sept. 7, 1951, he was elected Vice President, RCA Laboratories; and on June 4, 1954, he was elected Executive Vice President, Research and Engineering. In Oct. 1955, he was named senior executive Vice President. In 1961, he was elected President of RCA, and on Jan. 1, 1966, he became Chairman of the Executive Committee of the Board and Chief Executive officer of the Corporation. He is a director of RCA, of NBC, of RCA Communications, Inc., and of Random House, Inc. He is also a member of the Board of Directors of the Prudential Insurance Co. of America. Dr. Engstrom has been awarded honorary degrees by 14 colleges and universities. In 1958, he was the recipient of the Industrial Research Institute Medal for distinguished leadership in Industrial Research; in 1962, he received the Medal of Honor of the Electronics Industry Agency; in 1965, he was awarded the Charles Proteus Steinmetz Centennial Medal at the first annual meeting of the National Association of Engineers of which he is a founding member. In 1966, he received the Founders Award of the IEEE and the William Procter Prize for scientific achievement from the Scientific Research Society of America. Dr. Engstrom also is a member of the Royal Services Academy of Engineers and Scientists, and in 1965 the King of Sweden conferred upon him the rank of Commander of Vasa.

electronics industry. From its initial concern with communications and entertainment, electronics was steadily evolving into the role of a basic industry whose products and services are vital to virtually every other industrial activity. This provided a broader base than ever before for the company's growth.

COLOR TV AND THE CONSUMER MARKET

While all these factors contributed materially, the force that gave the greatest impetus to RCA's performance between 1962 and 1966 was unquestionably color television. The pioneering days of the late fifties and early sixties were over, and in five short years, color television mushroomed from an annual retail sales level of $200 million to more than $3 billion. This latter figure was achieved in 1966, when consumers spent more money to purchase color television sets than they did for all other home instruments, including black-and-white television, radio, phonographs, and tape recorders.

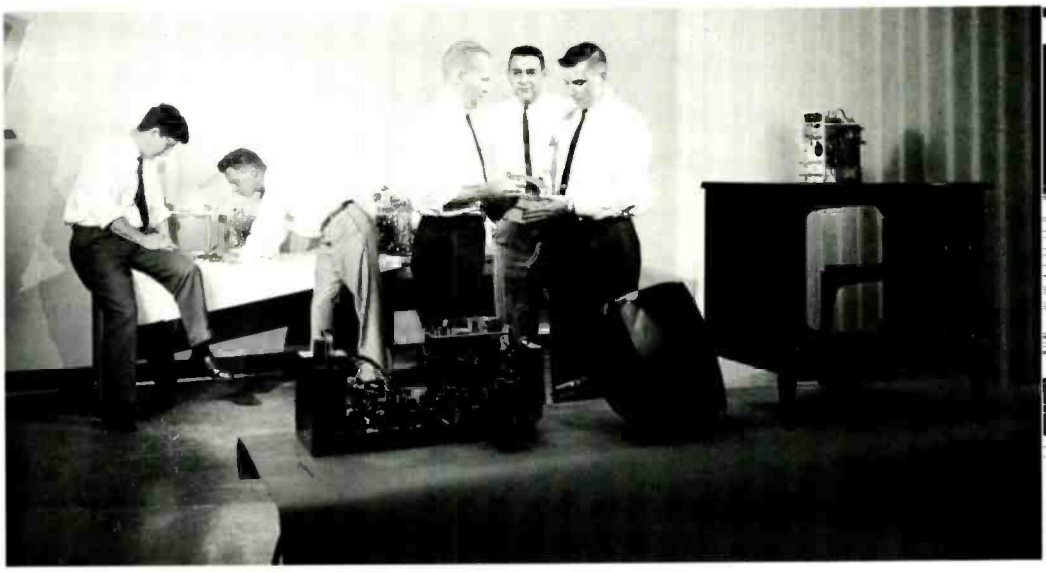
Beyond the manufacture and sale of sets and tubes, the color television industry embraces the production of studio and transmitting equipment, such as color cameras and video tape machines. It includes broadcasting, programming, service, and the production of the many electronic components that go into the final assembly of a set.

Because of its decision to blaze a trail in color, RCA had long before developed its own capabilities in all these areas. It was recognized that if color television were to succeed, it had to be presented to the public as a total system. As a result, many divisions of RCA experienced major gains in sales as public opinion on color television changed from the cautious interest of 1962 to the unrestrained eagerness of 1966.

RCA was in a position to take full advantage of the new opportunities presented by the rapid expansion of the market and to take the lead in many new developments. Slimmer cabinet styling replaced the earlier, bulkier models as the 90-degree rectangular color television picture tube gradually replaced the 21-inch round tube which had been the industry standard for nearly a decade. By the end of 1966, production of this older model was entirely phased out, and RCA was manufacturing four different color picture tube sizes—15", 19", 22", and 25"—for a diverse line of portable, tabletop and console model receivers. (When used in sets, these tube sizes are now designated as 14", 18", 20", and 23" picture diagonal.)

The addition of rare earth phosphors from materials research added greater brightness and clarity to the color picture. In 1966, integrated circuits were introduced for the first time into home instruments when RCA employed them in the audio stage of its color and black-and-white television sets.

The RCA engineers in the background discuss integrated-circuit applications in the 12-inch, portable, black-and-white, TV receiver while those in the foreground examine the complex deflection yoke for the 90° color picture tube. The chassis in the foreground shows the trend toward more compact color receivers using shorter rectangular picture tubes.



The versatile, battery-powered tape recorder found new uses in the home and in school lecture halls.

Standing among the more than 50 different loudspeakers used in Home Instruments Division products is W. E. Davis of Radio "Victrola" Engineering in Indianapolis. H. D. Ward of the Record Engineering Laboratory shows a tape cartridge from the Record Division and the YGG45 reel-to-reel stereo tape recorder produced by Home Instruments.

Portable television sets being readied for shipment at RCA's Memphis, Tennessee, plant.

This advanced RCA Spectra 70/45 data processing system at the new RCA computer center Cherry Hill, N. J. is one of a family of data processing systems which employ "third generation" monolithic integrated circuitry.

RCA Communications' Electronic Telegraph System (ETS) processes message telegrams to and from overseas points in fractions of a second at RCA's Global Communications headquarters in New York. In 1966, RCA's ETS processed more than 10 million overseas telegrams via the 100 full-duplex input and output buffers associated with the computers.

The years 1962 through 1966 also saw steady advances in the manufacture of color transmission equipment. A new, all-transistorized tape recorder for both color and black-and-white television, the TR-22, found a ready market among broadcasters and closed-circuit television operators both in the United States and abroad.

In 1964, as the result of a major engineering development effort, RCA's Broadcast and Communications Products Division presented an entirely new look in broadcasting equipment. The new line featured sweeping changes in design, appearance, and function, and employed the use of solid-state components wherever possible.

By the end of 1966, 450 out of approximately 650 commercial television stations in the country were equipped to originate color programs from film. About 150 stations could originate live color programs.

Leading the way towards full conversion to color was the National Broadcasting Company. In the autumn of 1962, about 68% of NBC's total nighttime programming was in color. By the end of 1966, the entire network schedule was broadcast in color, with the occasional exception of feature films originally photographed in black-and-white.

The spectacular growth of color television was the principal feature of a generally thriving consumer market for electronics.

In 1965, for example, RCA sold more black-and-white television sets than in any year since 1955. By the end of 1966, industry sales of both imported and domestic radios were approximately 44 million units, up from a little over 33 million units sold five years earlier.

Stereophonic sound was firmly rooted in the home instruments market, and industry sales of phonographs increased each year from 1962 to 1966, with RCA "Victrola" phonographs leading the way. Music on tape gained in popularity during the period, and the company responded by marketing a full line of reel-to-reel and cartridge tape recorders.

As phonograph and tape recorder sales increased, the RCA Victor Record Division also enjoyed a succession of peak years. In 1966 the Division completed three successive years in which all-time sales volume levels were reached. A significant development in 1965 added a new force to this aspect of the home entertainment market. This was the introduction of prerecorded Stereo 8 tape cartridge and player for use in automobiles and homes. RCA Victor Records pioneered in the production of musical selections on Stereo 8 cartridges, and a home player for the tapes was introduced in the 1966 home instruments line.

The Stereo 8 cartridge and player typified the growing trend to more casual electronic entertainment equipment, designed for use anywhere. The television set and the phonograph were no longer regarded only as items of furniture for the home, and demand grew for personalized, portable entertainment indoors, outdoors, and on the road.

COMPUTERS AND INDUSTRIAL ELECTRONICS

The expansion of the consumer electronics market in the five-year period had its counterpart in commercial and industrial markets. RCA served this market with a wide variety of products and services ranging from data processing installations to radar equipment for the aircraft industry.

Electronic data processing equipment was the most dynamic element on the commercial and industrial scene, both in technology and in business growth. In hardware alone, the sales volume of the computer industry rose from about $1.8 billion in 1962 to more than $3 billion in 1966.

The period brought significant advances for RCA in system design and programming concepts, and the company further solidified its position for the long run in the computer market.

At the end of 1962, the product line consisted largely of the 301 system for medium and small business enterprises, and the larger RCA 601 for industrial and scientific use. In 1963, a versatile new unit, the 3301 Realcom, was added to the line as the first computer designed to span the full range of data handling capabilities in a single system—business data processing, high-speed communications, real time management control, and scientific computation.

In the same year, a significant adjunct to these systems was introduced in the RCA 3488 mass memory, designed to hold several billion characters and to operate with either the 3301 or the 301.

Progress in circuit design and system concepts led in 1964 to a major step forward. RCA introduced the Spectra 70 series, the first in the industry of a new third generation of computers. The group initially included four compatible general-purpose computers—two of them employing the first monolithic integrated circuits to be used in commercial equipment. A fifth model was added in 1965.

Singly or in multiples, these systems were ordered by insurance companies, manufacturing industries, airlines, railroads, government agencies, and many other users in the United States and abroad.

As the 1960's progressed, computer systems were put to increasingly sophisticated use in a wide range of business and public functions. At their inception a decade and a half ago, electronic data processing equipment was regarded principally as immensely powerful tools for use in the repetitive and clerical tasks of commerce and industry. Through the past few years, progress in programming techniques as well as hardware has led to increasing application of the systems in more complex tasks of information processing, from management simulation to the analysis of physical, social, and other problems with many variables.

Within RCA, for example, computers were employed on a growing scale for management information. In this function, systems at various operating divisions and at corporate headquarters were programmed to supply current information on all aspects of the company's operations and to aid in planning and decision-making by indicating trends in the wide range of factors affecting production and marketing.

Another significant trend was the growing relationship between computers and communications—both in the development of computer-to-computer links and in the use of computers to increase the speed and flexibility of communications.

RCA introduced several advanced terminal devices during the 1962-1966 period for communication between computers and users. Among them were a voice response unit that provided spoken replies to inquiries telephoned directly to a computer, and a self-contained video display unit employing integrated circuitry.

The greater use of computers as tools in communication systems was evident in the operations and services of RCA Communications, Inc. In 1964, an Electronic Telegraph System (ETS), employing RCA computers of special design, was put into operation at the RCA Communications, Inc. facilities in New York to route, process, and transmit overseas messages electronically, in great volume at high speed. The innovation came at a time when communications satellites were on the verge of multiplying international channel capacity. The combination of expanded channels and electronic message switching promised, by the end of 1966, to revolutionize international communications in terms of volume and scope of services.

There were indications of this in two new services introduced by RCA Communications. In 1965, the company announced DATEL, a service for overseas data transmission from punched tape or cards, or magnetic tape, at speeds up to 1,200 words a minute. In 1966, it introduced a new service concept incorporating computer techniques in an Automated Information and Reservations Computer Operated Network (AIRCON) for message processing and reservations.

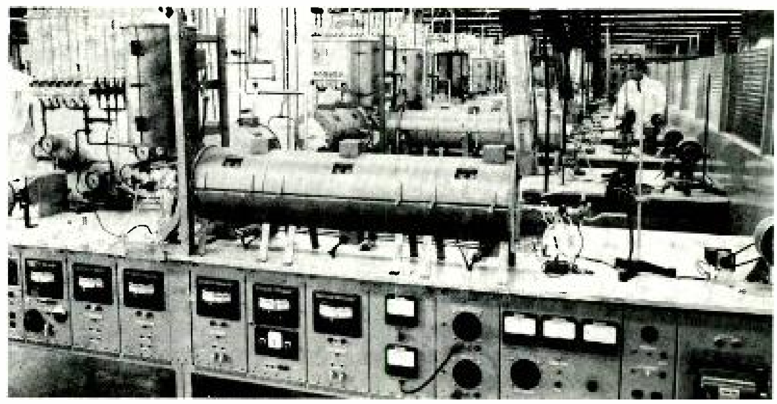
In addition to its activities in computers and data processing, RCA played a significant part during the period in supplying new products and services for other business needs. Among the notable contributions were airborne weather radar systems for commercial and business aircraft, and at the end of 1966, RCA was one of the largest suppliers of such equipment.

Two-way mobile radio communications systems were developed and installed in trucking fleets and public transportation bus systems, including those of the New York City Transit Authority. In the fall of 1964, the Western Union transcontinental microwave network, the longest single microwave project ever undertaken at one time, went into operation with RCA equipment in its 267 relay and terminal stations.

ELECTRONIC COMPONENTS

In 1963, RCA's Semiconductor and Materials Division was consolidated with the Electron Tube Division to form a new operating unit known as Electronic Components and Devices. The blending of the newer technology with the older in an organizational sense can be said to symbolize the coming of age of solid state electronics as a business. The move enabled all of RCA's talents in the field of electronic components and circuitry to be employed on a more closely coordinated basis. The results of the union have since demonstrated both the potential of the young solid state art, and the continuing vigor of electron tube technology.

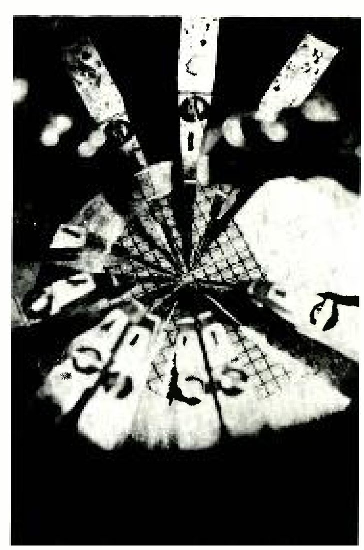
Electron tubes remained unchallenged in many areas. In the fall of 1964, RCA produced its three millionth color television picture tube, a short time

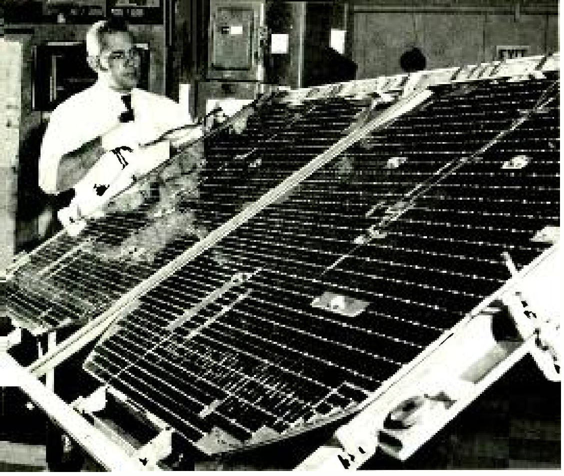


Vapor-deposition equipment in RCA's Harrison, New Jersey, plant produce "VAPODEP" superconductive ribbon. These superconductive ribbons, released in January 1966, provided outstanding performance, increased current capability, improved economies of application, and superior mechanical strength in the construction of commercial high-field-intensity magnets up to 100 kilogauss.

In November 1965, these high-temperature furnaces were added to RCA's integrated circuit production facility in Somerville, N. J. At the same time, RCA announced its entry into the integrated circuits market with a broad line of 17 new digital and linear integrated circuits.

One of the final steps in the manufacture of integrated circuits is performed by this probing equipment at RCA's plant in Somerville, N. J., where production facilities were expanded to meet growing demand in 1966.





Solar panels for Lunar Orbiter II were prepared for final testing at RCA's Space Center, Princeton, N.J., before joining the spacecraft that mapped the moon for possible manned landing sites. The spacecraft carried four solar panels (only two are shown) to convert sunlight directly into electricity to power the spacecraft and recharge its batteries for nighttime operation. Each of the four panels contains 2,714 individual solar cells.

Weather pictures from the RCA APT camera system on the Nimbus II satellite are automatically transmitted to small ground stations where they are reproduced on a facsimile machine as shown. Storage of the weather picture on the APT camera vidicon tube permits transmission to simple ground stations located in any area of the world. The APT system is one of two advanced RCA television systems aboard the experimental Nimbus II satellite.

after it had turned out its 25 millionth monochrome tube. Significant innovations were made in television pickup tubes, including improved vidicons for studio cameras and a number of special purpose types. Among the latter were several built for use in the Ranger lunar vehicle, and one employed for underwater television equipment used by the Navy to recover missiles and torpedoes.

Many other special tube types were provided by the new division, including a high-efficiency traveling-wave tube for microwave systems, high-efficiency thermionic converters, and special klystron power tubes employed in the 2-mile accelerator at Stanford University in 1966.

The application of new solid state technology and materials research led to significant contributions during the period in new and improved components and devices for a variety of uses. In 1964 and 1965, for example, RCA introduced the new "overlay" transistors and a promising line of silicon power transistors for use in public address and home sound equipment. The company also continued as a leader in the production of transistors for use in automobile radios.

A major new activity was launched in 1963 to engineer, develop and produce integrated circuits for general use. Two years later, RCA made its full scale entry into this new market with an initial line of 17 types for application in communications, instrumentation, and industrial and military equipment, as well as computers. By mid-1966, the family of new circuits had been increased to 25, and integrated circuit sales had become a significant factor in RCA's total components business.

The new Electronic Components and Devices activity launched other vigorous programs to develop new business. An outstanding example, based on pioneering work at RCA Laboratories, was the company's entrance into commercial production and sale of superconductive magnets, principally for use in nuclear research.

SPACE AND MILITARY ELECTRONICS

The most dramatic achievement for RCA in space between 1962 and 1966 occurred in 1964 when NASA's Ranger 7, with a six-camera payload designed and built by RCA's Astro-Electronics Division, reached the moon and sent back the most detailed photographs ever taken of the lunar surface. This was followed in 1965 with the successful launch of the Ranger 8 and 9 spacecraft, which together obtained and transmitted to earth nearly 13,000 close-up views of the moon.

The Tiros television weather satellite program continued an unbroken series of successes. In 1962, three Tiros satellites, developed by RCA, were placed into orbit, providing television pictures for world-wide weather forecasting.

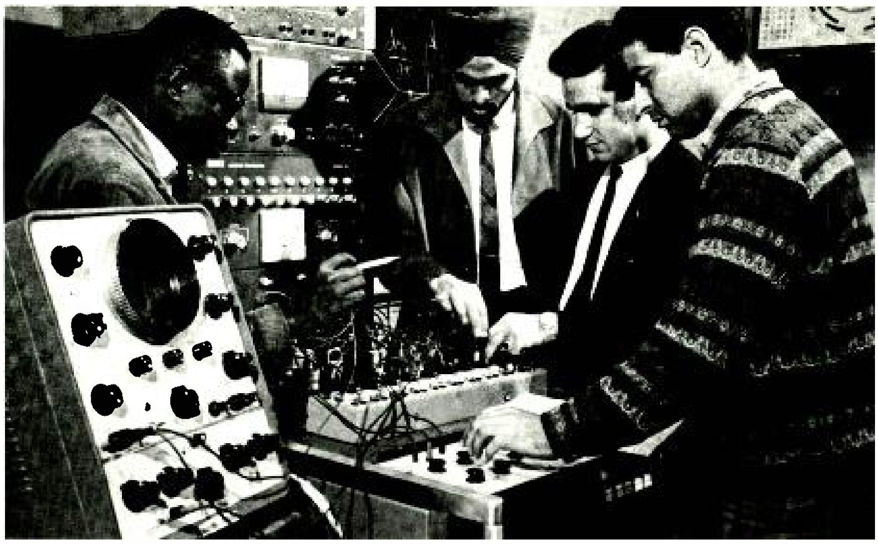
The following year, two more Tiros satellites were launched, and Relay I, a communications satellite built by RCA for NASA, completed its scheduled year-long mission. Among Relay's achievements were the first space transmission of a color telecast, simultaneous voice relays between the United States and Brazil, and the first trans-Pacific transmission from the United States to Japan.

RCA in 1963 was assigned major roles in the Apollo program, this country's attempt to land astronauts on the moon. The company was selected to develop communications and control systems for the Lunar Excursion Module, which was scheduled to perform the actual landing. In addition, RCA contracted to build the power and communications equipment for the Lunar Orbiter, designed to transmit pictures from an orbit around the moon in search of a suitable landing site. During 1965 and 1966, spacecraft in the orbiter series returned remarkable pictures of selected areas from altitudes as low as 28 miles above the moon.

The major RCA contributions to the nation's space program in the 1962-1966 period included the picture-taking systems for NASA's experimental Nimbus satellite to map global weather conditions; a second successful Relay communications satellite; three more Tiros weather satellites; and a continuation of the Tiros program under the name of Essa (Environmental Science Services Administration) which established the first operational weather satellite system.

In other aspects of the space effort, RCA delivered tracking radars for the Apollo Radar Instrumentation Ships and the Apollo Recovery Ships. It provided communications links between NASA headquarters in the United States and various overseas tracking lo-

In 1966 an RCA mobile two-way radio network was provided to the Singapore Police Department.



Students from more than 60 countries throughout the world have received training in electronics in courses conducted by the RCA Institutes.

RCA's Graphic 70 Videocomp was designed to set type electronically for the printing industry.

cations, including voice and teletypewriter circuits to tracking vessels at sea, alternate voice/data and teletypewriter circuits to Europe, Africa, the Caribbean, Australia, and several points in the Pacific. RCA computers were developed for test and checkout of the SATURN launch vehicle in the APOLLO program.

In 1964, the RCA Service Company was awarded a contract for the planning, installation, operation, and maintenance of communications for NASA's Spaceport at Merritt Island, Florida.

The company's military support activities were highlighted by operation and maintenance of the Ballistic Missile Early Warning System, the electronic systems used on the Air Force Eastern Test Range at Cape Kennedy, and the White Alice communications system of the Air Force in Alaska. The company began delivery of communications equipment for the Department of Defense AUTODIN data communications network in 1964. Delivery continued throughout 1966, and when the project is completed, the continental portion of AUTODIN will be the most advanced data communications system in the world, with individual switching stations capable of handling 6 million messages a month.

As one of the leading industrial contractors to the Department of Defense, RCA continued to supply a wide range of military electronic devices and systems. Among them were microelectronic receiving equipment, various types of radar, secure communications systems, laser range finders and related equipment, and mobile radio relay units.

In 1966, RCA became extensively involved in the challenging new area of underwater technology through a three-year contract awarded by the U. S. Navy to manage, operate, maintain, and support the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. AUTEC is a naval facility employing weapons, acoustic, and sonar ranges located in the deep-ocean areas south of Nassau.

THE INTERNATIONAL MARKET

Technological progress and rising aspirations in most parts of the world between 1962 and 1966 created new international markets for electronic products and services. This was especially evident in the spread of color television abroad.

In 1964, RCA Victor Company, Ltd., of Montreal, began the assembly of color picture tubes. In the same year, RCA sent a specially built mobile unit on a six-month tour to demonstrate the United States color television system to European governmental authorities. By 1966, RCA's Canadian subsidiary had substantially expanded its color picture tube facility, and had started construction of a new cabinet plant in Ontario.

In anticipation of regular color broadcasting in Europe, a new company, RCA Colour Tubes, Ltd., was formed in England in association with the British firm of Radio Rentals, Ltd., to produce RCA color picture tubes for the British and European markets.

On the other side of the world, the Philippines became the second Far Eastern nation after Japan to begin color broadcasting, employing RCA color studio and transmitting equipment.

In addition to supplying color and black-and-white television equipment to nations in Asia, Africa, and the Middle East, many other RCA products were in use throughout the world.

In 1963, RCA's Canadian subsidiary received a contract from the Canadian government for the design and construction of an advanced satellite communications ground station in Newfoundland. The station began operations in 1966. RCA Communications, Inc., was selected by the government of Thailand in 1966 to install Southeast Asia's first communications satellite earth station.

During the five-year period, RCA subsidiaries were active in the Latin American Free Trade Area, exporting electron tubes to this expanding market. The recording operations of RCA Italiana, conducted in Rome at Europe's most modern recording facilities, increased substantially. Two-way mobile radio units were supplied to the Hong Kong Ambulance and Fire Service, and to the Singapore Police Department, and NBC reached audiences in 93 countries through the sale of television films to government broadcasting authorities.

The continued growth of new opportunities abroad led at the end of 1966 to a realignment of RCA's organizational structure to capitalize upon its special skills for foreign markets. The change was designed to draw the domestic operating divisions more directly into RCA's overseas businesses in order to make the most effective use of the company's resources in an expanding world market.

NEW BUSINESS AREAS

Major diversification moves were made during the four-year period to develop positions of leadership in new technology and new markets, ranging over wide areas of information processing and education.

In 1965, RCA organized a Graphic Systems Divison to apply computer and electronic technology to processes used in the printing industry. The following year the Division marketed its first two products—the Graphic 70 Videocomp electronic typesetter, and the Graphic 70 Color Scanner, which electronically produced the four basic color separations needed in full-color printing. At the same time, a vigorous applied research and development program was launched to supply a flow of new products.

The company expanded into publishing and took major steps into new areas of education. In 1966, Random House, Inc., became a wholly-owned subsidiary of RCA.

The educational facilities of the RCA Institutes, Inc., were expanded substantially. In 1966, the RCA Service Company received multi-million-dollar contracts to operate two Job Corps Training Centers for the Office of Economic Opportunity.

In order to coordinate the sale of TV systems, cameras, learning laboratories, and other equipment to the educational market, RCA formed an Instructional Electronics Department in 1966. That same year, the nation's largest educational TV system, installed by RCA for the Catholic Archdiocese of New York, was put into operation, and a similar system serving the Miami Diocese was extended.

Other new opportunities explored in 1966 included an agreement with Hoffmann-LaRoche, a leading pharmaceutical firm, to collaborate in the development of new medical electronic equipment.

Also in 1966, the company established the Magnetic Products Division to speed the growth of RCA's business in computer and other tapes for use in industry and the home.

Finally, late in the year, the Boards of Directors of RCA and The Hertz Corporation approved an agreement for the acquisition of Hertz by RCA.

RESEARCH

Many of the products that so radically changed the character of the electronics industry between 1962 and 1966 represented the successful application of research performed in earlier years in the laboratories of RCA.

The company's research and development activities during the period were scattered widely through the principal operating divisions, spearheaded by theoretical and applied research at the David Sarnoff Research Center of RCA Laboratories at Princeton, N.J.

In 1963, and again in 1965, major expansion programs were undertaken at the research center to increase laboratory facilities and to accommodate new research activities associated directly with specific product divisions of the company.

The research program itself penetrated increasingly into new areas of basic materials and phenomena, and it produced a number of significant advances leading to new devices and technology applicable to present and future businesses for RCA.

Extensive research efforts relating to lasers led to a number of new laser devices and techniques for employing lasers in possible future communications systems. A highlight of the program was the development in 1965 of an argon laser producing the highest power of any visible light laser yet known. The device was translated into a new commercial product and placed on the market by RCA in 1966. RCA's scientists also achieved in 1965 the first injection laser to emit visible light at room temperature.

Continued research in computer memories led to a number of new concepts and techniques of considerable promise for the future. The program followed several different lines, including new types of ferrite devices, thin film techniques, and superconductive memories. The latter effort achieved in 1966 a new technology for making high-capacity superconductive arrays that promised to out-perform present mass storage electromechanical memory systems and to compete economically with them.

Experiments in thin-film techniques employing improved photosensitive materials resulted in an experimental tubeless television camera. This device employed networks of thin films of photoconductors and other semiconductor materials, and digital scanning techniques, to perform the functions of a pickup tube and picture processing elements in a conventional camera.

These are highlights of a wide-ranging effort that also produced new understanding of basic phenomena, explored new materials for a multitude of device applications, and developed new technologies for manufacturing microminiature devices in large arrays. The results promise to carry RCA forward in many existing and new areas of business in the years just ahead.

PROSPECTS FOR THE FUTURE

In assessing the performance of RCA between 1962 and 1966, and looking ahead at the prospects for continued growth and development, David Sarnoff told shareholders at the 1965 Annual Meeting, "In all my years with RCA, I have never seen our company more strongly positioned for progress than it is today—in personnel, in products and services, and in the promise of continuing profitability. Color, computers, components, and communications; broadcasting, service, records, and broadcast equipment are among the most active contributors to the country's growth—and they illustrate the breadth as well as the diversity of our strength."

These words were equally appropriate as 1966 drew to a close. Electronics in 1966 remained the nation's fastest growing industry, and its most challenging. No company was more determined than RCA to explore the many opportunities for service that electronics will offer in the years ahead.

This experimental "sun-pumped" laser, which is powered by the sun's rays collected in the parabolic mirror, was developed by RCA's Applied Technology organization, Camden, N. J., for NASA's Manned Spacecraft Center, Houston, Texas. This was the first step in a 50-million-mile communications link between Earth and spacecraft near Mars. Adjusting the equipment is RCA physicist Richard J. Tarzaiski, who helped develop the system. The device is believed to be the first to transmit television pictures over a light beam from a laser powered by sunlight.

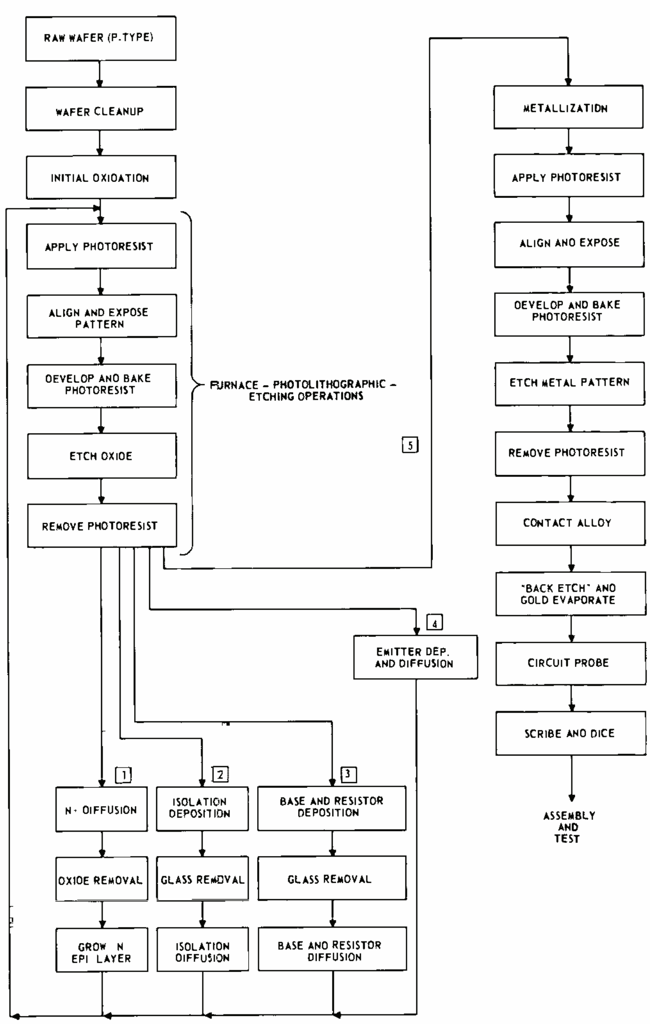
INTEGRATED-CIRCUIT OPERATIONS AT RCA SOMERVILLE—A Review

Development of integrated circuits was initiated at RCA Somerville in 1964. From a handful of engineers and scientists working with the most rudimentary facilities in a small developmental laboratory, the organization has grown to include a staff of more than 1,000. The organization represents the successful combination of a staff embracing a wide spectrum of skills with a large development and production facility. Production and Engineering operations have grown to include well-equipped development and model shops, as well as a multiplant manufacturing capability consisting of a factory in Palm Beach, Florida, in addition to the manufacturing and engineering operations located at EC&D's Somerville plant. Production operations already require nearly 100,000 square feet of floor space, with almost explosive further growth planned over the next five years. Engineering operations now require an area in excess of 30,000 square feet to accommodate a staff of more than 400. This paper reviews the production, testing, and quality control processes that have evolved in these integrated circuit operations.

E. M. TROY, Mgr.

Integrated Circuit Products Mfg. Operations
Electronic Components and Devices, Somerville, N. J.

Fig. 1—Typical wafer processing steps.



RCA's basic integrated-circuit production capability has been expanded since 1964 to include all processing required to produce a finished product, with the single exception of raw silicon-wafer manufacture. Expansion of the production capability to include epitaxial wafer processing and the manufacture of a complete line of packages (including the TO-5, ceramic flat pack, and ceramic plastic dual-in-line packages) has occurred during the past year.

Wafer processing is carried on in laminar-flow rooms especially designed for this purpose. These facilities, which now require more than 20,000 square feet of floor space, are maintained at better than Class 100 conditions and provide the dust-free environment so important for the critical wafer-processing portion of integrated-circuit fabrication. The laminar-flow rooms allow flexibility in equipment layout and product flow.

The simultaneous rapid development of monolithic silicon technology and production requirements has posed many equipment problems. Equipment being developed was subjected to numerous design modifications to permit accommodation of the technological changes that had occurred in the manufacturing process during the equipment design and fabrication period. Equipment versatility and the minimization of obsolescence was, and still is, the key consideration in the multimillion-dollar integrated-circuit production.

PRODUCTION PROCESSES

Wafer Processing

The basic monolithic process is still the cornerstone of integrated-circuit manufacture. Refinements and variations of this wafer-processing technique have been developed that have led to the fabrication of a wider variety of devices than was possible previously, as well as to improved process control and to circuit yield improvements. Although wafer fabrication is still essentially a batch process, recent advances in techniques have permitted substantial increases in lot sizes while at the same time minimizing labor costs and largely eliminating wafer damage caused by individual wafer handling by operators.

A flow chart showing the steps in the processing of a typical wafer is shown in Fig. 1. Following the first diffusion step ($N+$), an epitaxial layer is grown on the wafer. The wafer is then cycled several times through the furnace-photolithographic-etching series of operations to provide the requisite pattern of suitably doped layers within the silicon slice. Precise alignment equipment is used to define the required patterns on the slice,

Final manuscript received April 20, 1967

Fig. 2—View of Integrated-Circuit Diffusion-Furnace area.

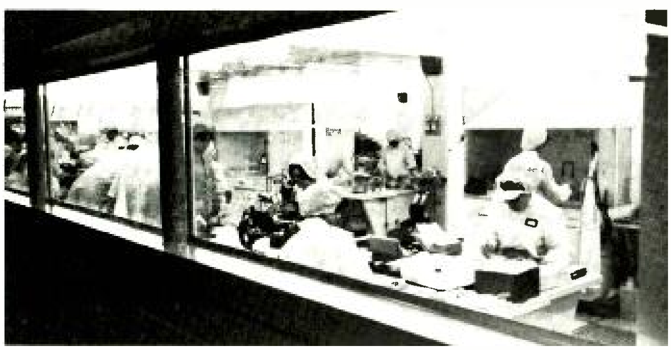
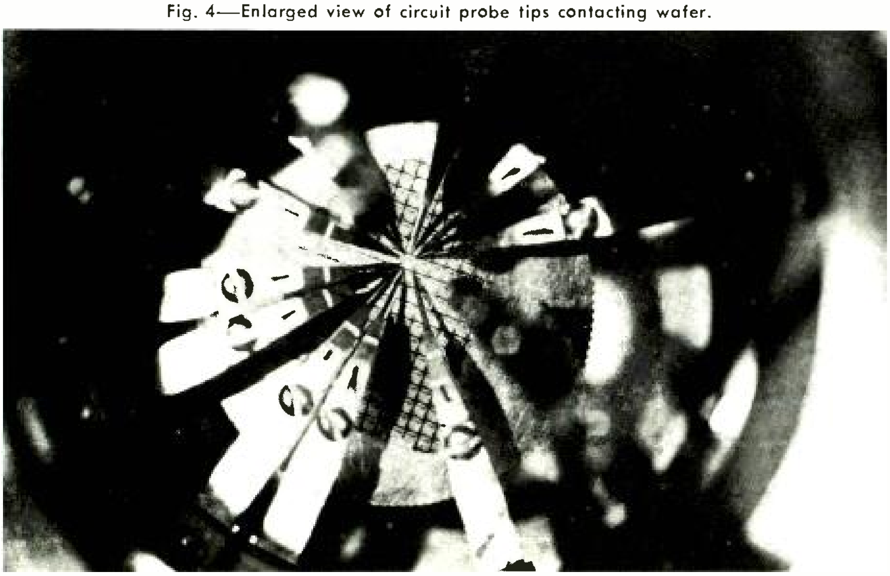


Fig. 3—View through window in Laminar Flow Room showing the Wafer Photolithography Processing Area.

Fig. 4—Enlarged view of circuit probe tips contacting wafer.



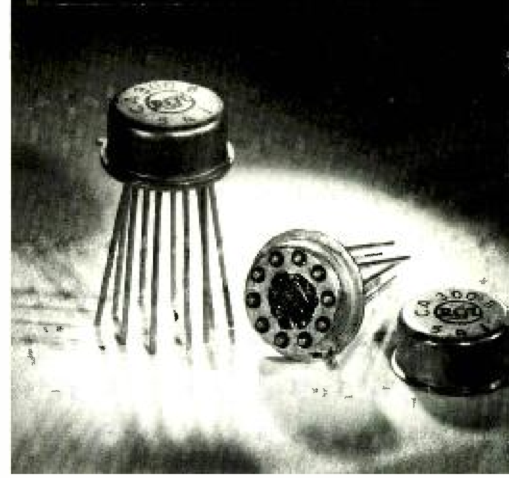


Fig. 5—Typical TO-5 and flat-pack headers with chip attached.

and windows are etched open in accord with these patterns. The patterns define and interconnect the various circuit elements on the chip. The wafers are then processed through a series of deposition and diffusion steps in which carefully controlled quantities of dopants are deposited on the wafer and diffused into the window openings under closely controlled temperature-time conditions. The wafer is then ready for metallization.

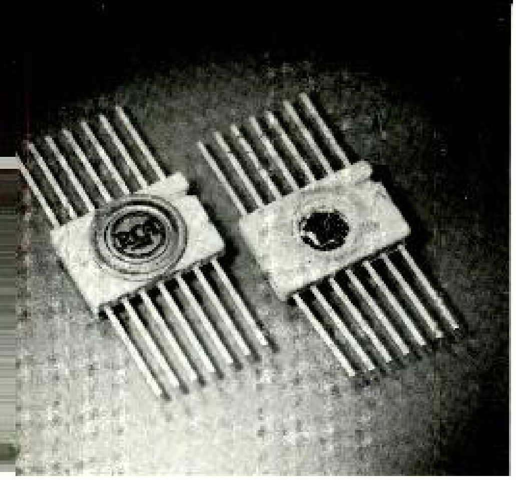
In metallizing, a thin film of aluminum is deposited by evaporation over the entire active surface of the wafer. A photolithographic step follows in which the interconnect pattern for each chip is defined on the wafer with photoresist; an acid etch is then employed to remove the unwanted metal surrounding the interconnect pattern.

At this point, the wafer is "back-etched" to clean up its back surface and to reduce its thickness. As a final step a layer of gold is deposited on the back of the wafer to permit metallurgical mounting of the chips it contains onto their respective packages.

In a significant volume operation where a large number of different chips are being processed concurrently through this process cycle, careful scheduling and control of product flow is necessary. For this reason, studies aimed at the implementation of computer-controlled product-flow techniques for this critical operation are currently underway. Fig. 2 shows a portion of the diffusion-furnace area. Floor gratings and ceiling nozzles are used to direct the laminar flow of specially filtered air during this operation. Fig. 3 shows a view through a window in the laminar-flow room in the wafer photolithographic processing area.

Chip Preparation

By far the most costly processes in the manufacture of an integrated circuit are the assembly, packaging, and testing of the device. Assembly costs are high because of the great amount of labor required. Package costs, especially for the ceramic type of enclosure, may be equal to or greater than the chip cost. Al-



though the cost of testing is not prohibitive. the cost of rejecting a packaged unit at final test is very substantial. The substantial loss arises from the fact that for every circuit rejected the entire cost of assembly and packaging is lost. Therefore. until such time as assembly and packaging become automated and their costs assume more modest proportions, the final test yield will exert a very strong influence on final product cost.

The method currently used to avoid assembly and packaging of defective circuits is to eliminate the defectives at the wafer/pellet stage. Circuit probing is used to evaluate the electrical performance of each of the circuits on a wafer and to determine the defective or marginal pellets. In circuit probing, a multiple probe head with as many as fifteen probes is used to contact the bonding pads on each chip. Fig. 4 shows an enlarged view of the circuit probe tips making contact with the wafer during this operation. The probe head is operated in conjunction with a conventional automatic test set such as that used at final test. A prescribed series of tests is performed on each chip as the probe head makes contact. The equipment is designed so that the probe automatically steps from circuit to circuit on the wafer after completion of each test sequence. During the probing process. chips failing to meet test requirements are physically identified so that they can be eliminated from the batch before it enters the assembly stage.

Because of the very small spacings on a chip. the large number of contacts to be made. the size of the contact pads (3 to 5 mils across), and the sensitivity of a number of the circuits to small changes in probe-tip contact resistance, circuit probing presents a unique problem in integrated-circuit processing. Making consistent simultaneous low-ohmic contacts on up to fifteen 3- to 5-mil pads located on the periphery of a chip 30 to 60 mils square on a production-rate basis presents extremely severe mechanical and electrical problems. After circuit-probe testing, each wafer is scribed with a diamond-tipped needle and diced into individual circuit chips by rolling or flexing techniques. Defective chips are separated out in a subsequent inspection.

Assembly

The first step in assembly is mounting. In this operation, a progression of automatic equipment developed by RCA is used to locate. orient, and mechanically and thermally attach the chip to its package by eutectic alloying. by ultrasonic bonding, or by nonmetallurgical means. Typical TO-5 and flat-pack headers with chips attached are shown in Fig. 5. In processing plastic packaged units, the chip is affixed to a mounting pad which is part of the metal lead frame shown in Fig. 6. Chips remain on the lead frame through the mounting and bonding operations. The frame contains the leads or posts to which the connections to the pads on the chip are made. The leads will ultimately be cut and formed to fit the finished package outline. Extreme care must be used in handling a chip during the mounting operation if mechanical damage is to be avoided. In all mounting techniques. the chip is transported, accurately positioned on the package or header, and properly aligned for bonding by tiny vacuum chucks with pick-up heads designed to contact the chip on its periphery.

After mounting. the unit proceeds through the wire-bonding operation. In this step. thin (1.5-mil) aluminum wires are connected between each of the pads on the chip and the corresponding post on the header. RCA uses ultrasonic bonding exclusively in the wire-bonding process because it is a low-temperature process and because it affords very-high-reliability bonds. The labor costs in the bonding step are very high with present assembly techniques. The high cost arises from the fact that from 8 to 14 wires must be manually bonded at both the pad and the post for a total of 16 to 28 bonds on each unit. Much work is being done in the industry in an attempt to find a practical means of automating the bonding technique so that the labor cost can be reduced.

Packaging

After bonding, the units are sealed in packages. RCA integrated circuits are currently packaged in three distinct configurations: the TO-5 glass-metal package. the ceramic flat pack, and the dual-in-line package. There are two types of dual-in-line package, one of ceramic and one of plastic.

The TO-5 package, an extension of the standard transistor-type package, has from 8 to 12 leads; the flat pack and dual-in-line packages have 14 leads. Ceramic packages, either flat pack or dual-in-line, offer the ultimate in hermeticity and package integrity. but their cost is high because of the basic complexity of their fabrication process. The dual-in-line plastic package is at present rapidly achieving popularity in the industry. Molded packages of this type. such as the one shown in Fig. 7, are less costly than the ceramic package and can be readily designed to accommodate more than 14 leads.

Fig. 6—A metal lead frame used in processing plastic packaged chips.

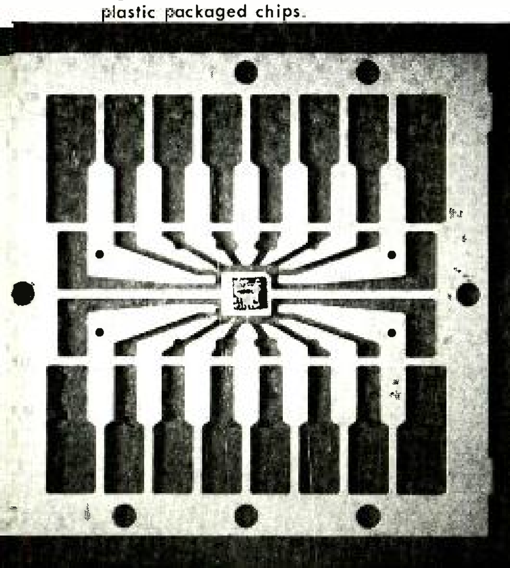


Fig. 7—A molded plastic dual-in-line package.

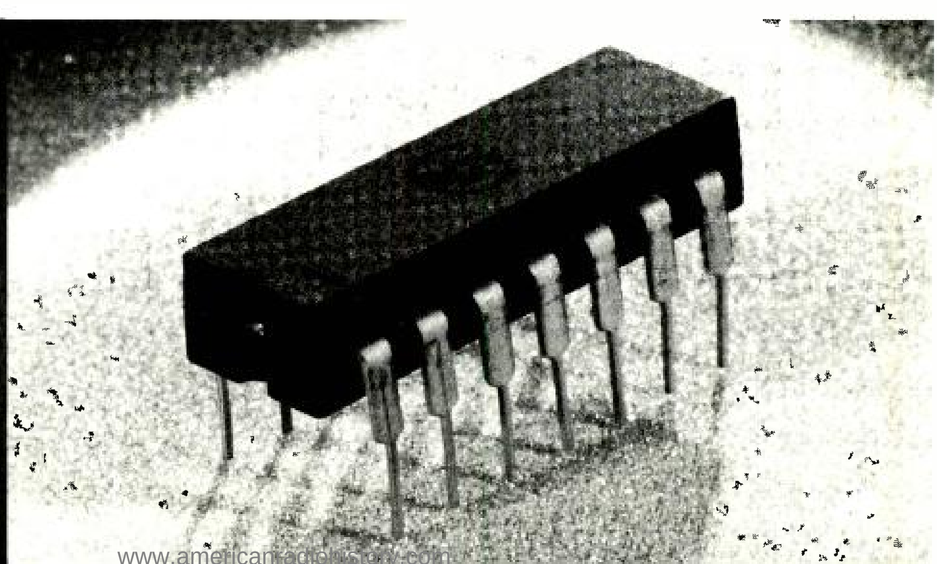
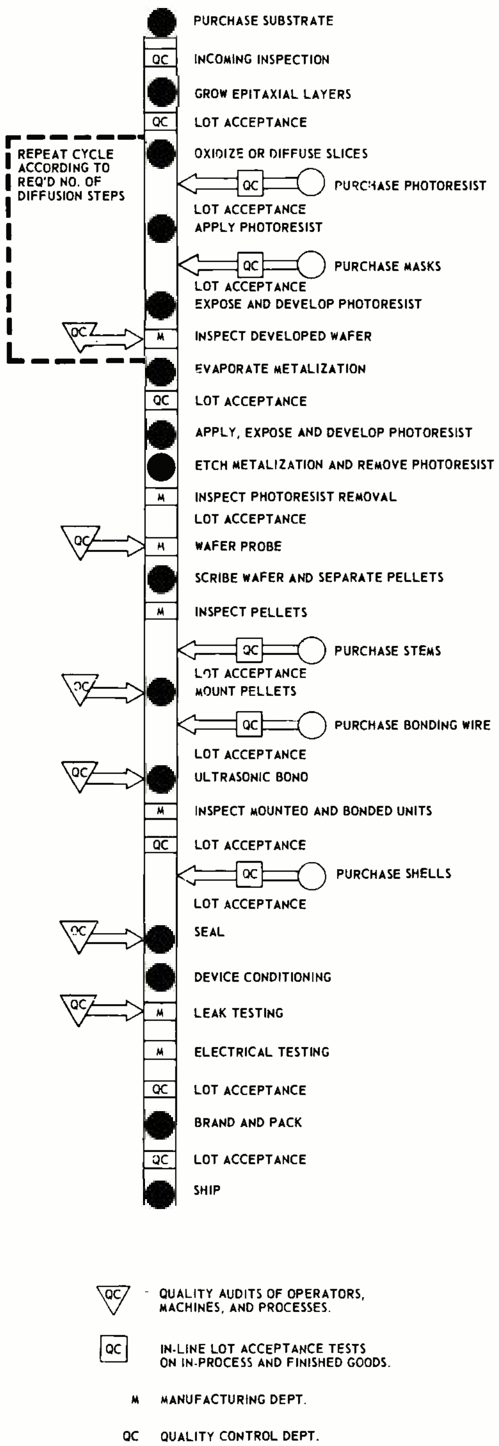


Fig. 8—A flow chart of RCA's integrated circuit manufacturing process and Quality Control check points.



RCA's techniques for hermetically sealing TO-5's and flat pack and dual-in-line ceramic packages is to weld a cap onto the package in a dry nitrogen atmosphere. Plastic packaged units are sealed by the plastic covering molded around the metal lead frame to which the chip is affixed during mounting and bonding operations.

The final step in assembly is preconditioning. In this step, circuits are put through a series of temperature-cycling tests and checks for package hermeticity.

TESTING

In final testing, the packaged units are evaluated 100% during an extended series of DC and AC tests. These tests include those performed during circuit probing plus a number of additional tests required to establish adequate circuit performance. In general, more than thirty-five DC and AC tests are performed on each circuit. Testing is normally done at room temperature without preheating, but for some circuits rigorous preheating requirements are imposed. In addition to the need for development and maintenance of sophisticated high-speed electronic test equipment, final testing presents some very serious mechanical handling problems. Present integrated circuits are housed in packages with 8 to 14 leads. As large-scale integration develops, packages with many more leads will become common. The problem will be to get these multilead packages into the test set at such a rate that maximum advantage can be taken of the inherently high test speed (thousand of units per hour) of the test equipment, while making sure that low-ohmic contacts are made to each lead. It appears that the most practical solution to this problem exists in the combination of an automatic handling system with the use of multiplexing to permit time-sharing by a number of test sockets. For those circuits requiring preheat, the problems involved in automatic handling increase substantially.

QUALITY CONTROL—PRODUCT ASSURANCE

The old axiom about not being able to test quality into a product was never more appropriate than for integrated circuits. The quality of the materials and the workmanship that go into a circuit during wafer processing and assembly directly determine the yield of acceptable circuits at final test and the ultimate performance and reliability of the circuit in its application. Because each successive step in wafer processing tends to mask the preceding steps, it is impossible to control production unless a rigorous quality-control program is enforced at each step of the process.

EDWARD M. TROY received the B.S. degree in Electrical Engineering from Rutgers University in 1948. Upon graduation, he joined RCA as a Product Development Engineer. In 1957 he was appointed Manager, Receiving-Tube Test Engineering, and in 1959 was appointed Manager, Receiving-Tube Design. In this position he had broad responsibility for the direction and coordination of engineering effort on electron-tube development and manufacturing problems and the introduction of improved designs, materials, and processing techniques to device manufacture. In 1963, he transferred to the Thermoelectric Products Engineering activity, where his responsibilities included the development and direction of technical programs on thermoelectric energy conversion. He was closely associated with the SNAP-10A and SNAP-17A thermoelectric programs at RCA. In November of 1965 he was appointed Administrator, Operations Planning for the Integrated-Circuit Operations Department, and in December was appointed Manager of Integrated-Circuit Products Manufacturing Operations. In this capacity he directed RCA EC&D's production build-up on integrated circuits. Mr. Troy is a member of Tau Beta Pi, Phi Beta Kappa, IEEE and the AMA.

Only by this means can reasonable yields be obtained. RCA's integrated-circuit production program is based on a comprehensive quality and reliability assurance program that meets MIL-Q-9858A standards and that is designed to control process variation and product quality. The program includes an inspection and verification of incoming raw materials, in-process quality control, and finished-product quality audits and reliability assurance checks. A simplified flow chart showing RCA's integrated-circuit manufacturing process and quality-control check points is shown in Fig. 8. The triangles represent quality audits of operators, machines, and processes; the squares represent in-line lot-acceptance tests on in-process and finished goods. These quality checks are performed in addition to the 100% inspection accomplished by manufacturing personnel at critical points throughout the production process. All production personnel receive extensive training in a company-sponsored training center; proficiency must be demonstrated before an operator is permitted to work on the production line.

Process-control charts are used to monitor all segments of the manufacturing process and to isolate any undesirable trends that occur so that timely preventive action can be taken. In many critical areas, such as bonding, individual control charts are kept for each operator so that trouble areas can be pinpointed. RCA's process-control techniques for integrated-circuit manufacture are among the most complete, sophisticated, and precise in the semiconductor industry: photomasks for the photolithographic process are checked to a dimensional accuracy of 10 millionths of an inch, the thickness of epitaxial layers is controlled to tenths of microns, and oxide and diffusion layers are controlled to hundredths of angstroms.

After final tests, all lots are sampled by Quality Department operators and tested on independent quality-control test facilities to determine adherence to all applicable operating specifications. After branding, a final visual and electrical quality audit is performed before product acceptance.

RELIABILITY ASSURANCE

The reliability of RCA's integrated circuits derives directly from the integrity of the design and manufacturing processes. A reliability assurance program has been established to determine the capability of all new integrated-circuit designs to meet comprehensive reliability standards. In addition to basic design reviews and reliability checks, mechanical and environmental testing is performed on all types of integrated circuits manufactured. These tests are as outlined in Fig. 9. Both shelf and operating life tests in the form of electrical performance evaluations are performed periodically on all circuits under ambient and high-temperature conditions. High-temperature life history of more than 5.5 million unit-hours has been accumulated. Tests are also performed in actual customer circuits as a further check on the reliability and life expectancy of the product. The reliability loop is completed by the performance of extensive failure analyses on integrated circuits that fail to meet environmental stress testing or customer specifications. Follow-up action is then taken in the design or manufacturing areas to eliminate the causes of these failures.

SUMMARY

Over the past three years at RCA EC&D, integrated circuits have moved from the research and design stage through the development phase into commercial product status. Production has advanced from prototype development to a full-fledged production operation with an annual output in the millions of units. From the early days when only three or four different chips or circuits were available, the product line has expanded to more than sixty circuits. Fig. 10 illustrates the growth in the number of circuit types over a three-year period. Fig. 11 outlines the current RCA integrated-circuit product line and shows the many types of circuits now available to meet the ever-expanding diversity of application needs.

Fig. 9—Mechanical and environmental tests performed on all integrated circuit type.

SUBGROUP TESTS & CONDITIONS

Subgroup	Test	Conditions	MIL-STD-750 METHOD
I.	Physical Dimensions	—	2066
II.	Solderability	--	2026
	Thermal Shock	65°C to +150°C — 5 cycles	1056B
	Moisture Resistance	240 hrs., temp. cycled 25°C to 65°C at 90% relative humidity	1021
III.	Shock	1500G's — 5 blows in each of 6 planes	2016
	Vibration, Fatigue	96 hrs., 20G's non-operating	2046
	Vibration	Variable Frequency (100 - 2000 cps)	2056
	Constant Acceleration	20,000G — 6 planes	2006
IV.	Terminal Strength (Lead Fatigue)	½ lb. — 3 90° bends 2 lbs. — 3 sec.	2036E 2036A
V.	Salt Atmosphere Corrosion (TO-5 Style Pkg.)	24 hrs. at 35°C	1041
	Soldering Heat	260°C	2031
VI.	High Temperature Storage Life Test	non-operating	1031
VII.	High Temperature Operating Life Test	$T_A = 125°C$	1026

Fig. 10—Growth in chip and circuit types over a three-year period.

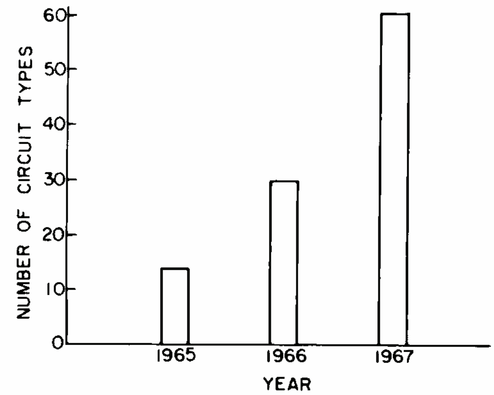


Fig. 11—RCA Integrated Circuit product line.

INTEGRATED CIRCUITS
MONOLITHIC SILICON TYPES

TYPE	Function
Linear - Amplifier	
dCA3000	DC
CA3001	Video
CA3002	IF
CA3004	RF
CA3005	RF
CA3006	RF
CA3007	AF
CA3008	Operational
CA3010	Operational
CA3011	Wide Band, Low Voltage
CA3012	Wide Band, High Voltage
aCA3020	Audio
aCA3021	Video
aCA3022	Video
aCA3023	Video
aCA3028	RF
aCA3029	Operational
aCA3030	Operational
aCA3031/702A	Operational
aCA3032/702C	Operational
Linear - Amplifier/Discriminator	
CA3013	Wide Band, Low Voltage
CA3014	Wide Band, High Voltage
CA3015	Operational
CA3016	Operational
Linear - Active Arrays	
aCA3018	Transistor General Purpose
aCA3019	Diode General Purpose
Digital	
High-Speed ECCSL*	
CD2100	Dual 4-Input Gate
CD2101	Quad 2-Input Gate
Ultra-High-Speed ECCSL*	
CD2150	Dual 4-Input Gate
CD2151	Dual 4-Input Gate
CD2152	Single 8-Input Gate
Low Power DTL	
CD2200	Dual 4-Input Gate
CD2201	Quad 2-Input Gate
aCD2202	Dual 4-Input Buffer Gate
CD2203	J-K Flip Flop
aCD2204	Dual 4-Input Gate Expander
aCD2205	Dual 3-Input Gate

*Pronounced EXCEL (Emitter-Coupled Current-Steered Logic)

THE RCA COMPUTER-CONTROLLED INTEGRATED-CIRCUIT TEST SYSTEM

B. J. WALMSLEY, LDR.
Test Engineering and Reliability
Integrated Circuits, Somerville, N. J.
E. C. CROSSLEY
Equipment Development
Harrison, New Jersey
B. V. VONDERSCHMITT, MGR.
Circuit Design, Integrated Circuits
Electronic Components and Devices
Somerville, New Jersey

and

S. N. LEVY
Automatic Test and
Measurement Systems
Camden, New Jersey

A Spectra 70/15 computer-controlled integrated-circuit test system is currently in operation at Somerville, N. J. This system provides great flexibility in testing and reduces the final product cost by eliminating the reject analysis normally performed by engineering personnel. The system offers the additional advantages of allowing on-line data analysis and diagnostic testing.

E. C. CROSSLEY was awarded O.N.C. and H.N.C. in Electrical Engineering, with endorsements in heat, light, sound, electronics, and measurements, at Bath Technical College, England. In 1955, he joined Westinghouse Brake and Signal Co., Ltd., Chippenham, England, where he worked on the design of specialized test and production equipment for rectifiers and semiconductor devices. In 1958, he was promoted to section leader, and in 1959 to Manager of Electrical Design in the Equipment Development Group. He joined the General Instrument Corp., Newark, in 1962 as a senior engineer to design test gear for large power rectifiers and SCR's. Since joining RCA in 1963, he has worked in the Equipment Development activity of Electronic Components and Devices at Somerville and Harrison, N. J., on a variety of production and test-equipment projects.

B. J. WALMSLEY received the B.Sc. degree in Physics from the University of Manchester, England, in 1950. From 1952 to 1958, he worked as a receiving-tube development engineer with Associated Electrical Industries Ltd., Enfield, Middlesex. In 1958, he was promoted to Section Leader of a Measurements group in the Transistor Development Department of the same company. In 1961, he joined RCA at Somerville as an engineer in the Rating Laboratory, and worked on Test Engineering and Reliability. He was promoted to Engineering Leader in 1962. In 1965, he transferred to the Integrated Circuits Engineering activity, and is now Group Leader of the Test Engineering and Reliability group.

S. N. LEVY received the BEE degree from Cornell University in 1955. He was employed at Hughes Aircraft Company from 1955 to 1959 where, as a design engineer, he worked on pulse doppler radar systems and participated in the Hughes graduate engineering study program at UCLA. He joined the RCA Service Company in Riverton, New Jersey, in 1959, as a field engineer for the BMEWS project. He later went to Thule, Greenland, to work on the installation of the computer system for the BMEWS Radar. After the system became operational, Mr. Levy continued on as Manager, Technical Maintenance, of the site with responsibility for engineering and maintenance of the radar, data processing, and display equipment. After leaving Greenland, Mr. Levy was responsible for system evaluation of all three BMEWS radar sites. In 1964, he joined the newly organized corporate staff group concerned with automatic testing in RCA. This group is responsible for implementing corporate policies, plans and programs relating to Automatic Test and Measurement Systems within RCA. Since that time he has been instrumental in implementing automatic test projects in several of the RCA divisions, with particular emphasis on computer controlled systems. Mr. Levy is a member of IEEE, Eta Kappa Nu and Tau Beta Pi.

B. V. VONDERSCHMITT received the BSEE from Rose Polytechnical Institute, Terre Haute, Indiana and the MSEE from the University of Pennsylvania. Since joining RCA, Mr. Vonderschmitt was associated with Monochrome and Color Television Design as part of the Electronic Components Division and the Consumer Products Division. In 1959, he joined the Semiconductor Division, Somerville, New Jersey, working in the Microelectronics Department. In 1963 he became manager of Integrated Circuit Applications. Since 1966 he has been manager of Integrated Circuit Design and Applications. He is a member of the IEEE, Tau Beta Pi and is a registered professional engineer. He has been awarded 13 patents.


E. C. Crossley


B. J. Walmsley


S. N. Levy


B. V. Vonderschmitt

Fig. 1—Computer-controlled test system.

One of the most expensive steps in the development of an integrated circuit is the engineering analysis of early samples. This analysis is performed to determine the correctness of the masks used in generation and to assure that the characteristics of the total circuit comply with specifications while allowing some leeway for variability in processing.

Usually a minimum of 20 lots of developmental integrated circuits (50 circuits per lot) are analyzed to determine compliance with normal process variability. For each of the 50 circuits, 30 to 40 parameters must be measured. This means that 10,000 to 15,000 readings must be analyzed and plotted, and averages and deviations calculated. In addition, an analysis of catastrophic circuit failures must be made to define failure modes and to separate failures due to processing from those due to design errors in the masks.

Until recently, these measurements and analyses have been accomplished by the application of vast amounts of expensive engineering manpower and have required much tedious manual analysis of data and plotting of distributions. The result was high finished-product cost. To help alleviate this high cost factor, the RCA Computer-Controlled Integrated-Circuit Test System was developed.

The system (Fig. 1) consists of an RCA Spectra 70/15 computer with peripheral magnetic tape station, card reader, card punch, I/O typewriter, and a Special Equipment Controller (SEC) that governs the operation of the Test Set. Four program segments—an Executive, a Test Program Generator, a Test Program Controller, and the specialized Integrated Circuit Test Program—control the types of tests to be made and the parameter to be measured. The system is capable of performing successive tests which include (1) the application of voltage and current of any polarity to certain prescribed terminals of the integrated circuit under test, (2) the connection of loads to certain terminals, (3) the measurement of a specific parameter at a prescribed terminal, (4) the comparison of this measured parameter to specified limits, (5) the classification of the device by the use of sorting logic, and (6) data logging. The system is also capable of performing diagnostic tests and of providing typed-out messages which indicate the specific component or groups of components within the integrated circuit causing the circuit failure.

SYSTEM COMPONENTS

The Computer and Its Peripheral Equipment

The computer used is an RCA Spectra 70/15 with an 8192-byte high-speed core memory. Connected to the 70/15 is a Spectra magnetic tape station, a card reader, a card punch, and an input-output typewriter. The typewriter is the main control device for the entire test system. The only other test control available for routine operation is a start button on the test equipment. The minimum of controls and indicators permits testing to be accomplished by an unskilled operator.

The magnetic tape station is used for storage of operating programs and integrated circuit test programs; new integrated circuit test programs generated by design engineers are entered through the card reader. The card punch is used for placing test data on cards for storage and later analysis.

The Special Equipment Controller (SEC)

The SEC is a general purpose device that can be connected to any RCA Spectra computer; it is capable of controlling a wide variety of test equipment. The SEC was designed and built by Advanced Technology, DEP, Camden, to meet the general requirements specified by the Automatic Test and Measurement Systems staff. Details of its functions in the system are described below.

Integrated Circuit Test Equipment

The integrated circuit test equipment was designed and built by Equipment Development, EC&D, Harrison, to meet the special requirements of the Integrated Circuit Engineering Department at Somerville.

One of the prime functions of the test equipment is to connect voltage or current stimuli to one or more of 40 terminals of the device under test. Constant voltage supplies are accurate to ±1 millivolt at the device terminals and are capable of dissipating as well as supplying current at any voltage within their range, including zero volts. Constant current supplies are accurate to ±0.1 percent or ±1 microampere. Provision is made for switching power supplies on and off, in sequence, as instructed by the computer.

The test equipment also connects loads or networks (such as diodes, resistors, or combinations of both) to any device terminals or in series with stimuli—whichever is necessary to fully test the device.

The current flowing to or from any device terminal and the voltage on any device terminal may be measured by the test equipment. The values read are put in digital form before being read into the computer memory. The test equipment measures current in the range from 1 nanoampere to 1 ampere and voltage in the range from 100 microvolts to 100 volts.

SYSTEM INTERCONNECTIONS

A block diagram of system components, and the major functional areas of each is shown in Fig. 2. The interface of the RCA Spectra computer and the

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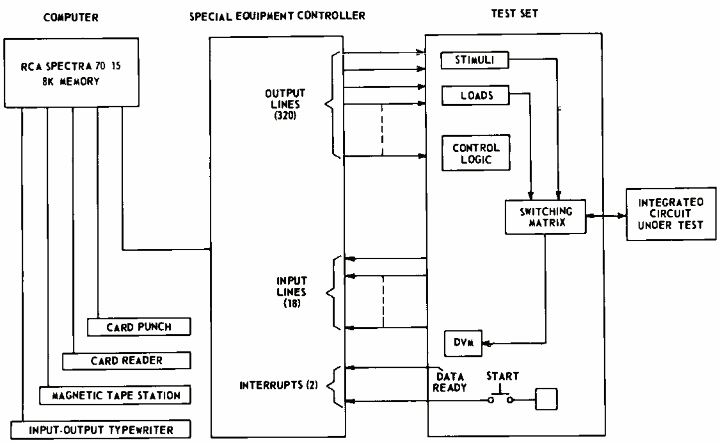

Fig. 2—Block diagram of system components and their major functions.

Test Set is accomplished through the SEC and consists of three categories of control lines:

- Output Lines: Convey instructions required for one parameter test from the computer to the Test Set through the SEC.
- Input Lines: Convey test results from the Test Set to the computer through the SEC.
- Interrupt Lines: Carry pulses signaling requests not included in program words (e.g., start, and test-set initiated interrupts requesting a read-in of test data).

The digital voltmeter in the Test Set is used as a high-impedance analog-to-digital converter. The Test Set also contains control logic and test stimuli circuits in addition to the switching matrix that controls the connection of 40 test device terminals to any of 15 cross-points: 5 stimuli, ground, and 9 lines. The 9 lines can be connected to networks on a plug-in load card or used for interconnections between terminals of the device under test.

COMPUTER PROGRAMS

There are four computer program segments.

1) Executive (EX)
2) Test Program Generator (TPG)
3) Test Program Controller (TPC)
4) Integrated Circuit Test Programs

Executive (EX)

The primary function of the executive is to handle interrupts from the SEC and the typewriter. Depending upon the requirements of these interrupts, the executive calls in other programs or branches to appropriate subroutines. The executive resides in memory at all times and occupies approximately 1200 bytes.

Test Program Controller (TPC)

The function of the test program controller is to govern the sequence of device-testing operations. It routes test words to the SEC, accepts the parameter values from the Test Set, performs comparisons, and prepares the statistical summary. The TPC resides in memory with the executive when testing is in progress; it occupies 3400 bytes.

Test Program Generator (TPG)

The primary function of the test program generator is to accept cards punched with new test programs, check for any error in test programming, compile a series of test words, and store the test program on magnetic tape. The TPG resides in memory with the executive when test programs are being generated and occupies 3400 bytes.

Integrated Circuit Test Program

The test programs are groups of test words comprising the parameter tests for one type of integrated circuit. Hundreds of different types of integrated circuit test programs are normally stored on magnetic tape by the TPG. The TPC calls out one, places it in memory, and performs the specified tests. One integrated circuit test program composed of 50 parameter tests occupies 3500 bytes of memory.

TESTING PROCEDURE

The testing procedure is divided into two major phases: test program generation and device testing.

Test Program Generation

The test programs used with the RCA Computer-Controlled Integrated-Circuit Test System are generated by assembling a number of simple statements. These statements, which comprise the test program language, have been developed in such a way that engineers with little knowledge of computer programming can, by following a simple format, generate their own integrated circuit test programs. For example, to connect terminal 5 to power supply 4 an engineer writes the statement PO5 = PS4; to set power supply 4 to +0.8 volt, the engineer writes PS4 = +0.800. In a similar manner, loads may be connected (PO2 = L1,L1 = 1), limits may be specified (LU1 = −0.850,−0.750), and the digital voltmeter programmed (DVM = PS3,G,O,TO4,SO2). These statements are then grouped to form test words. One test word specifies all information necessary to test one parameter. A typical test word, composed of statements similar to those just described, would appear as follows:

Crossley, Walmsley, and Levy

```
T1$PO5=PS4$PS4=—5.000$PO2=G$
PO9=L1$DVM=L1,G,O,TO4,SO6$
LU1=—0.850,—0.750.
```

Test Word

```
T1$PO2=G$PO3=L1$PO4=L1$L1=1$PO6=PS3$PS3=+6.00$P13=PS4$
PS4=—6.000$PO9=L6$DVM=L6,G,1,TO4,SO2$LU1=+0.600,+1.000$
LU2=+0.300,+1.300$LU3=0.000,+1.600
```

Explanation of Instructions (Instructions are separated by a $)

Instruction	*Meaning*
T1	Test No. 1.
PO2 = G	Device pin No. 2 is connected to ground.
PO3 = L1	Device pin No. 3 is connected to line 1.
PO4 = L1	Device pin No. 4 is connected to line 1.
L1 = 1	Line 1 is connected to terminal 1 on plug-in load card.
PO6 = PS3	Device pin No. 6 is connected to power supply 3.
PS3 = +6.00	Power supply 3 is to supply +6 volts.
P13 = PS4	Device pin 13 is connected to power supply 4.
PS4 = —6.000	Power supply 4 is to supply —6 volts.
PO9 = L6	Device pin 9 is connected to line 6.
DVM = L6,G,1,TO4,SO2	The DVM is connected between line 6 (connected to pin 9) and ground. It is to read on a 10-volt full-scale range 4 ms from receipt of start; a Data Ready interrupt is to be generated 2 ms after the DVM has completed its reading.
LU1 = +0.600, +1.000	Limit 1 is +0.6 volt to +1 volt.
LU2 = +0.300, +1.300	Limit 2 is +0.3 volt to 1.3 volts.
LU3 = +0.000, +1.600	Limit 3 is 0 to 1.6 volts.

Fig. 3—Complete test word and explanation of parameters.

TABLE I—Examples of the More Important Input Messages

Input Message	*Explanation*
ICxxxxxxx	Selects the IC test program corresponding to the number typed in.
T,*a*,*b*$*c*,*d*	Specifies that parameters *a*, *b* through *c*, and *d* be run
DVM,*a*,*b*$*c*,*d*	Specifies that DVM readings on parameters *a*, *b* through *c*, and *d* be typed out.
P	Requests that DVM readings be saved on EAM cards.
PTP	Requests that DVM readings be saved on magnetic tape.
SP	Requests that the statistical summary be typed out.

A complete test word and an explanation of the format and allowable instructions for each test statement are shown in Fig. 3. When all parameters to be measured have been determined and written as test words, the test words are assembled into the test program.

The test program is punched on EAM cards and read into the computer. During the reading operation, the TPG checks the accuracy of the statements and the punctuation. The test program may then be used immediately or stored on magnetic tape for use at a later time.

Device Testing

Any of the test programs that have been generated and stored on magnetic tape may be transferred to memory and made immediately available by the input (through the input-output typewriter) of a simple nine-character message: ICxxxxxxx, where the last seven digits represent the identification of the test program desired. When loads are required for a particular test sequence, a programmed load card must be inserted in the Test Set before testing begins.

The operator has various options available to him with which to control the mode of operation of the Test Set and the form of the output data. The operator may wish to perform only certain tests, to type out certain parameter values, or to save all the data on EAM cards or magnetic tape. The more important of the input messages required to specify the desired option are listed in Table I.

Actual testing commences when the operator pushes the start button and causes the generation of an interrupt, a 10-microsecond pulse that causes the computer to set 312 lines (39 bytes) of the SEC output to the binary configuration of a certain test. The setup of the test configuration begins but with the voltage and current regulators not yet enabled. Before setting the last eight lines, the computer performs a parity check and, if satisfied, issues the last byte to the remaining eight lines. One bit of this byte is used to initiate the test sequence; the times specified in the instructions are measured from receipt of this signal which starts a counter in the Test Set, allowing the Test Set to assume control of the test.

At a specified time, a read command is issued to the DVM. Simultaneously, the counter is stopped so that no change can take place during the period in which the DVM is reading. At the end of the reading period, the DVM generates a signal that starts a second counter; the second counter controls the shutdown sequence. The final operation in the cycle of one parameter test is the generation of an interrupt at a specified time to inform the computer that the test is complete and that data is ready. The computer then resumes control, reads the data into memory and compares it with up to six limits. Immediately after the computer has accepted the data from one parameter test, the program changes the SEC lines, where necessary, so that the test equipment can receive instructions for the succeeding test. The change takes place in approximately 0.5 millisecond.

At the end of a sequence of tests, the computer performs the sorting logic necessary to categorize the device and puts out a signal to the Test Set that lights one of the 14 category lamps on the front panel.

When the testing of a group of units has been completed, the operator may call for a statistical summary by typing in SP. A sample statistical summary is shown in Table II. This summary consists of a seven-cell histogram of each parameter, an average value of each parameter, and yield information for each set of limits. This type of condensed information is very useful to the circuit engineer in evaluating new devices and studying trends.

TABLE II—Example of a Statistical Summary

PARAMETER TEST YIELD				#TESTED = 020			#PASSED =010	
T#		L3	L2	L1	U1	U2	U3	AVG.
1	2	1	1	4	4	0	3	0.2028
2	8	2	8	0	0	0	0	0.1823
3	2	0	0	10	0	0	0	3.5350
4	0	0	0	0	3	7	2	0.2252
5	0	0	0	10	0	0	0	3.9990

COMPOSITE TEST YIELD
LI-U1 = 0 L2-U2 = 3 L3-U3 = 7 FAILED = 10

COMPUTER-CONTROLLED TEST SYSTEM ADVANTAGES

The advantages offered by a Computer-Controlled Test System are many. Integrated circuit test programs can be stored on magnetic tape where they are rapidly accessible. The programmed signals for the terminal connections and stimuli magnitudes can be quickly routed to the test equipment from the computer core memory. The computer can accept readings in digital format from the test equipment, make rapid comparisons to multiple limits, and sort the device under test into one of several categories depending on the results of a series of tests. A wide selection of data logging equipment is available with computers so that a choice can be made of a data logging device most suitable to the user.

In addition to controlling the inputs to, and outputs from, a test set, a computer offers the additional advantages of on-line data analysis and diagnostic testing. For on-line data analysis, computer programs can be written to perform statistical analysis on the data as it is being generated. It is extremely valuable to integrated circuit engineers to have summarized data on a sample lot of devices instantly available so that new devices can be readily evaluated.

Most non-computer controlled integrated circuit test sets can perform tests in a fixed sequence only. It is extremely desirable, however, in diagnosing faults in an integrated circuit (particularly when investigating yield problems) to have the following additional capability that only a computer-controlled test system can give:

1) The ability to branch to a specified test depending on the result of a previous test.
2) The ability to perform arithmetical operations on test results.
3) The ability to perform a search routine to determine a particular point on a characteristic curve. (Examples are a maximum, a minimum, a crossover point of two curves, and a sharp change in slope.)
4) The ability to perform logical functions on the results of a series of tests.

All these functions can be written into an integrated circuit test program. Simple typed-out messages can be used to indicate the reasons why a device does not meet specifications. With this diagnostic capability and a well-organized test program, the circuit engineer can pin-point the problem areas in a circuit within a very short time and can contribute greatly to lower-cost higher-quality products.

RCA NEW BUSINESS PROGRAMS

A Corporate Staff Activity to Evaluate New Opportunities

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Division Vice President

and

L. F. JONES
Mgr., Engineering

New Business Programs, Princeton, N. J.

NEW Business Programs is a Corporate Staff activity established for the purpose of identifying, evaluating and exploiting major new business opportunities for RCA. Though such new businesses must fall outside the established interests of present manufacturing divisions, the help and close collaboration of these divisions is sought.

The New Business Programs organization consists of Industrial and Automation Products located at Plymouth, Mich. Medical Electronics presently at Trenton, N. J., and the New Business Programs staff at Princeton. In addition, the staff has resident representation in Washington, D. C. and has made arrangements through RCA Great Britain for representation in Europe. The organization is shown in Fig. 1.

INDUSTRIAL AND AUTOMATION PRODUCTS DEPARTMENT

This activity develops and produces a variety of electro-mechanical products. The mechanical orientation of engineering within this group is a unique asset within RCA. The largest segment of I&A's business is in the manufacture of gauging, testing and automatic assembly equipment produced on a custom basis for the automotive industry. The I&A business has experienced steady and substantial growth. Metal detection equipment is produced for a variety of applications that require the identification of foreign metal particles as in food packaging, textiles and certain mining and quarrying operations. I&A produces the popular VE-DET vehicle detector which employs loops buried in the roadway for use in ascertaining the presence of motor vehicles by inductive coupling. Signals thus generated can be used to activate traffic lights, count vehicles at toll booth entrances, sense the direction of travel and actuate "wrong way" signs on ramps, or sense the speed in order to activate warning signs or alert police. I&A also makes the TP-66 motion picture studio TV projection equipment sold by the Broadcast and Communication Products Division. (For further information on I&A's operations, see Reference 1.)

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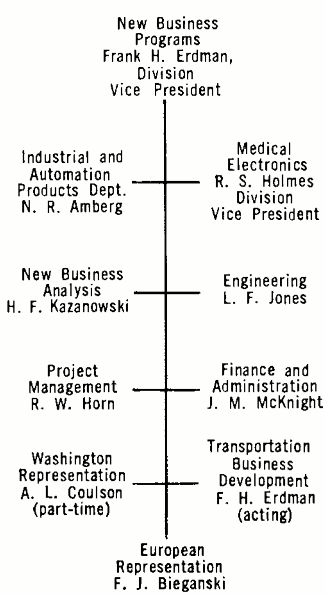

I&A further carries out a special responsibility of New Business Programs, namely that of providing automation equipment to other RCA divisions. This service, available to any division that requests it, facilitates the spread of automation within RCA. The most recent equipment in this category is an automatic assembly machine for Stereo-8 cartridge production, used by the Record Division at Indianapolis. Another example related to RCA internal automation is computer controlled automatic equipment for testing components. An installation at EC&D in Somerville, New Jersey, for automatically testing integrated circuits, features a Spectra 70/15 computer, which operates in conjunction with a controller (interface) and software provided by New Business Programs. I&A will produce additional controllers for automatic test installations in various RCA locations. Plug boards, printed circuits, transistors and integrated circuits will be tested. In addition to controllers, which are of modular design so as to satisfy the requirements of each application, New Business Programs will provide software assistance and will make arrangements with EDP to obtain computers and peripheral equipment.

NBP PRINCETON STAFF

One objective of the NBP staff is to identify, in cooperation with Corporate Planning, broad areas in which new RCA businesses may be developed. After preliminary identification, the engineering, marketing, manufacturing and financial aspects of such opportunities are evaluated and full business programs developed. When a plan is recommended and approved by top management, NBP establishes a new business venture. An example was the establishment in 1966 of the Medical Electronics activity of NBP. (See article this issue.)

Typical of the broad areas currently under investigation by NBP are automation, transportation, nonentertainment home systems and food procesing. Each will be described briefly.

Automation

In addition to current activities in automation at I&A in Plymouth, steps are being taken to expand this effort so as to prepare for a more significant penetration of the potentially large market. The projects under study relate to retail food and banking automation, new peripheral devices for data processing, and various applications of computer-controlled automatic testing. In each case systems studies and market analyses are underway, and engineering development has been initiated where feasible.

Transportation

This is another broad area offering potentially attractive business opportunities. Its importance is emphasized by the Federal Government's recent establishment of the Department of Transportation. It is timely that NBP take exploratory steps to investigate and evaluate the transportation market. Of particular interest to us is the control of vehicular transportation. There is a nationwide drive to achieve safety, economy and convenience in automobile, bus and truck transportation. Comprehensive systems approaches are needed. Accordingly, New Business Programs has begun a systematic study of this whole area. To assure increased emphasis, Vehicular Traffic Systems, has been established as an activity of I&A. It is headquartered in Trenton, N.J., and the marketing and engineering organizations are being developed.

Home Systems

Home entertainment products—radio, television, phonographs and records—already are part of the Corporation's mainstream business. This is not so for non-entertainment products, however. Therefore, NBP has begun a series of studies relating to the opportunities for profit that may exist for RCA in this latter area. Innovation in marketing in this area may be as important as innovation in design.

Food Electronics

The acceleration of the freeze-drying of foods by means of radio-frequency heating has been the subject of extensive experiments by EC&D. The current RCA program is directed toward a continuous-product-flow system. This method lends itself to the uniform application of RF-energy and may effectively displace the batch-type freeze-drying systems now in use throughout the food processing industry. Detailed economic studies are being prepared and, if product tests currently underway show that a viable business can be established, NBP will assume the responsibility for program implementation.

OPERATING POLICIES OF NEW BUSINESS PROGRAMS

The main objective of New Business Programs is to establish within the RCA framework sizeable new business ventures, autonomous and responsible for their own profits and losses. Prior to establishing a line organization for a new business, we must evaluate its requirements and markets from such standpoints as engineering needs, size and nature of the potential market, competitive situation, marketing methods, start-up costs, capital investment required, production needs, social and economic environment, effect on corporate image, patent and legal position, manpower mix and service requirements. It is the New Business Programs staff at Princeton which has prime responsibility for making such evaluations and for developing an overall business plan which will make it possible for Corporate management to decide whether or not to embark on the selected ventures.

Many engineering feasibility and design questions are encountered in this evaluation process, as well as questions relating to the development of experimental and prototype demonstration equipment. These engineering needs are met by NBP's own personnel and also by turning to appropriate engineering groups throughout RCA. Market evaluations, too, are carried out by the NBP Princeton staff, using outside specialists when required.

Through the purchase of investigatory services of RCA Great Britain, the New Business Programs activity is evaluating European products which might be manufactured and sold in the U.S.A. Particular attention is paid to gauging, assembly, sensing and other industrial developments and products which could augment the I&A activity at Plymouth. The representative in Washington, D. C., maintains effective liaison with the non-defense and non-space federal organizations interested in major government programs. Transportation, automation and crime prevention are examples of areas in which there is current federal government interest. Increasing federal support in these areas over the next several years is in accord with sociological and economic trends and could form the basis for an RCA new business evaluation.

T. A. Smith, Executive Vice President for Corporate Planning, establishes corporate policies relating to business diversification and expansion. New Business Programs works closely with Mr. Smith, coordinating and tailoring its programs to fit into the guidelines of overall corporate policy.

NPB maintains close liaison with RCA Laboratories and the RCA product divisions. Located at the David Sarnoff Research Center, NBP has ready access to the concepts, the technologies and the research staff involved in the research programs of the Corporation. This proximity has proved invaluable. As for the product divisions, liaison with their engineering and long-range planning groups already has been established on a systematic basis and has resulted in effective communications as well as collaboration on several programs. Four of the DEP divisions, for example, have performed engineering services for NBP. All divisions are encouraged to submit ideas for new businesses.

Whether RCA enters a new business or market depends heavily on the company's broad engineering know-how and on whether this can be brought to bear in the particular circumstances under consideration. One responsibility of New Business Programs is to develop an answer to that question and, in so doing, provide the engineering assessment so vital to a new business decision.

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FRANK H. ERDMAN, Division Vice President, New Business Programs, has been associated with RCA since 1963. He graduated from Swarthmore College in 1941 with a BS in Mechanical Engineering. While at Swarthmore, he was the recipient of the Thomas B. McCabe Engineering Award. He later took graduate courses in mathematics and engineering at New York University. Mr. Erdman joined the Applied Research Department of the Wright Aeronautical Corporation in 1941 and subsequently became Head of the Applied Mechanics Section with responsibility for stress and vibration analysis. From 1946 to 1953 he was associated with the McDonnell Aircraft Corporation, where he held a series of management positions of increasing responsibility, becoming Assistant to the President in 1952. In 1953 he became Vice President of Experiment, Inc. (now a subsidiary of Texaco), a research and development firm specializing in solid and liquid propellant propulsion systems and commercial product development. In 1958 Mr. Erdman was named President of the U.S.I. Technical Center, a division of U.S. Industries, Inc. Five years later, in 1963, he joined RCA as Administrator of Program Planning for the Missile & Surface Radar Division in Moorestown, N.J. Mr. Erdman transferred to RCA's David Sarnoff Research Center in Princeton at the end of 1963 to head up a newly formed New Business Programs activity. A recent outgrowth of this activity has been the Medical Electronics group announced in December 1966. Mr. Erdman is a member of Sigma Tau, Sigma Xi, the American Institute of Aeronautics and Astronautics, the American Society of Mechanical Engineers, and the Society of Automotive Engineers. He is a registered Professional Engineer and has had several patents issued to him.

LOREN F. JONES graduated from Washington University with a BS in EE in 1926 and attended the Graduate School of Business of Stanford University. He joined GE as a development engineer and transferred to RCA in 1930, where he undertook engineering assignments in several European countries. On his return to Camden, N. J. he was active in broadcast and associated fields. In 1937-1938, he represented RCA in several nonmilitary engineering projects in Russia. During World War II, Mr. Jones represented RCA on a corporate-wide basis in government research and development projects. He served as chairman of the Direction Finder Committee and as a member of the Communications and Radar Divisions of the Office of Scientific Research and Development, for which he was awarded the Presidential Certificate of Merit. He was a member of the Scientific Advisory Board of the United State Air Force. In 1951 he originated and organized the New Products Division of RCA. As a result of one of the programs of this Division, RCA established Electronic Data Processing as a new business. He managed the marketing and product planning of EDP and subsequently became Manager of Product Planning, IEP, and of Advanced Technology. Mr. Jones presently is Manager, Engineering, New Business Programs. He is a member of Sigma Xi, the Institute of Electrical and Electronic Engineers, and the Franklin Institute. He is an associate fellow of the American Institute of Aeronautics and Astronautics.

RCA MEDICAL ELECTRONICS

A New Business Collaboration with Hoffmann-La Roche Co.

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For many years there has been an interest in medical electronics in many parts of RCA. Exploratory work has been done in RCA Laboratories, and in some of the operating divisions work has been carried to the extent of producing, demonstrating, and selling equipment. A notable example is the use of TV equipment in the operating room and for remote monitoring. A radio pill has been demonstrated which could send telemetric signals from inside the human body to an outside receiver. Devices useful in medical research have been worked on, and use of the electron microscope for medical investigation is well-known.

It was apparent, however, that a sizable entry into the field by RCA should be based on designing and producing those types of equipments needed in relatively large quantities. This would capitalize on one of RCA's greatest capabilities. It meant that the business should be based on supplying the needs of practicing doctors and hospitals, rather than supplying the limited market for tools of research.

The need, then, was to find a way of entering the practicing physician and hospital environments. To do so would require determining what electronics could do for the potential users, and finding a means for proving it to them (clinical testing) and bringing it to them (marketing). Thus, RCA's existing capability in the development and production of electronic devices would have to be supplemented by an equally strong capability in the clinical development and marketing of such devices. An obvious solution was to team up with an organization having the required clinical and marketing capability.

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COLLABORATION WITH HOFFMANN-LA ROCHE CO.

The Hoffmann-La Roche Company was interested in entering the medical electronics business. The two companies recognized that they each had what the other needed, so, in April 1966 an agreement to collaborate in the field of medical electronics was negotiated. The two firms will work together on the development of new devices. RCA will design and manufacture the devices, and Hoffmann-La Roche will handle the clinical evaluation and marketing. Also, RCA will offer to service the devices.

Hoffmann-La Roche started operations in New York City in 1905, although the Swiss parent company had been making drugs since 1896. From an initial staff of nine employees, the American subsidiary has steadily grown until now it encompasses three major product lines, over 6,000 employees and a 100-acre, 70 building plant site at Nutley, New Jersey. On an international basis, Hoffmann-La Roche is the world's largest pharmaceutical organization. Its major product lines are 1) pure pharmaceutical specialties, 2) pure alkaloids, and 3) bulk chemicals. Roche is a major producer of tranquilizers and sulfonamides. It produces over 75% of the vitamins made in the USA. It is, in fact, a pioneer in pharmaceutical research and quality control.

It was as an extension of the Roche philosophy of considering its activities to be the "health field" that sparked its interest in medical electronic devices as an adjunct to drug products. Since these instruments would be utilized by the medical profession for the benefit of the sick, they are in keeping with Roche policies.

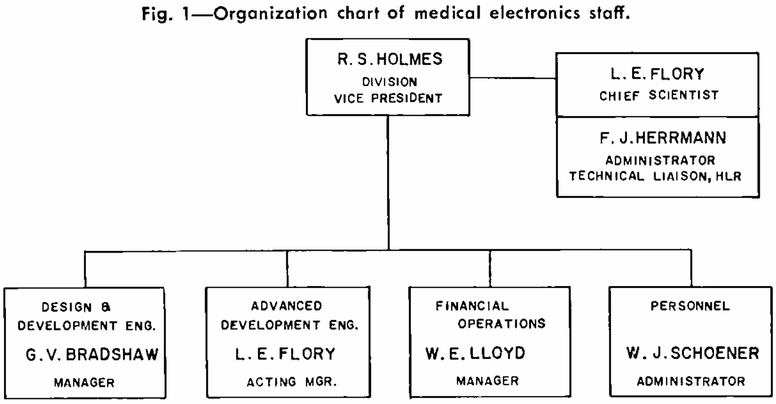
The news that a major electronic company and a major drug company had agreed to pool their resources to make available medical electronic products was warmly received by the medical profession.

THE MEDICAL ELECTRONICS MARKET

In order to determine how two companies, RCA and Hoffmann-La Roche, could enter this field on a national and eventually international scale, a team composed of representatives from the two companies made a thorough business survey of medical electronics, looking ahead ten years.

The medical electronics business today is based upon a few established clinical devices, such as x-ray and electrocardiographic equipment, pacemakers, defibrillators, and a large variety of devices for use by medical researchers such as recorders, transducer amplifiers, etc. Excluding x-ray equipment, scientific equipment used in pathology and experimental laboratories, and data-processing equipment used for administrative purposes, the medical electronics business at present is on the order of $200 to $250

Fig. 1—Organization chart of medical electronics staff.



RALPH S. HOLMES, Division Vice President, Medical Electronics, received his BS in Electrical Engineering from the University of Nebraska in 1923 and later did postgraduate work at New York University. In 1923 he joined the General Electric Company in Schenectady, New York, and worked as a development engineer until 1930 when he transferred to RCA in Camden, New Jersey. In Camden he worked on broadcast receivers and in 1931 was made engineer-in-charge of development and design of television receivers. In 1940 he was named Section Leader in charge of radar systems. He transferred to RCA Laboratories when it opened in 1942, and successively became Head of Radio and Radar Systems, Manager of Technical Services and Manager of Contract Projects. He was made Project Engineer in charge of color television receiver development and design in 1950, then Director, Contract Research Laboratory. In 1959, he was named Director of Project PANGLOSS, a large-scale Navy communications project. In 1963, upon conclusion of Project PANGLOSS, he was made Director, Special Projects Laboratory. In June 1966 he was appointed Staff Vice President, Communications Research, RCA Laboratories, and on November 9, 1966, was appointed to his present position as Division Vice President, Medical Electronics. More than twenty U. S. patents on television, radar and communications systems, have been issued in Mr. Holmes' name. He has been for the the past 13 years chairman of the Board of Editors of the RCA Review. He is the author of many scientific and technical papers and contributer to research and television reference books. A member of Sigma Xi and the American Society of Naval Engineers, Mr. Holmes is a Fellow of the IEEE. He is RCA Laboratories representative to the National Security Industrial Association. In 1937 he received the Modern Pioneer Award of the National Association of Manufacturers. In June, 1959, he was awarded honorary membership in Eta Kappa Nu.

million annually. The growth anticipated over the next ten years, with the special incentive of federal and local legislation designed to expand health care, is expected conservatively to reach approximately $500 to $600 million. It is a characteristic of the medical field that the market is limited more by the rate of invention and perfection of useful devices than by the willingness or ability of the users to purchase these products. This provides a special impetus for innovation, and success in this field will demand a large measure of creativity and venturesome spirit.

Relatively few types of devices are in wide use by clinical practitioners. The demand for new and advanced techniques and equipment for general medical use is rising in accord with the effort to extend medical services to greater numbers of people. So far there has been a serious lag in the application of new technologies to meet this need. It seems natural that techniques and devices being developed by researchers today will result in clinically useful diagnostic and therapeutic devices tomorrow. Thus, it is this area in which RCA and Roche will concentrate their efforts, so that the fruits of research will become widely available to the public through the practicing medical specialist, in the hospital and in the office. The special experience and knowledge of Roche with respect to the medical profession, combined with the technological resources of RCA, provide an ideal basis for achieving this special goal of providing new tools for the practicing doctor, making possible more effective methods than are now available for diagnosis, treatment, and prevention of disease. A number of potential products already have been identified and show promise for development into devices that will represent a significant advance in their fields.

RCA DIVISIONAL INVOLVEMENT

In January 1967, 21,000 square feet of space was leased in Trenton, New Jersey for the immediate build-up of the engineering and administrative staff needed to work on the development of the proposed product line. A number of development engineering assignments are being carried out by other RCA activities to support the goal of early product introduction while the Medical Electronics staff is being assembled. This work is now being done by CSD and Applied Research in Camden, by M&SR, Moorestown and by RCA Service Company at Cherry Hill.

When the products have been developed, prototypes will be clinically tested by Hoffmann-La Roche and, when approved, will be made in RCA production facilities. It is anticipated that within two years the Medical Electronics facility will move to a location where the complete cycle of development, design and production can be carried out.

Medical electronic devices must be safe, of very high quality and highly reliable. Also it is important that adequate service be available when required. The RCA Service Company will offer such service. The technical service units are strategically located throughout the United States and can be geared to provide prompt efficient service to practically every potential customer, whether he be a physician in office practice, in the laboratory, in the clinic or in the hospital.

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AN INTEGRATED CIRCUIT FOR REMOTE CONTROL TV RECEIVERS

An integrated circuit has been developed to replace the four-stage discrete-component amplifier employed in the remote-control TV receiver. The integrated remote-control amplifier offers an improvement in performance and eliminates 19 discrete components. The 10-lead TO-5 package contains three individual amplifier stages connected by external capacitors to form an amplifier chain with 120-dB gain. In addition to high gain, the integrated remote-control amplifier has low noise and good limiting capability. The performance is maintained over a wide temperature range and remains relatively constant for nominal changes of the power supply. The use of pretested integrated circuits simplifies the manufacturing of the remote control amplifier.

L. A. HARWOOD

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THE discrete-component amplifier in the remote control unit employs a relatively large number of components; therefore, the integration of this circuit is very attractive. However, the requirements which must be fulfilled by this amplifier are very difficult, as evidenced by the following description of the remote control system.

This system, shown in Fig. 1, has been successfully employed in RCA TV receivers for many years. A portable transmitter generates acoustic waves at eight discrete frequencies corresponding to the eight controls in the TV receiver. The signal, selected by means of individual push button switches, is detected in the receiver by a condenser microphone and fed to the amplifier. After amplification the signal is applied to eight selective filters through an output transformer. The filtered signal is amplified; and the rectified DC component activates a relay corresponding to the chosen function.

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Since the signal strength will vary depending on the position of the transmitter with respect to the receiver, reliable operation must be maintained for a wide range of signals. The remote control unit must be immune to undesired signals such as those generated by clinking coins or jingling keys. Performance must remain essentially unaffected by line voltage variations or the nominal temperature rise in the receiver.

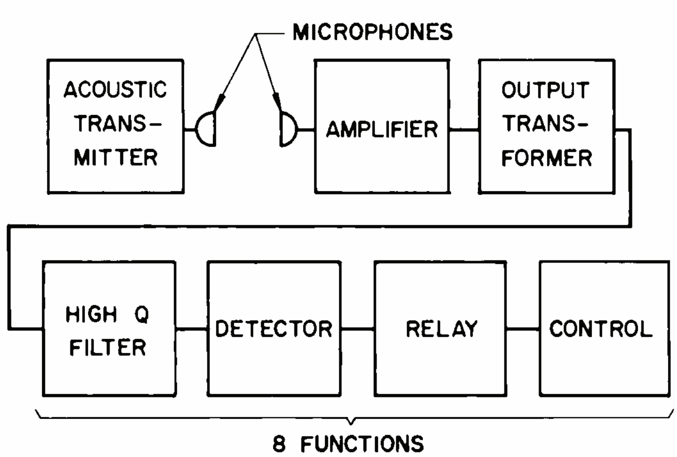


Fig. 1—Remote control system for color TV.

Thus the important characteristics of the amplifier are low noise, high gain, large output signal and good limiting capability.

The extent to which these requirements can be fulfilled by an integrated circuit is not obvious.

For example, in a high gain amplifier the effect of coupling through the substrate and through capacitive elements will vary depending on the circuit configuration and the geometry of the components on the chip. Considering that the amplifier gain is approximately 120 dB, the largest concern is the proximity of the input and output terminals which is dictated by the size of the chip.

The integrated remote-control amplifier described in this report demonstrates that with proper circuit design and careful layout of the components on the chip, a high gain amplifier with good stability is feasible.

DESCRIPTION OF THE INTEGRATED-CIRCUIT AMPLIFIER

The schematic of the high gain amplifier developed for the remote control receiver is shown in Fig. 2a. The amplifier operates over a 35 to 45 kHz frequency range and provides 120-dB gain for the signal which is derived from a condenser microphone. The three stages are coupled by means of external capacitors and the output signal is developed across the impedance of a tuned transformer. The operation of the amplifier is optimized by selecting a suitable circuit configuration for the individual stages.

In the input stage the first two transistors form a Darlington amplifier with an input impedance sufficiently high to avoid excessive loading of the microphone.

The third transistor is connected as an emitter follower and furnishes amplified signal to the second stage by means of an external coupling capacitor connected from pin 3 to pin 4. An external feedback network, formed by resistors R_{17} and R_{18} and the capacitor C_1 is provided to maintain the three transistors properly biased and also to establish a high-pass characteristic for this stage.

For reasonable beta values ($\beta > 50$) of the first transistor the DC voltage drop across the resistors R_{17} and R_{18} is negligible. Consequently the voltage gain of the first stage is determined by the value of the DC voltage on pin 9 and to a first approximation is independent of transistor beta values.

The collector currents of transistors Q_1 and Q_2 are chosen to optimize the noise figures of this stage. The resistance value in the collector of the transistor Q_2 and the effective capacitance to ground determine the high frequency performance of this stage. The overall response of the first stage is illustrated in Fig. 3. As can be seen, the frequency response is tailored to resemble a selectivity curve centered around 45 kHz. A 6-dB-per-octave roll-off at very low frequencies results from the divider action between the capacitive source impedance and the resistive termination of the first stage. The effect of the RC feedback network between pins 1 and 3 becomes noticable at intermediate frequencies below the passband and combined with the divider roll-off, yields a 12-dB-per-octave slope. As the frequency increases above some 20 kHz, the reactance of the microphone becomes negligible in comparison with the input impedance of the transistor, and the effect of the feedback due to the RC network vanishes. The amplifier reaches its maximum gain at 30 kHz and remains constant over a relatively narrow frequency range before continuing to drop at a 6-dB-per-octave rate.

To prevent damage to the circuit by an accidental voltage discharge from the coupling capicitor C_1, a diode D_1 is included on the chip and is connected between pin 1 and the ground pin 2. To limit the discharge current a 1,000-ohm resistor R_{16} is provided external to the integrated circuit. (The external capacitor C_1 is charged by the 300-volt supply necessary to polarize the capacitive microphone.)

The second stage consists of a grounded emitter amplifier followed by an emitter follower. The collector current in the transistor Q_4 is regulated by an internal supply and the gain of this stage is de-

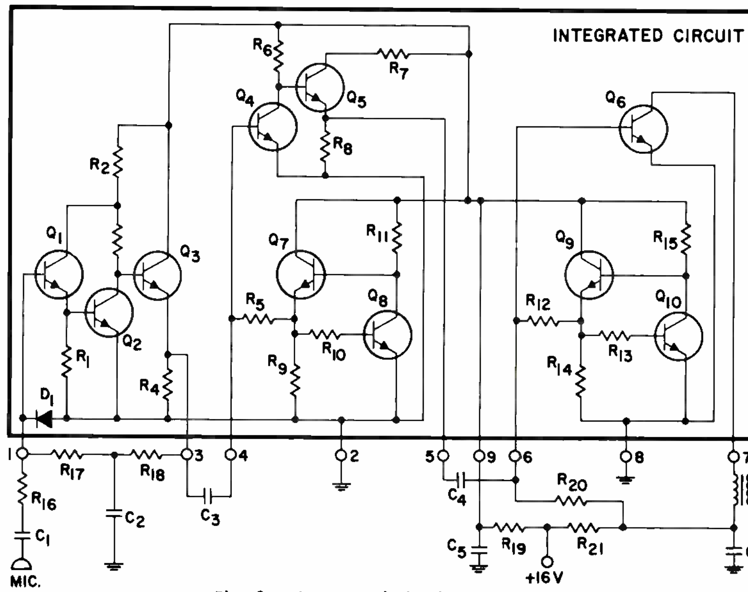


Fig. 2a—Integrated circuit amplifier.

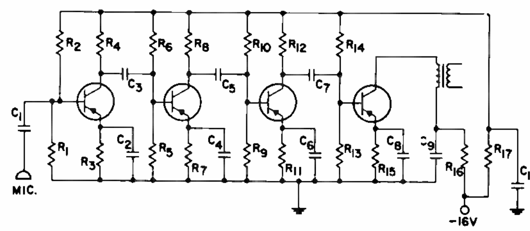


Fig. 2b—Discrete components amplifier.

termined by the value of the resistor R_6. The voltage gain, approximately 40 dB, is independent of temperature and transistor beta values. The emitter follower serves as an impedance transformer and its output is fed to the third stage by means of a coupling capacitor external to the chip connected from pin 5 to pin 6. The frequency response of this stage is determined mainly by the product of R and C values in the collector of the grounded emitter amplifier. The gain remains constant up to 2 MHz, then rolls off at a 6-dB-per-octave rate.

The internal bias supply (formed by transistors Q_7 and Q_8, and resistors R_9 R_{10} and R_{11}) provides a low-impedance source at a stably fixed reference voltage. The bias supply is, in essence, an amplifier stage with negative feedback to stabilize its operation and the collector potential of Q_8 is maintained at a fixed $2V_{be}$ value. Thus the collector current in Q_8 is independent of temperature and can be set by the value of R_{11}. An equal amount of current will flow in the collector of Q_4 because of the matching characteristics of the transistors Q_4 and Q_8. The value of this current is given by:

$$I_c = \frac{E_B - 2V_{be}}{R} \qquad (1)$$

where E_B is the supply voltage; V_{be} for silicon transistors has a value of approximately 0.7 volts; and R is the resistance in the collector of the transistor Q_8.

The last stage consists of a single grounded-emitter transistor together with a reference supply to control its collector current. The collector of the transistor is terminated in an output transformer which resonates with its collector capacitance and stray capacitance at a frequency of approximately 180 kHz. The response of this stage is shown in Fig. 4. The secondary winding of the output transformer feeds eight tuned circuits, corresponding to the eight controls in the TV receiver. The internal bias supply is structurally identical to the one used in the second stage and the previously explained design considerations also apply in this case.

The simplicity of the integrated amplifier becomes evident from a comparison with the discrete component amplifier in Fig. 2b. The integrated circuit replaces 4 transistors, 4 capacitors and 11 resistors.

The structure of the amplifier with the integrated circuit and that of the original amplifier with dicrete components are illustrated in Fig. 5 and 6, respectively.

The physical layout of the integrated circuit is shown in Fig. 7. The chip is 55 mils square. Because the voltage gain from the input to the output terminal is on the order of 120 dB, the arrangement of components is critical. The input and output terminals are located at the opposite ends of the chip. The individual stages are placed in separate isolation "boats" in such manner that the first and third stages are separated by the second stage. Thus the relatively large output signal is prevented from reaching the input terminal by the multiple reversed biased junctions of the isolation boats.

To avoid common impedance coupling, a separate ground terminal for the output stage is provided and individual metalization paths feed the $+B$ supply to the respective stages.

The geometry of the first two transistors (lower left corner) in the input stage is optimized for low noise performance at relatively low frequencies. This explains the relatively large size of those transistors.

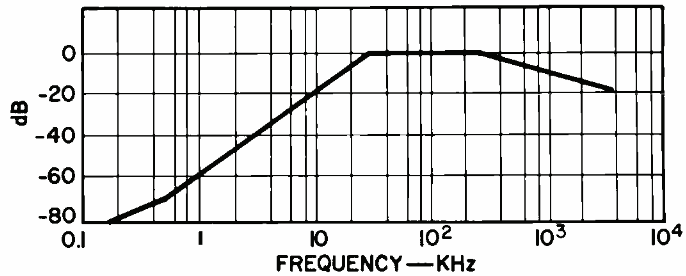


Fig. 3—Frequency response of the first stage.

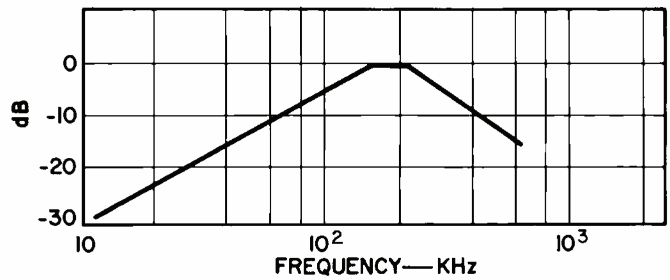


Fig. 4—Frequency response of the third stage.

PERFORMANCE OF THE IC AMPLIFIER

The performance of the integrated-circuit amplifier is established by its sensitivity and ability to reject undesired signals and those aspects deserve a detailed discussion.

Sensitivity of the Remote Control Receiver

The useful sensitivity of the remote control receiver is determined by the noise level at the input terminals of the amplifier, the signal to noise ratio required for reliable operation of the relays, and by the gain necessary to amplify the small input signal to a usable level.

The noise sources present in the amplifier can be represented by the noise generators acting in series with the condenser microphone as shown in Fig. 8.

The source noted as E_{1N} in Fig. 8 is the equivalent noise voltage of the condenser microphone produced by the fluctuations of the air molecules. The magnitude of this noise was derived by Van der Ziel; for a membrane of 1 square centimeter and a bandwidth of 1 Hz, this level is 160 dB below 1 volt.

The source E_{2N} is the equivalent noise voltage generated in the first stage of the amplifier, and includes the thermal noise from the resistor R_{17}. This E_{2N} is a function of the noise figure of the amplifier F, the frequency of operation f, the noise bandwidth Δf, and the source impedance which in this case is determined by the capacitance value C of the condenser microphone. The expression derived for E_{2N} is:

$$E_{2N} = \sqrt{\frac{4FKTR\Delta f}{1 + \omega^2 R^2 C^2}} \qquad (2)$$

The resultant noise voltage, acting in series with the condenser microphone is the root mean square value of E_{1N} and E_{2N}.

The minimum signal to noise ratio required at the output of the system, i.e. the relay coil, is a function of the "pull-in" and "drop-out" currents of the relay. The relay contacts close when the rectified component of the applied signal reaches the pull-in level and they remain closed until this current drops below the drop-out limit. The amplified noise is also rectified in the output detector and produces a dc current in the relay coil. The amplitude of this current must be maintained below the drop-out level or the relay will function improperly. Typical values for the pull-in and drop-out currents for the relays in the remote control unit are 7.5 mA and 1.5 mA respectively. An acceptable limit for the current due to noise rectification is 0.5 mA. The ratio of the pull-in current to the noise current establishes the required minimum signal to noise ratio and the numerical value in this case is 15:1.

The signal to noise ratio at the input terminals depends on the transfer characteristic of the receiver. In the remote control amplifier the last stage operates as a limiter and its characteristic is nonlinear. However, for signals below the limiting level, the characteristic of this stage is compensated by that of the output detector and the resulting transfer function is essentially linear. Thus the previously established signal to noise ratio applies also at the input of the amplifier.

Fig. 5—Integrated circuit amplifier.

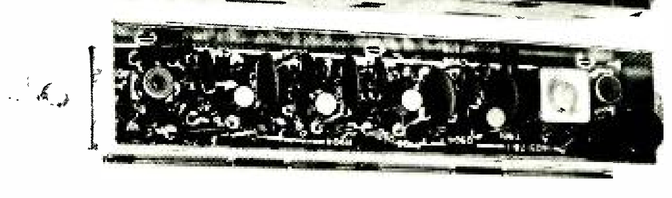


Fig. 6—Discrete component amplifier.

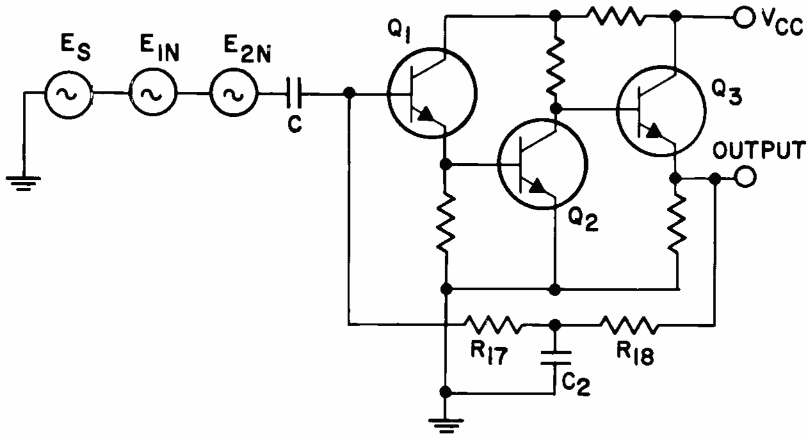


Fig. 8—Equivalent circuit of the first stage.

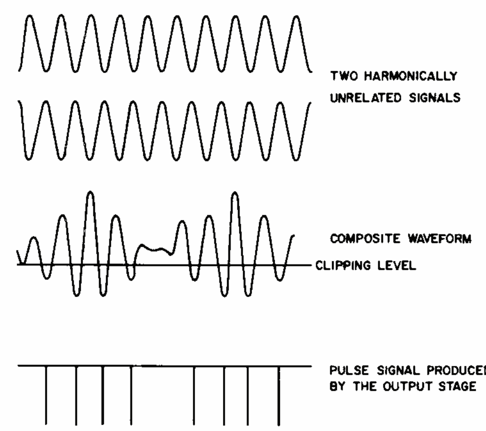
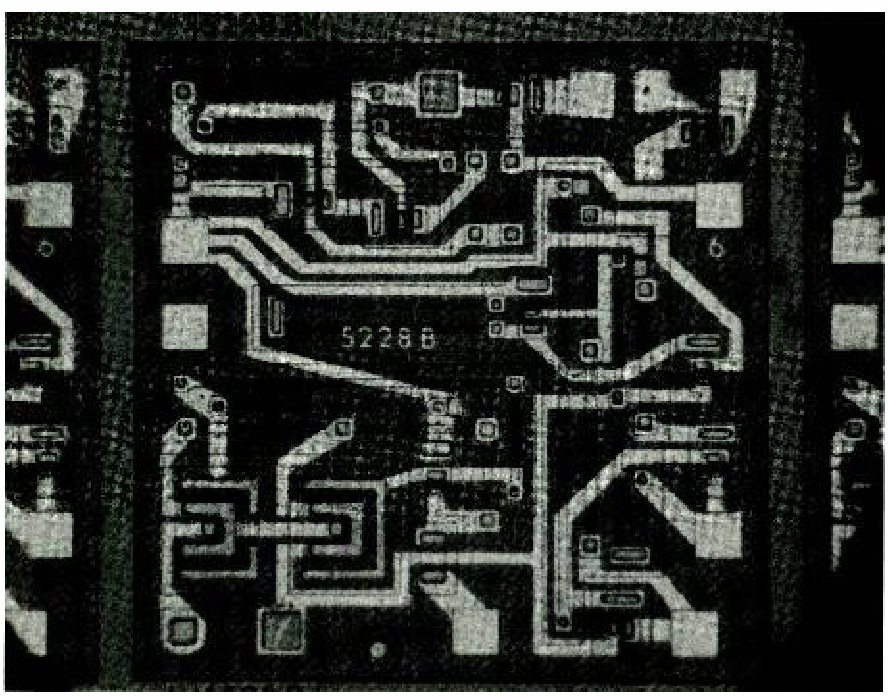


Fig. 9—Rejection of undesired signals.

L. A. HARWOOD graduated from Munich Institute of Technology in 1949 with a BSEE. He received his MSEE in 1959 from the University of Pennsylvania. Following engineering experience at Pilot Radio Corp. and Picattiny Arsenal, Mr. Harwood joined RCA in 1952 as an engineer in the Home Instruments Division; his experience in television receivers includes work in development and design of UHF and VHF tuners, development of parametric and tunnel diode converters, and development of a transistorized UHF tuner for TV receivers. Now located with the Home Instruments Division in Somerville, he had most recently been a member of the Home Instruments Affiliated Research Labs., Princeton, N. J. He has been granted several patents in his field of work; he is a member of the IEEE.

Fig. 7—Integrated remote controlled amplifier.



The noise level is determined by the selective circuits preceding the output detectors. Each channel is approximately 1 kHz wide and, using Van der Ziel's data, the computed value of E_{1N} is 0.3 μV. The equivalent noise voltage E_{2N} calculated to be 1.13 μV for a receiver having the following parameters: $F = 6$ dB, $R = 30$ kΩ, C = 100 pF, and f = 40 kHz. The magnitude of the resultant noise signal acting in series with the reactance of the microphone is 1.17 μV; and the smallest detectable signal is 15 times larger, 17.7 μV.

The gain of the integrated-circuit amplifier is approximately 120 dB and the amplitude of the output signal is adequate to drive the detector circuits.

The measured sensitivity at a level 3 dB below limiting is 20 μV which is reasonably close to the computed value and compares very favorably with the discrete components amplifier.

Rejection of Undesired Signals

In the remote control receiver the rejection of undesired signals is determined primarily by the limiting characteristic of the amplifier since the succeeding filtering is insufficient to protect against the various sources of interference.

The filters consist of high-Q circuits tuned to eight discrete frequencies which are spaced at 1.5 kHz intervals. With practical Q values the response 1.5 kHz of resonance is 12 dB down; however, the range of signals at the input of the amplifier may exceed 100 dB. Thus the variation of the signal level at the input of the detector must be kept smaller than 12 dB and it is one of the functions of the amplifier to provide adequate limiting of the signal.

An important characteristic of the remote control unit is its immunity to random signals such as produced by clinking of coins, jingling of keys, ringing of the telephone, etc. A common feature of such signals is the simultaneous presence of several harmonically unrelated components at frequencies which are close to the eight channels. The resultant waveform of two simple signals is shown in Fig. 9.

In a linear amplifier this waveform is preserved and the frequency components of the signal coinciding with any of the eight channels may activate the relays. This undesired effect can be reduced considerably by nonlinear processing of the composite signal as indicated in Fig. 9. The signal from the output stage consists of pulses which appear at a rate unrelated to the frequency of either of the input signals. The fundamental frequency of the output signal is equal to the beat frequency of the input signals and is easily rejected by the selective filters. The harmonics are reduced in amplitude so that they will not cause much concern.

Limiting

The output stage of the integrated-circuit amplifier operates as a limiter to satisfy the system requirements outlined in the previous sections; this stage is designed to produce narrow pulses of constant amplitude which are independent of the level or waveform of the input signal. The repetition rate of these pulses is equal to the frequency of the input signal, and the fundamental frequency component is obtained through filtering. The sinusoidal signal is rectified by the output detector and the resulting dc current energizes the relay coil of the addressed function. The amplitude of the pulse is designed to produce the required pull-in current. The relationship between the amplitude of the pulse and the circuit parameters is considered in the following paragraph.

The pulse waveform is determined by the response of the output stage to a signal processed in the preceding stages. The operating point of this stage is of considerable importance and it is established by the internal V_{be} supply and by the external resistors R_{20} and R_{21}. In absence of signal and noise, the collector potential is approximately V_{be} (0.7 volt) and the current in the primary winding of the output transformer is determined by the supply voltage and the resistance value of R_{21}. The inductance of the primary winding resonates with the stray and collector capacitance at approximately 180 kHz. A negative signal applied suddenly to the base terminal of the transistor releases the magnetic energy stored in the transformer winding and the collector circuit rings at its natural resonant frequency. The sinusoidal waveform, generated by this process is distorted by the presence of the transistor. The base to collector junction is forward biased during the negative peaks of the output signal and the resulting waveform is a clipped sinewave.

This waveform is generated during each cycle of the applied signal. The output from the first two stages, when overdriven by a sinusoidal signal, is a square wave. Both stages are biased so as to produce unsymmetrical limiting and the duty cycle of the negative pulse is reduced to a small fraction of the full cycle.

The ringing time of the resonant output circuit is now restricted by the duration of this signal and it is possible to control the number of the clipped sinewave pulses appearing in each cycle of the applied signal. The integrated-circuit amplifier produces only one pulse per cycle so the repetition rate of those pulses is equal to the frequency of the desired input signal.

The signal waveforms at various points of the amplifier are shown in Fig. 10.

The previously described process explains the conditions prevailing in presence of relatively large signals. Small signals are amplified without distortion and the output from the second stage is a sinewave contaminated by noise. In absence of signal the random noise pulses drive the output stage into cutoff and saturation and the output consists of clipped noise with a spectrum centered at the resonant frequency of the output circuit (180 kHz). The applied sinewave signal modulates the random noise and therefore the resulting output is in the form of noise bursts appearing at the rate equal to the frequency of the applied signal. The fundamental frequency component is recovered by the subsequent filtering.

The nonlinear operation of the output stage, maintained at all signal levels, is the important characteristic which determines the immunity to random interference signals. The limiting characteristic of the amplifier is shown in Fig. 11.

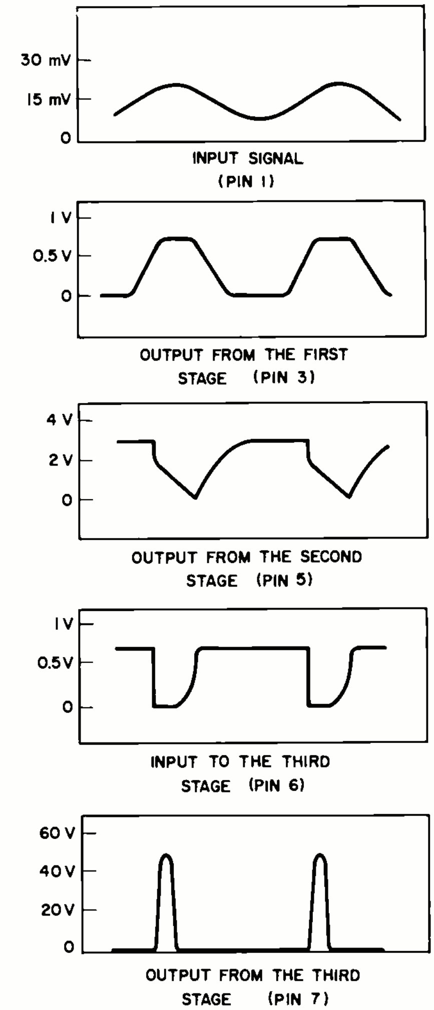


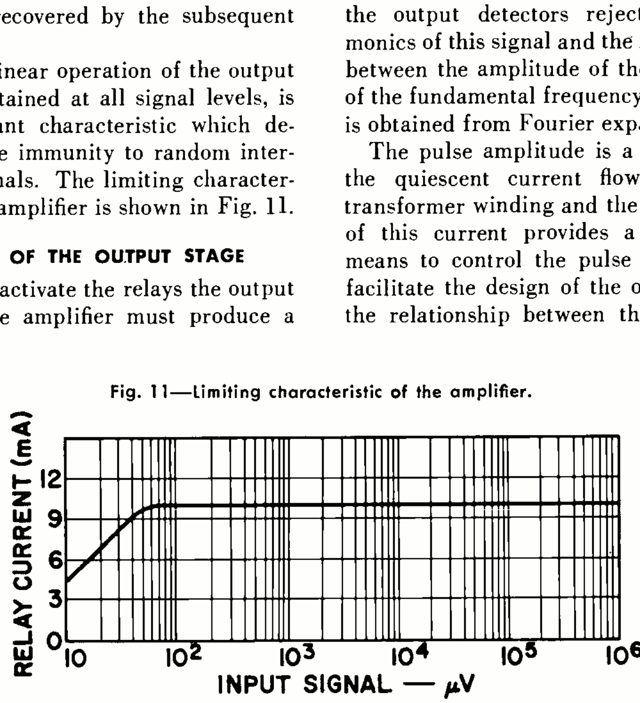
Fig. 10—Limiting of a large input signal.

DESIGN OF THE OUTPUT STAGE

In order to activate the relays the output stage of the amplifier must produce a pulse signal which is sufficiently large to develop the required pull-in current in the relay coil. The filtering preceding the output detectors rejects the harmonics of this signal and the relationship between the amplitude of the pulse and of the fundamental frequency component is obtained from Fourier expansion.

The pulse amplitude is a function of the quiescent current flowing in the transformer winding and the adjustment of this current provides a convenient means to control the pulse height. To facilitate the design of the output stage the relationship between the quiescent

Fig. 11—Limiting characteristic of the amplifier.



collector current and pulse amplitude is developed in the following analysis.

The waveform for the ringing of the resonant output circuit is given by:

$$e(t) = I \sqrt{\frac{L}{C}} \frac{\omega_o}{\omega_d} \exp(-\alpha t) \sin \omega_o t \qquad (3)$$

where: $\alpha = R/2L$; $\omega_d = \sqrt{\omega_o^2 - \alpha^2}$; $\omega_o = 1/\sqrt{LC}$; and L is the inductance of the primary winding of the output transformer, C is the total capacitance in parallel with L, R is the resistance of the primary transformer winding, and ω_o is the angular resonant frequency of the tuned circuit.

The amplitude of the first peak of this signal is obtained from Equation 3 by setting $t = T_0/4 = 1/4f_0$. The Q value of the primary transformer winding is larger than 10 and the following simplifications apply;

$$\alpha = \frac{R}{2L} = \frac{\omega_o R}{2\omega_o L} = \frac{\pi f_0}{Q}$$

$$\alpha \frac{T_0}{4} = \frac{\pi}{4Q}$$

hence:

$$\exp[-\alpha (T_0/4)] \approx 1$$

also:

$$\frac{\omega_d}{\omega_o} = \sqrt{1 - \frac{\alpha^2}{\omega_o^2}} = \sqrt{1 - \frac{R^2}{4\omega_o^2 L^2}} = \sqrt{1 - \frac{1}{4Q^2}}$$

and:

$$\frac{\omega_o}{\omega_d} \approx 1$$

Thus the peak value of the pulse is given by:

$$e_p = I \sqrt{\frac{L}{C}} \qquad (4)$$

and the quiescent collector current is:

$$I = e_p \Big/ \sqrt{L/C} = \frac{e_p}{\omega_o L} \qquad (5)$$

The relation between the peak value of the pulse and the amplitude of the fundamental frequency component is obtained from the Fourier series expansion for the clipped sinewave:

$$C_n = e_p \frac{4t_o}{\pi T_s} \left| \frac{\cos\left(n\pi \frac{t_o}{T_s}\right)}{1 - \left(2n \frac{t_o}{T_s}\right)^2} \right| \qquad (6)$$

Since $n = 1$, and $(t_o/T_s) = (f_s/2f_o)$ (where f_s is the frequency of the input signal) we obtain:

$$C_1 = e_p \frac{2f_s}{\pi f_o} \left| \frac{\cos \pi \frac{f_s}{2f_o}}{1 - \left(\frac{f_s}{f_o}\right)^2} \right| \qquad (7)$$

The term C_1 is the amplitude of the sinusoidal signal required across the primary winding of the output transformer.

From Equations 5 and 7 the expression for the collector current is given by:

$$I = \frac{C_1 \pi \left[1 - \left(\frac{f_s}{f_o}\right)^2\right]}{2\omega_o L \frac{f_s}{f_o} \left| \cos \pi \frac{f_s}{2f_o} \right|} \qquad (8)$$

Since $R \approx E_s/I$, where E_s is the supply voltage, the value of R is expressed by;

$$R \approx \frac{E_s}{I} = E_s \frac{2\omega_o L \frac{f_s}{f_0} \left| \cos \pi \frac{f_s}{f_o} \right|}{C_1 \pi \left[1 - \left(\frac{f_s}{f_o}\right)^2\right]} \qquad (9)$$

For the integrated-circuit amplifier: $E_s = 13$ V; $f_s = 40$ kHz (center frequency) $f_o = 180$ kHz; $C_1 = 7$V and $L = 18$ mHy.

And the computed values are: $I = 2.5$ mA; $R = 5$KΩ and $e_p = 50$V.

Thus, a 50-volt pulse signal is required to produce the pull-in current in the relay coil. The corresponding quiescent collector current in Q_6 is 2.5 mA and is established by a value of $R_{20} = 5$KΩ.

CONCLUSION

The developed integrated-circuit amplifier improves the performance of the remote control unit employed in RCA TV receivers. The integrated circuit eliminates nineteen external components and as a result of this the manufacturing of the amplifier is simplified and its reliability improved. The new circuit demonstrates that the proximity of the integrated components on the small chip and the circuit layout on the printed board are not limiting factors in the design of a high gain amplifier for the remote control receiver.

ACKNOWLEDGEMENTS

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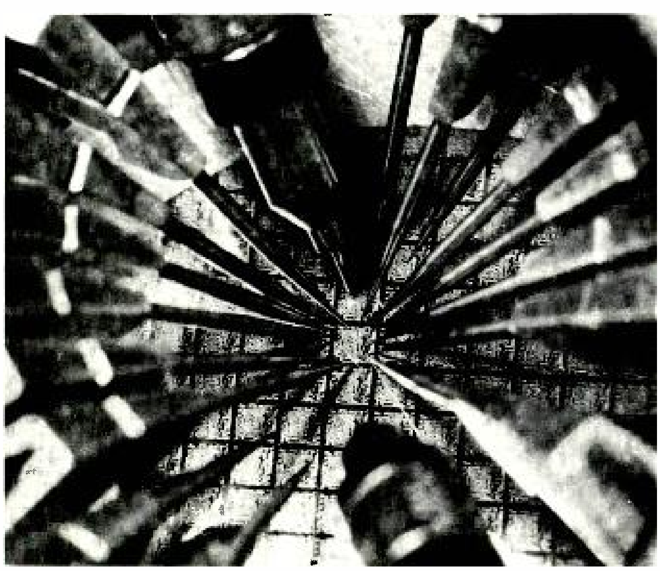
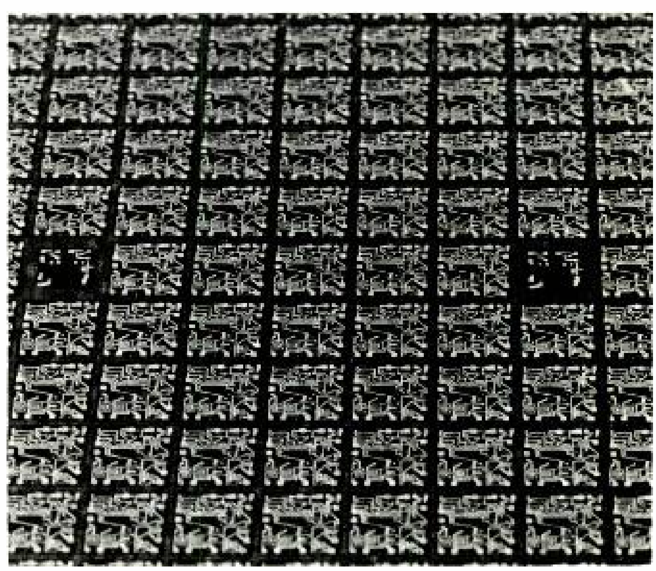


Multiprobe tester for integrated circuits



Section of an integrated-circuit wafer

RFI Control
Whose Responsibility?

Radio-frequency interference is a challenge to the contractor, subcontractor, and certainly the engineer-designer of electronic system equipment. This paper describes the responsibilities and the teamwork and control which must be exercised by the various groups.

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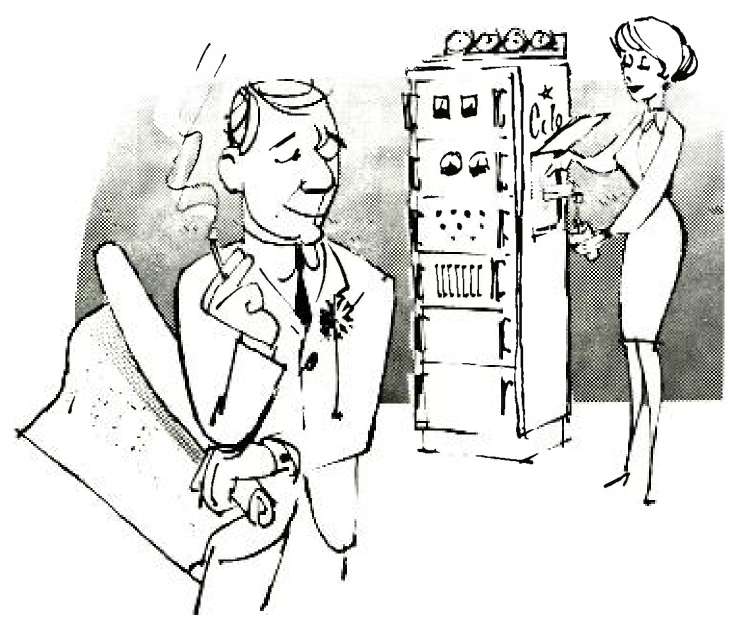
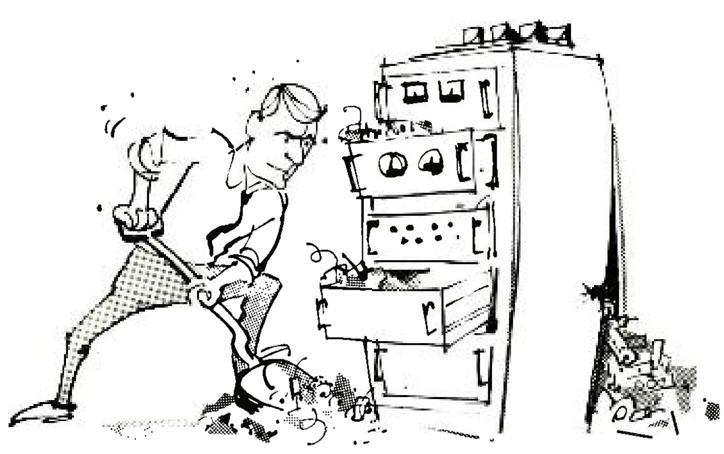


Who needs an RFI engineer? I never do anything wrong.



Emergency stoking.

The growing awareness of the problems associated with electromagnetic compatibility (EMC) and radio-frequency interference (RFI) has resulted in the question of responsibility being examined by all those persons concerned. Whose responsibility is EMC and RFI? One can reply to this question with a trite answer, a meaningless answer, or *think* about the question and come up with a real answer.

One *can* say that the responsibility lies with whomever has the system responsibility. This of course, does not solve the problem: the systems contractor is so wholly dependent upon subcontractors that without their cooperation, he could never solve the problem.

One *can* also say that the responsibility lies with everyone who is concerned with the system. This is a meaningless answer because it implies responsibility to everyone and yet the order of responsibility is not clear. An individual subcontractor can certainly not be identified with responsibility for problems on a system basis nor with the problems of subsystems other than his own.

The question then must be answered by an examination of the functioning of particular systems so that principles, rules or guidelines may be developed. These can be applied to particular systems and the question of responsibility will be clarified.

Unfortunately, in endeavoring to examine a particular system one cannot find the specific examples from one individual system. Systems designers and equipment designers are too knowledgeable and too clever to permit enough difficulties to develop in a particular system to illustrate our discusion properly. Consequently, let us examine a purely hypothetical situation which is conjured up from many different sys-

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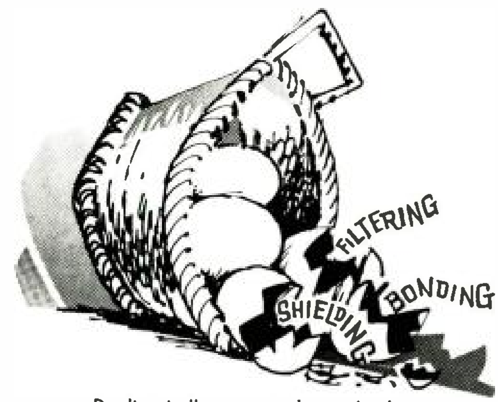
Problem solving.



Don't put all your eggs in one basket.

tems and thereby have a whole series of problems to discuss. Our system may look as though it were put together by a "Keystone Cops" routine, so one must bear in mind that no designers operate in this fashion.

A HYPOTHETICAL SITUATION

The hypothetical situation to be considered will be the design of a communication transmitter. Because of competition, this must be a low budget, highly cost competitive design. There is design criteria given for the frequency range and the RF power output from the antenna. The size, weight, and input power is also specified. Needless to say, a tight cost constraint is put on the completed design.

Now that we have effectively tied the hands of the design engineer, we direct him to proceed and develop the optimum design. The design engineer mulls over the problem a bit and then gets to work. His first decision is to use power tubes in the final amplifier stage which require forced air cooling. He now has started the fire which traditionally the RFI engineer has to extinguish. In an effort to reduce the number of frequency multiplying stages in the transmitter, the design engineer decides to triple in the final RF stage and to work all preceding multiplying stages to their maximum power limits. This adds a rather large log to the fire. The design engineer then decides to use tubes all with the same heater voltage so as to reduce the size and weight of the power supply. He even goes a step further and grounds one side of the heater winding of the power transformer and runs a single lead to all the tubes. This furnishes another rather large log to the fire. The air cooled tubes previously mentioned require a necessary level of forced air cooling that can only be furnished by a rotary blower, which because of the space constraint has to be a small high speed blower of over 10,000 RPM. An AC-DC universal type motor with brushes and commutator is needed to drive this blower. The fire is now burning brightly; it has plenty of fuel; a crisis is at hand and the RFI-EMC engineer is called in.

If one attempts to solve all the hypothetical problems which have been described, the basic constraints of the design will have to be removed. Costs will go up, weight will increase, the size of the equipment will get larger.

Let us examine the various ad hoc solutions which can be brought to bear to solve the problems which have been identified. A filter was placed on the input power line. A band rejection filter tuned to one-third the transmitter output frequency was placed in the final amplifier tank circuit in an effort to reduce the radiation of harmonics from the antenna. In terms of the analogy we have been using, we have now merely poked the logs around a bit—the fire is still burning brightly.

The blower motor which is required creates such a high level of interference that the power line filter will not be very effective in reducing interference to tolerable levels. Additional filtering can be provided to the blower motor leads, but the only type which could fit in the limited space was a metallized capacitor which, in itself, is a source of interference. In addition, the frequency multiplying stages generates numerous harmonics and the filter in the final amplifier tank circuit was not fully effective. The high speed blower causes other problems in addition to interference; carbon dust from the brushes of the motor gets into the air stream flow from the blower and shorts out some of the insulation in the final amplifier stage. The "comedy of errors" is complete; the equipment does not function. Some one has to put out the "fire" or the equipment will disappear with resounding Wagnerian background music in a re-enactment of the "Twilight of the Gods."

THE RESPONSIBILITIES

How can such difficulties be overcome? Who is responsible for the avoidance of such compounded confusion? In the first place, the inherent good sense of the technical manage-

Nobody here but us chickens!

ment and the skill of the designer will eliminate most of these problems before they start. But one cannot depend on problems solving themselves. There must be a positive identification of responsibilities and a clear identification of control in the various steps of the design process. Secondly, an orderly approach to the assignment of responsibility will establish a clear criteria as to what must be accomplished at the various stages of the design process.

The responsibilities can be separated into two parts: those which are incumbent upon the system designer and secondly those which must be assumed by the suppliers of the subsystems of whatever configuration the system designers must use. To illustrate how this is accomplished, let us set down design criteria which when used, by the design group, will identify their responsibility in the control process. This design criteria is applicable to the transmitter design described previously.

1) Provide sufficient low level frequency multiplying stages to preclude the necessity for tripling in the final stage.
2) Use twisted pair filament leads to cancel out inductive fields.
3) Place low power stage in compartments and provide effective shielding isolation between stages in the common filament, bias and plate supply leads.
4) Provide space allocation for necessary cooling.
5) To reduce the harmonic frequencies, each stage succeeding the oscillator should be tuned. Parallel tuning is preferable since it minimizes the transfer of off-frequency signals.
6) Overdriving of lower power stages must be avoided.
7) The cabinet must have an effective shield.
8) Internal leads must be carefully routed to avoid interference.

Every item in the foregoing criteria if not adhered to will supply a log for the metaphorical "fire" that must be extinguished before one can say there is a good RFI-free design. In this transmitter design, it is quite clear that the responsibility for the RFI control is with the system designer. No matter how good the subsystems are, unless they are put together following a set of rules which have been given sketchily there will be an RFI problem.

The next logical question which must be asked is: *If all of the foregoing rules were applied in the design of an equipment and this equipment is installed, how do you explain the RFI problems which arise on a particular installation?* The glib answer to this question is simply that one does have problems if this is always done. But, since as a matter of fact, such problems exist, one must identify their source. This is relatively easy to answer remembering that in many installations there are other items used which are not electronic equipment but which can cause interference problems. Fluorescent fixtures, switches and portable tools are examples of this phenomena.

To illustrate this, let us examine an innocent looking item such as a portable electric drill. A portable electric drill is fitted with a universal electric motor, having a commutator and brushes. In addition to turning a drill point, it is capable of generating electromagnetic energy which may interfere with the operation of nearby electronic equipment. The levels of interference generated by this drill have been found to vary over extremely wide limits. At a given frequency, two drills, otherwise supposedly similar, have generated interference levels which were different by factors of as much as a thousand to one. Laboratory analysis of many of these drills has resulted in a compiliation of a list of factors which influence the generation of this interference. These factors include:

1) Arcing at the brushes. This is the source of 90% of the interference.
2) Capacitance and inductance of the field and armature coils form local resonating circuits for multiples of line and commutator frequencies.
3) Discharges of electrostatic energy built up between moving parts.
4) Poor concentricity between the commutator and bearings, causing brush bounce.
5) Too few commutator segments.
6) Too little or too much brush spring tension.
7) Lumped windings in the motor fields.
8) Poor mechanical balance of the armature has been found to result in armature shaft "whipping," particularly at high speeds. This in turn results in brushes bouncing on the commutator and arcing between the brushes and the commutator.
9) Armature shaft of too small diameter resulting in shaft whipping, particularly under load.
10) Radiation of interference from air vents adjacent to the commutator, and from the plastic covers of brush holders.

It should be obvious from the foregoing that most of the factors mentioned could have been corrected by an improved portable drill design. Manufacturers of portable electrical drills have followed these rules and their designs are relatively interference free. Not only do they solve the interference problem by exercising this control but they end up with a better drill. There is adequate brush area on the commutator, the motor shaft is sturdy, the bearings and the commutator are concentric and contamination of the motor by loose particles is eliminated. This improved design is clearly a case of a manufacturer taking the responsibility for an RFI-free design.

From the foregoing, the question of responsibility begins to get clarified. Every guideline, every criteria in itself results in better equipment. If the guidelines are followed for a transmitter, a good transmitter will be produced and it will be RFI-free because it will be a minimal source to other equipments, and it will be minimally susceptible to other equipment. If the rules are followed for a portable drill, a very fine drill will result—efficient, thorough and capable of doing a good job—and it will be RFI-free.

This then is the answer to the question of responsibility. The responsibility must rest with whomever the control of the program lies. In the case of the system contractor, he must be responsible because he is in a position to control. For the manufacturer of a simple device only of minimal importance, he must be responsible because the manufacturer is in a position to control the device. Unless the particular system contractor or device manufacturer is in a position to control, then no responsibility can be charged against that individual.

ROCCO FICCHI received his BS degree cum laude from St. Joseph's College in 1941 and has completed graduate courses at the University of Pennsylvania. Prior to joining RCA in 1958 he spent 15 years with various consulting firms, specializing in electrical distribution systems for the chemical, refinery, and atomic energy industries. He has been involved in three major programs at RCA—Atlas, BMEWS, and Minuteman—and has been particularly concerned with problems associated with the performance of electronic equipment in the electromagnetic environment. He has authored over 20 technical papers, is the author of **Electrical Interference** published in 1964, and is general editor and a contributing author for the forthcoming EMC Handbook. He has been active in the History of Science Society, the New Jersey Academy of Science, and the American Association for the Advancement of Science.

RECENT ADVANCES IN TRAVELING-WAVE-MASER SYSTEMS

The traveling-wave maser circuit, the closed-cycle liquid-helium refrigerator, and the superconducting magnet have recently experienced significant improvement. This article analyzes some of the current engineering advances, the latest findings on important parameters, and particularly the unique combinations of these components of traveling-wave maser system design. The TWM system is ready now for more effective utilization by the systems engineer.

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THE traveling-wave maser (TWM) has been undergoing development for about eight years.[1] The closed-cycle liquid-helium refrigerator and the superconducting magnet have undergone periods of equal development. All of these disciplines have long since passed the stage of scientific curiosity and are well into the area of engineering development.

Some excellent discussions of the basic physical principles of microwave masers are available, and therefore will not be covered here.[2] This article analyzes some of the recent engineering advances, particularly the unique combination of techniques such as dielectrically loaded slow wave circuits, cryogenic refrigeration, and superconductivity, employed in traveling wave maser system design.

As fairly well recognized by most engineers, traveling-wave masers provide the lowest effective noise temperature (10°K) of any microwave amplifier. However, a number of significant maser characteristics such as virtually complete freedom from intermodulation distortion, extreme gain stability, and insensitivity to pump power fluctuation as related to gain saturation, are not as well understood. These properties are also reviewed here.

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* Formerly called DEP Applied Research.

The economics of operation, second generation refrigeration, solid state pumping, and new maser crystals are all leading to a new device, capable of competing both from a performance and economic viewpoint with the more traditional low noise microwave amplifiers.

The final utilization of course rests with the systems engineer's imagination and ability to utilize these unique properties to create new systems previously not realized.

TRAVELING WAVE MASER CIRCUIT DEVELOPMENT

After the initial maser principle was first demonstrated with a resonant microwave cavity, research effort was directed toward distributing this bulk negative-resistance amplification mechanism along a propagating circuit to form a traveling wave amplifier. That is, the incoming power carried by the wave increases with distance as $\exp(2\alpha l)$ (where α is the gain coefficient and l is length of amplifier). The first TWM was designed by DeGrasse, Schulz-DuBois, and Scovil at Bell Laboratories. It employed a ruby-loaded comb circuit. The immediate advantages of greater bandwidth and gain, as well as ease of tuning, became evident when compared with the narrow band, limited-gain cavity circuits. Additional advantages were discovered such as nonreciprocal forward gain, large reverse isolation, and the ability to artificially broaden and tune the resonance linewidth. These all evolved over a number of years with various slow-wave circuits and paramagnetic crystals.

Let us look at the TWM circuit briefly and review some of the basic parameters.

Equations 1 and 2 for the gain and bandwidth expressions define the maser material and important circuit parameters required for useful application:

$$G_{db} = \frac{27.3 \times (c/vg) N}{Q_m} \qquad (1)$$

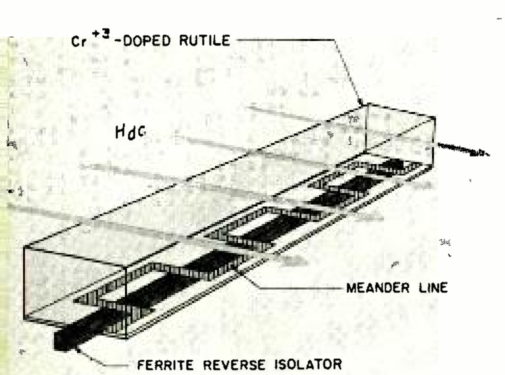
where c/vg is defined as the slowing factor, N expresses the length of the circuit in free space wavelengths, and Q_m is the magnetic Q of the circuit. This may best be described by:

$$\frac{1}{Q_m} = \frac{\gamma^2 h I \Delta N \sigma^2}{\pi \mu_o \Delta f_e}$$

The important parameters are: I, inversion ratio; N, the thermal equilibrium population difference per unit volume; and f_l the magnetic resonance linewidth. The bandwidth expression is given as:

$$B = f_l \left(\frac{3}{G_{db} - 3} \right)^{1/2} \qquad (2)$$

Fig. 1—Schematic of the traveling wave maser circuit.



L. C. MORRIS was graduated from LaSalle College with a BA degree in Physics and Mathematics in 1956. His post-graduate education is extensive and interdisciplinary, ranging from advanced work in circuit theory to quantum and statistical mechanics. At RCA Mr. Morris has been associated with microwave physics and quantum electronics. In particular, he has been associated with each step in the evaluation of masers, from the early cavity type to the traveling wave class of the present day. In 1961, he became Leader of the Maser group. In this capacity, Mr. Morris was responsible for a group engaged in research on elevated temperature masers, packaged masers, superconducting maser magnets, and multichannel masers. Mr. Morris is now Manager, Applied Physics section, which includes activities in laser and maser applications and microwave physics studies. He is a member of the IEEE, is active in the professional-technical groups of the IEEE, and has published ten papers.

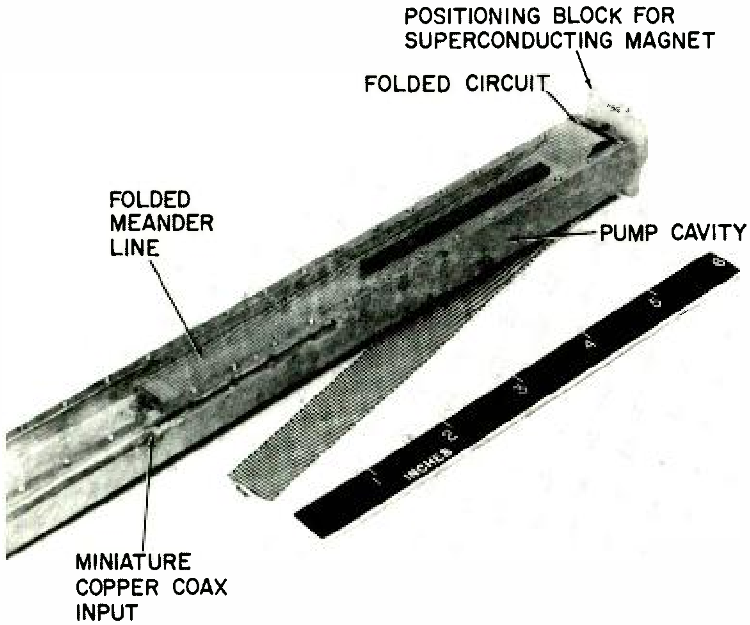


Fig. 2—A meander-line slow-wave structure. The active crystal is placed on both sides of the circuit.

From these two equations, we can describe the important parameters: a circuit that provides a long interaction time with the maser crystal (large slowing); and crystals with good inversion ratios (the ratio of power emitted to power absorbed by the crystal), large population differences for large gains, and wide resonance linewidths for adequate bandwidth.

The meander line circuit with iron-doped rutile ($Fe^{3+}:TiO_2$) incorporates these desirable parameters and is of the type developed by RCA.[3,4] Fig. 2 shows a typical meander line maser and its associated components. The active crystal shown is chromium-doped rutile. The circuit is a copper flattened helix photoetched on a 1-mil substrate. It may be folded a number of times to reduce linear length and enhance the packing density. What has been accomplished with this type of circuit and how it may be conveniently and effectively combined with a superconducting magnet and closed cycle refrigerator will be discussed in later paragraphs. Let us now look at a few of the other advantages of the traveling wave maser that were not as obvious to system designers when the initial maser development began.

IMPORTANT PARAMETERS

Gain Stability

Gain sensitivity, defined as $\Delta G/G$ for a traveling wave maser, may be expressed as:

$$\frac{\Delta G}{G} = \ln G$$

Before discussing the property of gain stability for the TWM, the property of nonreciprocal gain and reverse isolation must be briefly reviewed. The TWM generally has high gain in the forward direction and much greater attenuation in the reverse direction. This characteristic provides unconditional stability, against a varying input or output impedance. This results from the fact that the optimum transition probability (or maximum gain) varies with the microwave magnetic field orientation. For maximum interaction. positive polarized fields are required; for minimum gain, negative polarizations are required; that is, the gain mechanism in itself is completely nonreciprocal. The slow-wave circuits generally employed for traveling wave masers have these regions in which the fields have both senses of circularly polarized fields about the propagation axis. Thus the location of the maser crystal in the proper magnetic RF field provides maximum gain. The ratio of gain forward to gain backward is an important parameter. A typical number is 20:1 for the rutile meander line circuit at C-band.

When a ferromagnetic material is placed in the negative polarized field, additional reverse isolation is obtained. This is analogous to a classic ferrite isolator. The material is generally some form of yttrium-iron-garnet (YIG). Its shape factor, linewidth, and volume, along with its ability to resonate at values of magnetic field close to the paramagnetic resonance value, determine exactly how much isolation may be provided. Fig. 3 shows the boundary conditions and shape factors that may be employed for various gadolinium substitutions in YIG.

Isolation greater than 100 dB in the reverse direction is common for TWM circuits, and ferrite resonance linewidths are presently much wider than paramagnetic linewidths; therefore circuits with adequate isolation and tracking over a 50% range can be easily designed.

Another important parameter, a key to stability as well as extended bandwidth, is the fact that the TWM is virtually insensitive to fluctuations in pump power if the pump transition is fully saturated.

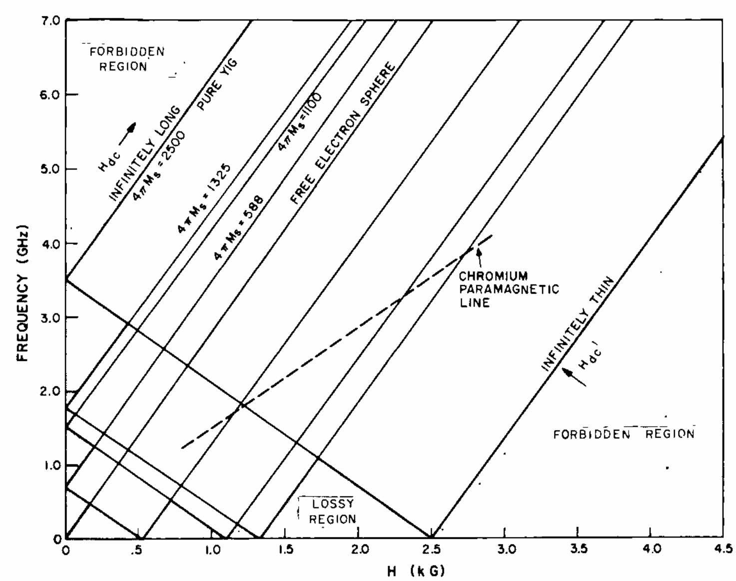


Fig. 3—Various boundary conditions and usable shape factors for gadolinium substitutions in YIG.

The TWM also has the ability to artificially broaden the pump linewidth by providing staggered magnetic fields and sweeping the pump frequency across a broadband at a rate faster than the relaxation time between the pump energy levels.[5] These characteristics provide assurance that the maser will be very stable against either amplitude or frequency variations in the pumping circuit.

Gain stabilities of ±0.03 dB/hour have been measured recently with a traveling wave maser, and short term stabilities have been measured to approximately ±0.002 dB/5 min.

Broad Bandwidth

The ability to inhomogeneously spread the pump energy may also be extended to the magnetic field. By providing a series of discrete magnetic fields f_l (the material linewidth) may be inhomogeneously broadened and additional bandwidth can be exchanged for gain. How this is accomplished with a superconducting magnet will be described later in this article. Both these parameters, broad pumping and varying bandwidth, are electronically variable elements controllable from outside the cryogenic environment. Therefore gain can now be exchanged for bandwidth, and the amplifier response can be tuned and shaped without altering the physical configuration of the circuit.

Intermodulation and Dynamic Range

An extremely important property of the TWM is its literal freedom from distortion. This was first discussed by E. O. Schulz-DuBois, and demonstrated by Tabor, Chen, and Schulz-DuBois of Bell Labs.[1,2] This parameter may well prove to be one of the most important properties of this type of low-noise quantum amplifier. The results of this work are briefly reviewed here. Although the experimental confirmation was done with a ruby-loaded comb circuit, the results are equally applicable to a rutile-loaded meander line circuit.

When the center frequency f_1 of any amplifier is in close proximity to a higher powered RF signal level f_2, gain compression occurs. In conventional microwave amplifiers which achieve their amplification through a single-valued characteristic curve, appreciable amounts of intermodulation or frequency mixing occurs with this gain compression. For the TWM case it was recognized that intermodulation levels would be very small compared to the signal even when the gain is run into compression.

Briefly, intermodulation depends upon the short spin-spin relaxation times, while the gain saturation process is proportional to the spin-lattice relaxation time. The difference is some seven orders of magnitude.

For a traveling wave maser, the third-order terms are the only signals that can readily fall within the structure passband. The second order terms fall far outside the normal circuit operating band. From the theoretical predictions, the intermodulation distortion power levels can be expressed as:

$$P(2f_2 - f_1)\ \text{dBm} =$$
$$2P(f_2)\ \text{dBm} + P(f_1)\ \text{dBm} - A$$

Fig. 4 illustrates the dependence on gain saturation and intermodulation terms and how they are related. The experimental data obtained by the Bell workers yields $A = 95$. Essentially, intermodulation distortion terms are below the noise level of the maser even when the amplifier is operated in a state of gain compression, and the TWM is still a very linear amplifier.[6] Even a one or two order of magnitude reduction in spin lattice relaxation times will still permit us to achieve this low distortion property.

In summary, some of the more important, but lesser known, TWM characteristics are:

1) The maser crystal is a bulk device virtually free from burnout by large overload signals.
2) The maser crystal linewidth may be magnetically broadened, and gain can be exchanged for bandwidth electronically and remotely.
3) The TWM is unconditionally stable and relatively insensitive to pump power and frequency fluctuations.
4) The maser is virtually distortionless and has large dynamic range.

Let us now look at the major supporting components utilized in traveling wave maser design.

MAJOR SYSTEM COMPONENTS

Superconducting Electromagnets

The utilization of the superconducting magnet has provided the major impedance toward making the TWM a practical device.[7] The combination of superconducting shielding with high current-carrying capacity of the superconducting wire permits the generation of extremely uniform fields over reasonable gap openings.[7,8] Fig. 5 shows the general magnet components. Magnets weighing between 5 and 15 lbs and provide large fields with extreme uniformity. Hence the need for the heavier (100- to 200-lb) permanent magnets has been eliminated.

This combination of independent superconducting coils and magnetic shielding has provided a number of additional advantages. Spatially controlled

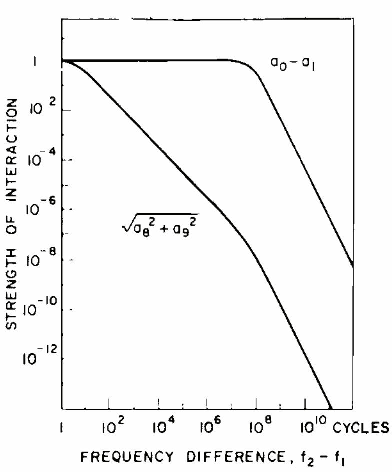


Fig. 4—Comparison of the frequency dependence of gain saturation and intermodulation. The ordinate is in units of $2m^2 T_1 T_2$ and the frequency scale on the abscissa is applicable to the ruby maser transition. (From Ref. 6)

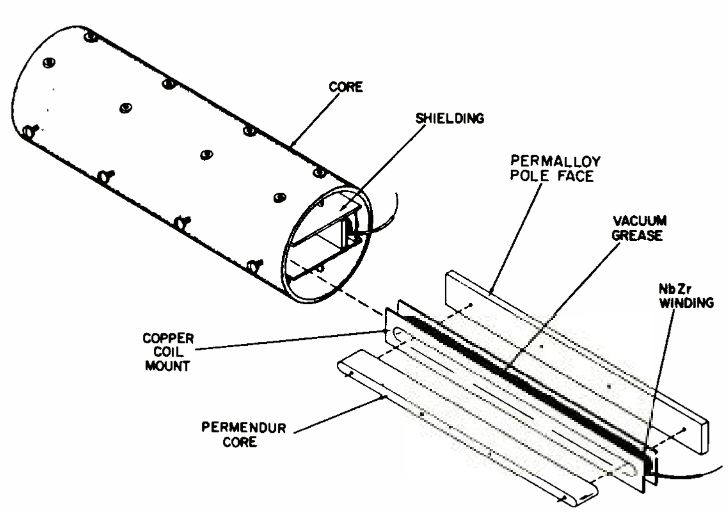


Fig. 5—Exploded view of superconducting magnet and coil assembly.

magnetic field profiles (see Fig. 6), remote electronic control of gain and bandwidth, and independently controlled gap openings permitting multi-channel operation are among the most important.

By properly controlling the magnetic field profile along the length of the magnetic circuit, gain may be remotely exchanged for bandwidth. Fig. 7 is an example of a seven-coil-wide bandwidth maser magnet. Fig. 8 shows the tunable gain and bandwidth for this amplifier: this is again accomplished by adjusting the coil current though the magnet.

Essentially, maximum bandwidth is fixed by the natural linewidth of the material, the number of independent superconducting coils employed, the dispersion characteristics of the slow-wave circuit, and the efficiency of the pump circuit.

The utilization of a common core with independent well openings provides a layer of superconducting shielding which permits multichannel operation as shown in Fig. 7. Under these conditions not only may the gain and bandwidth be adjusted remotely in each channel, but all channels may be independently tuned for exact gain and phase tracking—an important parameter for radar application.[9] Fig. 9 gives the tunability for various 1-dB bandwidth settings. (This TWM superconducting magnet assembly was first designed for the Advanced Technological Satellite (ATS) and is presently installed in a 40-ft antenna at the Mojave tracking station.)

The final selection of a superconducting magnet configuration depends upon the closed cycle refrigeration to be employed, the number of driving leads, and the utilization of superconducting persistent switches; these factors will be reviewed later in this article.

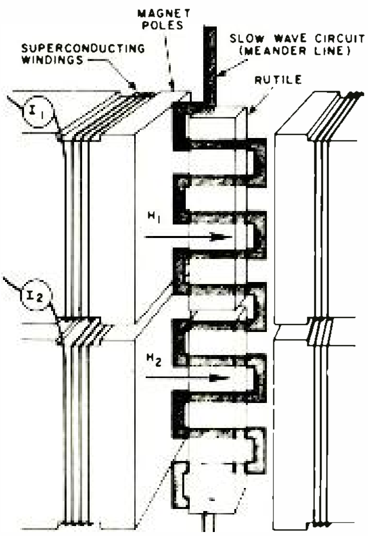


Fig. 6—Schematic of single-step magnetic stagger tuning. Each element of crystal length is resonant within its own magnetic field (H_1, H_2, etc.); by slightly displacing each field, gain may be traded for bandwidth.

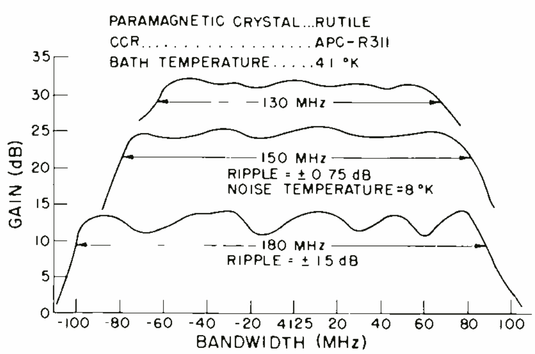


Fig. 8—Relationship of gain to bandwidth for the ATS traveling wave maser.

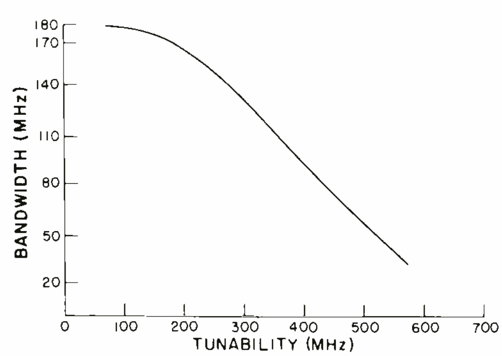


Fig. 9—Relationship of tunability to bandwidth for a constant 25-DB gain.

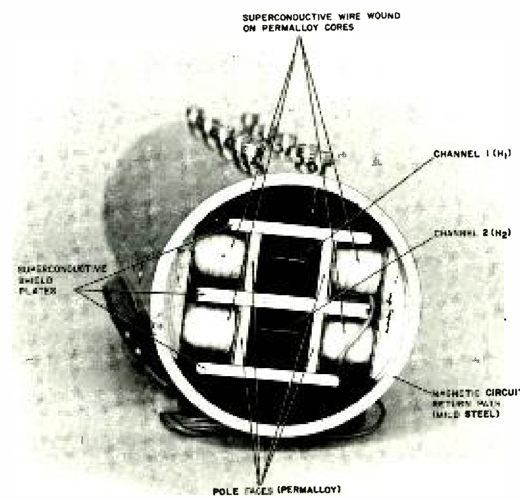
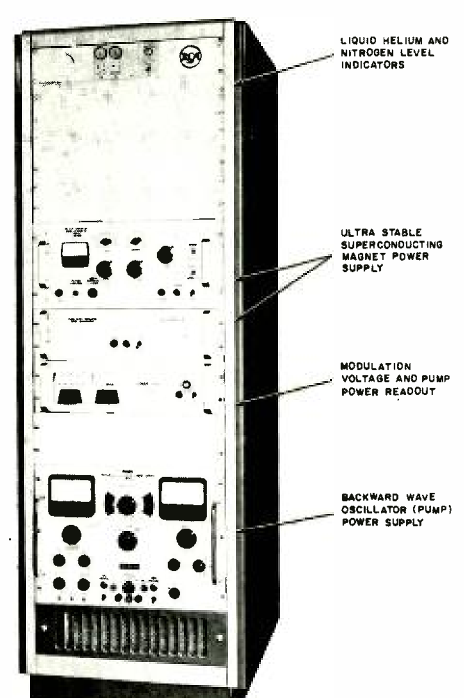


Fig. 7—The ATS dual well magnet (top view).

Fig. 10—Typical maser control console for a broad tunable bandwidth traveling wave maser system.



Pump Circuit and Controls

Pump power for full saturation may be expressed as:

$$P = h\nu\Delta N/2T$$

where P = power absorbed by the spin system, w = the stimulated transition value, h = Planck's constant, ν = frequency, T = spin lattice relaxation time, and ΔN = population difference between pump levels.

There is a physical limit to the maximum power absorbed by the pump spin system. Essentially the pump transition and signal transition are quantized and the maser system operates in the "pump saturated mode." By combining broadband sweeping techniques with full pump power, the difficult pump stability problem generally encountered in other low noise amplifiers is eliminated.

Present TWMs developed at RCA utilize one backward-wave oscillator swept across the pump band at a rate approximately ten times faster than the natural relaxation time of the crystal. Over the past two years these backward wave oscillators (manufactured by O.K.I., Japan) have shown remarkable improvement in power, frequency range, and life time; tubes operating for well over 1,000 hours with over 1 watt of power in M band (50 to 75 GHz) are presently available. The expected life of these tubes is 3,000 hours.

The controls for a TWM undergo a variety of packaging configurations, depending upon the system requirements (Fig. 10). The essential components are BWO power supplies (or klystrons), a magnet control supply, and adequate cryogenic indicators. With the increased reliability of the subcomponents, the need for elaborate monitoring, control, and adjustment is being eliminated, and simpler control centers are beginning to evolve. This simplicity of controls, the lack of pump power regulation, and the utilization of persistent superconducting switches, are greatly reducing the need for control design. Consequently a reduction in system cost also will result.

Closed Cycle Refrigeration (CCR)

Recent advances in closed cycle refrigeration have been deliberately withheld from discussion in this article, until some basic knowledge of all components that require refrigeration was presented. What are the cryogenic loads presented to the CCR? The main types are: 1) Input and output microwave leads, 2) Magnet current and control leads, and 3) Pump power dissipated in the slow wave circuit and maser crystal.

Until early 1966, almost all closed cycle refrigeration at 4.2°K was rather expensive ($70,000 to $90,000) with limited capacity (0.5 watts) and relatively small working volumes (see Fig. 11).

Over the past three years we have had the opportunity to evaluate three separate closed cycle refrigerations designed

Fig. 11—The A. D. Little CRYR-210 closed cycle refrigerator: 11a, refrigerator system; 11b, compressor unit.

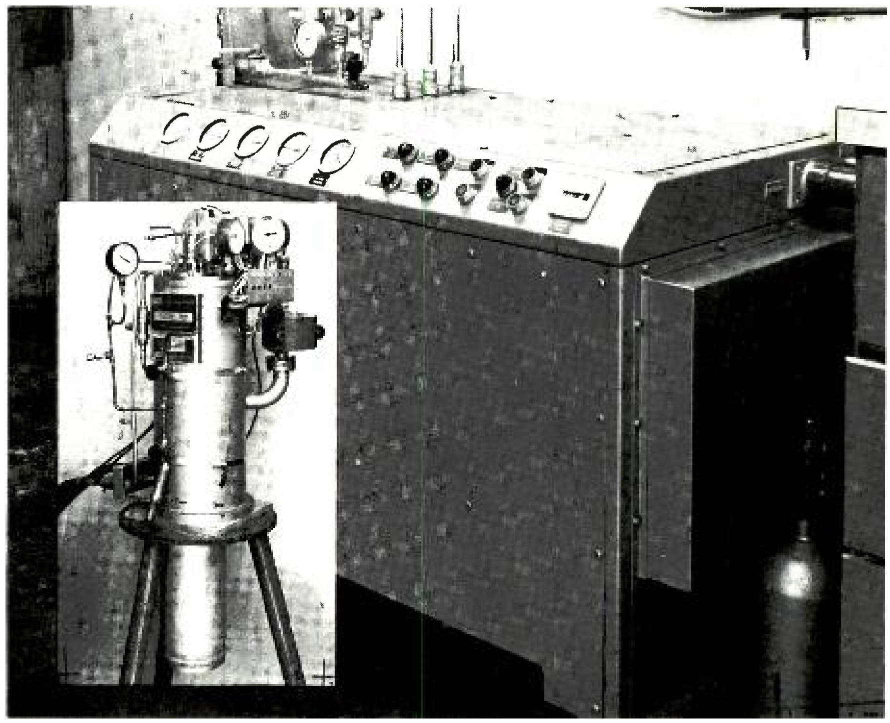


TABLE 1—Comparison of closed-cycle refrigerators evaluated by RCA

Refrigerator Manufacturer	Compressor Weight (lbs)	Compressor Size (feet)	Compressor Power (kW)	Cold Box & Engines Weight (lbs)	Cold Box & Engines Size (feet)	Excess Capacity at 4.2°K with Maser Installed (watts)	Cool-down time with Maser Installed (hours)	Redundance and MTBF	Remarks
ARTHUR D. LITTLE No. 210 *Compressor*—Oil lubricated. Works in only the horizontal orientation. *Cold Box*—May operate in any orientation.	800	3 x 6	5	120	2 x 4	0.05	24	No redundancy 2500 hours MTBF	Requires high vacuum. Marginal working area.
LINDE No. Rhe-1 *Compressor*—Water cooled. Works only in the horizontal Position. *Cold Box*—May operate in any orientation.	800	3 x 6	4	150	4 x 3	1	24	No redundancy in engine 3000 hours MTBF	Not as stringent vacuum requirements. Temp. stability marginal. Tends to leak. Largest operation expen.
AIR PRODUCTS AND CHEMICALS *Compressor*—Air cooled. Works in all orientations. May be antenna mounted. (Two compressors.) *Cold Box*—Operates in any orientation.	180	2 x 3	4	170	3 x 6	0.8	7	5000 hours MTBF Redundant	High vacuum requirements. Least expensive to operate in the field.

NOTE: Since we evaluated the ADL 210 machine, a series ADL 400 has been built and is now operational. Although no claim is made here for direct experience, reports indicate that a number of the disadvantages listed above have been eliminated.

Fig. 12—The A.D. Little 340L closed cycle refrigerator.

vacuum dewar prior to modification. Fig. 13a and 13b show the schematic and JPL modifications.

Essentially the selection of a cooler depends upon a number of important operational considerations other than capacity alone. These are:

1) The period of operation which is tolerable without maintenance
2) The cool down and warm up period
3) The size, weight, and power that is available
4) The attitude and motions of the compressors and cold box

Small coolers with dry lubricated, completely sealed compressors (Air Products and Chemicals) are available. Designers of transportable, easily assembled military systems may now consider the use of the maser and its closed cycle by leading cryogenic manufacturers. The Arthur D. Little CRYR-210, the Linde Rhe-1, and the Air Products and Chemicals R311—a redundant system (see Table I).

The major areas of difficulty encountered were: 1) limited capacity (0.5 watts), 2) small working volume, 3) the requirement for high vacuum integrity, 4) oil contamination, and 5) limited operating time between maintenance periods. These problems were not indigenous to any one manufacturer, each had its own unique set of problems. An important point, however, is that some of these problems exist even today at temperatures greater than 4.2°K.

Gaseous helium systems (15°K), although smaller, do not necessarily exhibit greater reliability characteristics since those components below the 15°K heat station are passive; i.e., a Joule-Thompson valve, an additional heat exchanger, and bypass switches. These do not add a note of unreliability. Therefore when reliability is the sole basis for the selection of a refrigeration system at an elevated temperature (>4.2°K), without consideration of the total system parameters, a costly mistake may be made.

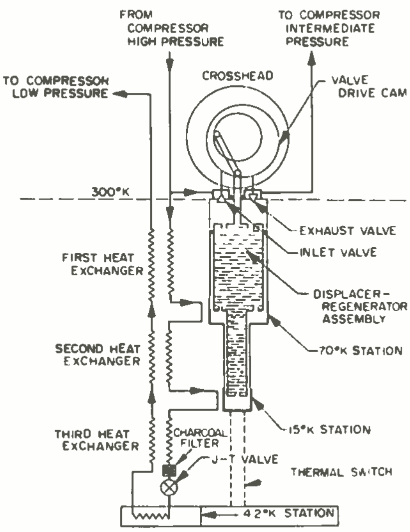
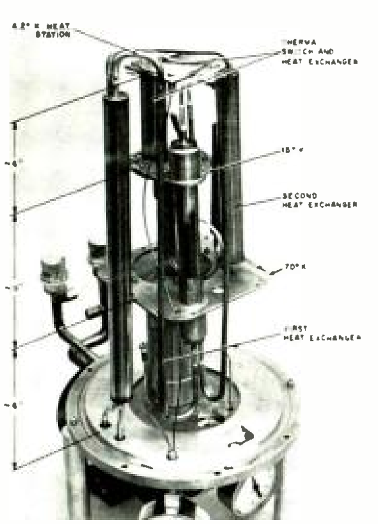


Fig. 13—The JPL modifications to the 340L 15°K parametric cooler: 13a, schematic showing JT value and heat exchanger added to CCR; 13b, top view of JPL internal refrigerator.



Second-Generation Coolers

Recently, workers at JPL under the direction of Dr. W. Higa extended the range of the ADL 340-L 15°K cooler to 4.2°K by adding a novel heat exchanger and Joule-Thompson valve. This, coupled with a unique thermal switch, resulted in a 1.0-watt (at 4.2°K) reliable, low cost CCR. The details of the heat exchanger design, thermal switch, and J-T valve are beyond the scope of this paper. However, as of this date, over a ½ year of operation without failure has been achieved. Fig. 12 shows the basic cooler without

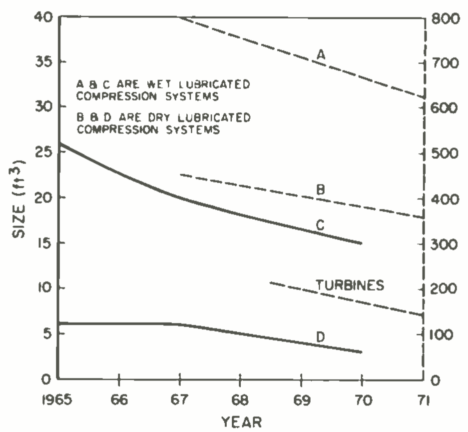


Fig. 14—Projected sizes and weights for closed cycle cooling systems.

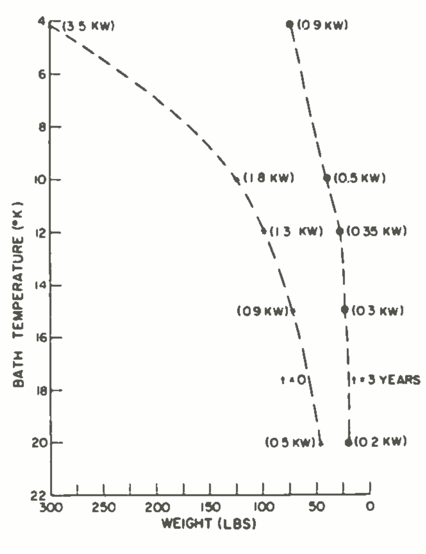


Fig. 15—Bath temperature and weight vs. primary power for a one-watt refrigeration system.

refrigerator. Fig. 14 shows the projected curves of size and weight for closed cycle coolers. These curves are based upon a study of most existing coolers, presently available or under development.[10] Fig. 15 gives both temperature and weight variations for a 1-watt refrigeration system.

TRENDS AND FORECASTS

Effective utilization of the traveling wave maser now rests primarily with the imagination and understanding of the systems engineer. As for the future developments, three major areas of improvement are predicted.

First: Improved materials with large linewidths resulting in larger bandwidths and reduced pump power requirements are closest to realization. Bandwidths of 500 MHz or greater are most likely to evolve. Fig. 15 shows a predicted bandwidth vs. development time curve for traveling wave maser circuits.

These material improvements may allow traveling wave masers to exhibit other forms; for example, masers with 50 MHz of bandwidth and 100% tunability, or combinations of reasonable bandwidth; e.g., 100 MHz and 40% tunability, may be produced. This combination of amplifiers will result from the improvements in maser materials. Some of the improvements have already been observed and will be reported in papers by Dr. Wittke of RCA Laboratories.

Second: Highly reliable closed cycle refrigeration is already a fact of life. Competent cryogenic manufacturers are now working toward much reduced costs, and major price reductions are very close. Fig. 16 shows the projected curve of periods between maintenance operations.

Another important characteristic worthy of system consideration is the fact that additional refrigeration capacity may be had at relatively little additional cost. For example, systems capable of producing 150 liters of helium/hour may be combined with thousands of small quantum amplifiers in a closed cycle configuration, thus drastically reducing refrigeration costs. Phased arrays in which thousands of low noise gain and phase stable amplifiers are required may make this application feasible. Fig. 16 shows the projected cost for such a system based upon data on existing helium liquifiers, solid state pumps, and improved maser crystal. Fig. 17 shows the cost per watt of refrigeration.

Third: Another major area which shows promise for improvement lies with the pump circuitry and supporting controls. Recent advances with Gunn oscillators operating in the limited-space-charge-accumulation mode have already shown oscillation at 51 GHz—a maser pump frequency. The utilization of solid state pumps integrally coupled to the slow wave circuit, or in close proximity, will eventually evolve. This technique combined with persistent superconducting switches will eliminate the need for power supplies complex. It will also virtually eliminate the control center as we have come to recognize it.

Optically pumped masers, nuclear quadrapole masers, and phenomena interaction in maser materials are additional areas of investigation both at RCA and elsewhere. The scope of this paper does not permit adequate discussion of these techniques and their eventual application. However, these phenomena also will play an important role in the eventual application of microwave quantum amplifiers to complex electronic systems. In addition, the use of turbo-compressor closed-cycle refrigeration systems have not been reviewed because sufficient operational information and long periods of test data are not yet available.

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Fig. 16—Forecasts of various elements of operation and cost in traveling wave maser system design.

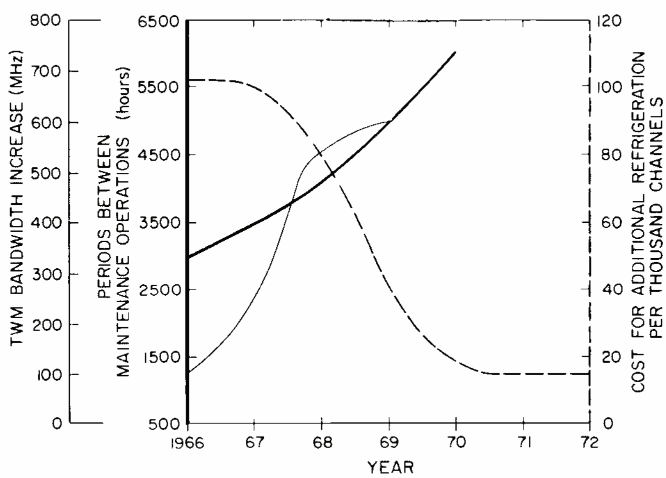
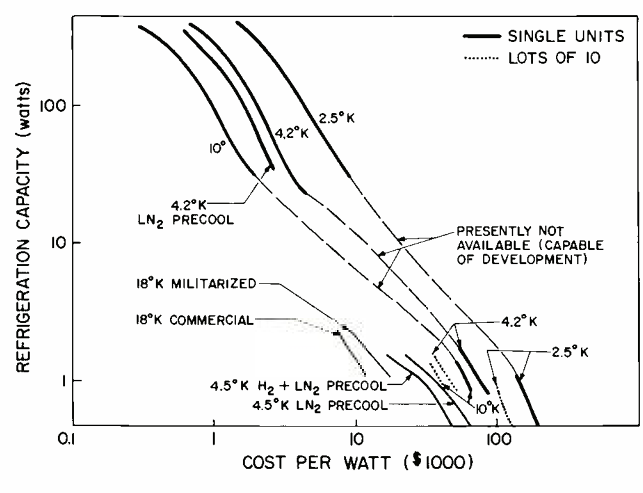


Fig. 17—Projected cost per watt of refrigeration capacity.



LOW COST MASS MEMORY

This paper covers the development of a low-cost mass memory system in the 200-millisecond average access time, 70-million eight-bit byte capacity region. Three card handling concepts were investigated: a quadrant machine, a vertical machine, and a simplified version of a presently designed random-access mass memory. It was decided to implement the latter concept with breadboard hardware.

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THE simplest design is inherently the best from the standpoint of both cost and total performance. Consequently, the design which employs the fewest number of mechanical motions and actuators was the most desirable. Evaluation of candidate design concepts was based on this philosophy as well as the probability of meeting the performance specifications.

CARD HANDLING CONCEPTS

A basic decision had to be made as to whether the card selection technique was to be analog or digital in nature. It was felt that a high degree of technical uncertainty was inherent in an analog approach. Furthermore, the decision to utilize an existing card influenced the placing of more emphasis on digital selection techniques, since the card is notched in a quasi-digital pattern. However, the decision to utilize this type of card imposed limitations on the design concepts which could be used to achieve the other requirements.

In general, if the number of discrete cards in a deck is a power of two (such as 256) then the minimum number of mechanical actuators necessary to select one card out of the total deck is equal to the exponent—eight in this case. However, the notch patterns of the card used are not set up to allow for this minimum number and modification to the card was neither desirable nor allowable.

This consideration led to the "bin storage approach." In this approach, 256 cards are stored in 256 individual bins, making the presence or absence of any notch pattern on the card immaterial. Individual card selection can then be made with the minimum number of mechanical actuators operating on "doors" in front of each bin. This is a very feasible selection concept, and it is estimated that the time required to open a door from the initiation of selection will be a maximum of 50 milliseconds. If all 256 bins are parallel to each other and are made of 0.031-inch thick sheet metal on 0.062-inch centers, then 16 lineal inches of bins are required. Under these conditions, the average card travel distance to the read/write head will be on the order of 24 inches—or traveling at 400 inches/second, average travel time per card will be 60 milliseconds. This will yield an average maximum access time of 110 milliseconds.

To further reduce the access time it was proposed to take the bin storage approach and arrange the bins as rays of a quadrant with a pair of pinch rollers at the apex of the quadrant. The "front doors" of the bins would be located on a circumference at a radial distance of approximately 2.5 inches, yielding a total arc length of 4.0 inches for the 256 bins. This would give a 0.010-inch space for each bin having 0.005-inch thick walls. At the rear of the bin, the card return point, the corresponding pitch would be 0.113 inch on a 29.0-inch circumference. For this situation, the travel distance to the read/write head would be the same for all 256 cards and would be on the order of 16 inches, or result in an access time of 40 milliseconds, thus yielding an estimated maximum access time of 90 milliseconds.

The reason that these concepts were not implemented further is that a reliable way could not be conceived to return the card to the bin after selection. An analog system carrying a single fixed gate could be utilized, but projected cost and technical uncertainties ruled this out. A stack of 256 individual overlapped return gates was proposed, but no method of actuating the proper gate could be conceived.

Since there are 16 bail tab notches on the bottom of the card used, it was proposed to arrange the 256 cards in 16 groups of 16 cards each. A selection scheme similar in nature to the random-access mass memory selection scheme could then be employed. In order to reduce the complexity of the machine, it was suggested that the cards be retained in a horizontal orientation and the transfer plates and channels, which are necessary in the random-access mass memory return mechanization, be eliminated. This proposal would have increased the number of return gates by a factor of two and would have negated the experience gained on early mass memories. This experience demonstrated that card return into a deck was marginal from a reliability standpoint, if the returning card was allowed to return in contact with the cards in the deck. Consequently, it was decided to retain the vertical orientation of the cards and utilize a return scheme similar to the random-access mass memory. The 16 cards per deck, 16 decks per machine concept did offer distinct advantages from a technical standpoint as well as the probability that it could be implemented to achieve all the requirements.

MECHANICAL DESCRIPTION

As implemented, the machine contains 256 cards arranged in 16 decks of 16 cards each (see Fig. 1). As no read/write station was associated with the machine, a card recirculate assembly was incorporated to select and return cards. The unit is housed on a frame from an existing random-access mass memory and uses one of the first power supplies from this memory. All logic necessary for machine operation and control is self-contained. Gross size of the selection and return mechanism is 19.0 inches wide by 21.0 inches high by 23.0 inches deep (see

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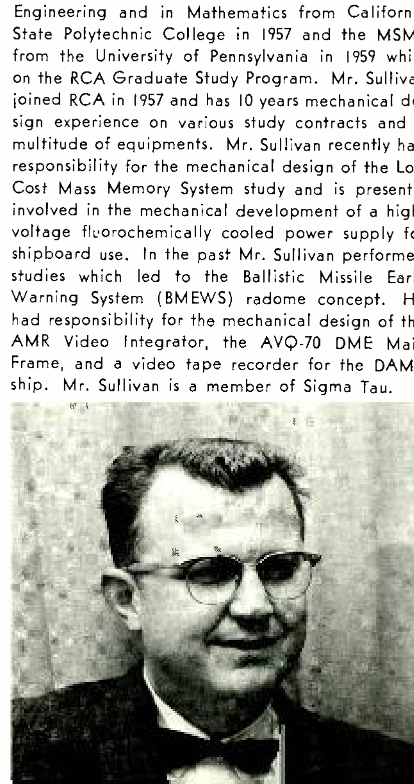

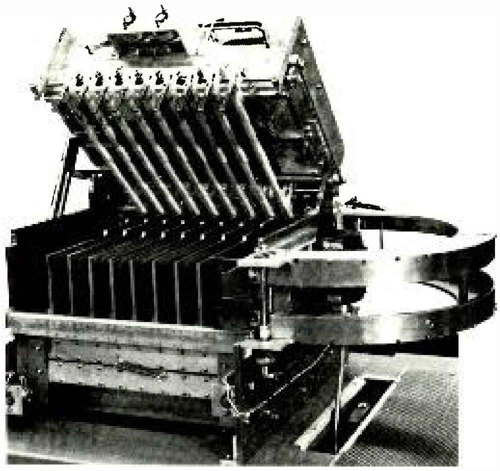

Fig. 1—Low-cost mass memory, illustrating card decks.

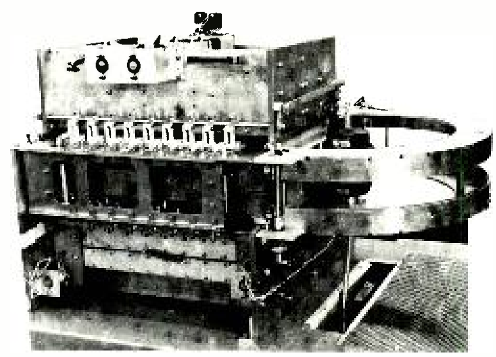

Fig. 2—Low-cost mass memory, illustrating selection and return mechanism.

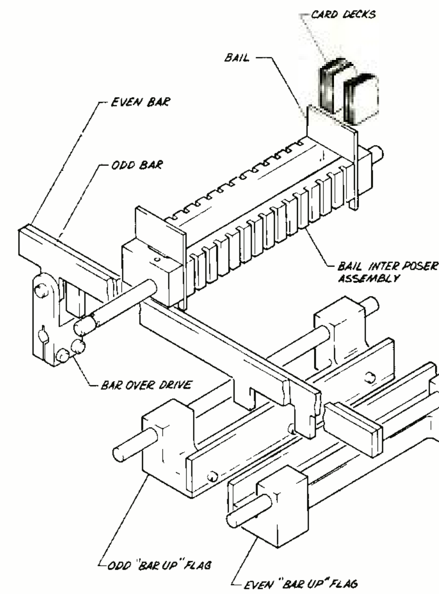

Fig. 3—Card selection bar assembly.

Fig. 2); it weighs approximately 160 pounds. All mechanical actuations are performed by rotary solenoids.

There are five main assemblies in the mechanism:

1) Lower Bar Assembly;
2) Gripper, Upper Bar, and Upper Channel Assembly;
3) Extract Transport Assembly;
4) Entry Transport Assembly; and
5) Frame, Transfer Plates, and Lower Channel Assembly.

The lower bar assembly contains 16 select bars, eight bail interposer assemblies, and two bar-up flags. The basic operation concept of this assembly is an interposer-on-an-interposer technique. The select bars are grouped in eight pairs with each pair capable of paired horizontal and individual vertical translation. The bars ride on rollers and have a light spring retaining them at each end. The horizontal drive is by means of clevis driving the bar in an open notch. A tab is located near the center of each bar—the tab on the odd numbered bars is to the right of center, and the tab on the even number bars is to the left. When one pair of bars is actuated, their tabs, and only their tabs, line up over the two bar-up flags. If one of the two flags is actuated, the select bar will rise. The bars are designed to bottom out on the bail interposer housings so that, in a fully actuated condition, they are level. The bail interposer assemblies are very similar in operation to those utilized in previous random-access mass memories with the exception that one bail assembly covers two decks of cards rather than one. When the bars, bails, and flags are operated in their proper sequence, one mechanical card address, the desired card, and an unwanted one from the adjacent deck, will be raised 0.250 inch out of their decks (see Fig. 3). Further selection and extraction of the card is performed by the gripper assembly.

The gripper assembly operation can best be understood by analogy to an eight-pole, double-throw, center-off, momentary toggle switch. Eight pairs of fixed jaws are located slightly above the card deck line and slightly outside the deck width. Each pair of decks is separated by a 0.250-inch thick divider plate. Located in this width at the same level as the fixed jaw is a movable jaw. There are eight of these moving jaws, all ganged together. When the action of the lower bar assembly has lifted two cards up into the gripper-zone area, the moving jaw closes right or left making the final one-out-of-two card selection. The jaw closure mechanism is kinematically identical to the well-known Geneva mechanism to minimize the impact strain on the moving parts (see Fig. 4). The entire jaw assembly is now translated by an eccentric mechanism actuated by a 95-degree rotary solenoid driving through a Scotch yoke. This principle of operation approximates simple harmonic motion for the forward translation of the gripper assembly. The present design incorporates the added feature of being able to change the travel distance in increments of 0.125 inch from 1.0 inch to 2.0 inches. Measured actuation times on a test rig ranged from 45 milliseconds for a 1.0-inch stroke to 70 milliseconds for the 2.0-inch stroke.

For the extract transport design, two endless belts spanning the length of the transport are so located that they are out of the recording area at the top and bottom of the card. Located inside the loop formed by the belts are sixteen fixed rollers—eight top and eight bottom. Riding against these rollers on the driving side of the belt are sixteen spring-loaded rollers. When the gripper brings the card forward out of the deck and releases it, the movement of the belt will tend to deflect the card into contact with the spring-loaded roller. This roller, riding on the belt against the fixed roller provides a "pinch" and the card is accelerated from the gripper terminal velocity to the belt velocity of 400 inches/second (see Fig. 2). A test fixture was designed and built to evaluate both the principle of operation and the card wearing characteristics of this concept. The card wear was found to be well within acceptable limits and the operational concept was found to be very feasible.

The entry transport is a reduced cost version of an existing design employing sheet metal construction. The card guide fairings are secured to the top and bottom plates by means of tabs on the fairings and holes in the plates. Of necessity, a portion of the holes lie in the card track but no detrimental effect to the card has been noted. The final drive set of pinch rollers is located in the plane of the final rest position of the card. Therefore, their tangent point must be located to the rear of the card deck at a distance equal to the radius of the rollers plus an arbitrary amount of clearance. The card must then skid this distance (0.375 inch) in free flight before it has completely entered the return channels. To negate the possibility of the card bouncing back into the entry transport a pawl spring latch was incorporated in the de-

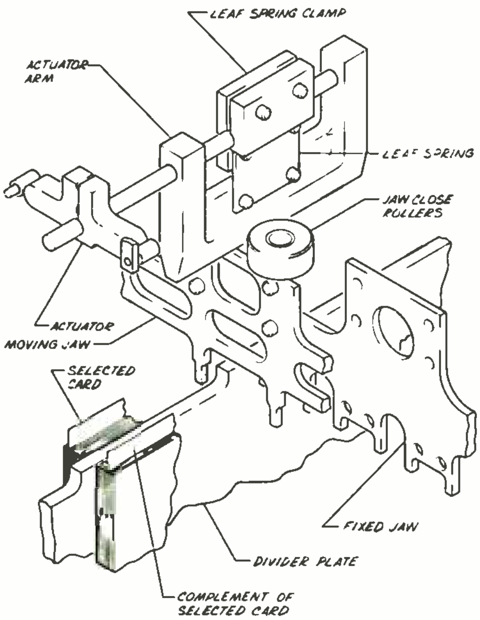

Fig. 4—Jaw closure mechanism.

sign. While this concept appeared sound, the implementation did not work out exactly as planned. A new design utilizing nine ganged shutters which would prevent the card from bouncing back into the channel was designed but never incorporated into the unit because of lack of time.

The upper and lower channels and the transfer plates are similar to existing designs; however, all the lower channels and all the upper channels are ganged together to common drives. To restrain the card from lifting when the upper channel is actuated, a fixed pin protrudes through the channel to a point slightly above the card line. This pin, in conjunction with an overhang from the entry transport, prevents the card from lifting. The transfer plates are ganged together in two sets, one left hand and one right hand, and actuate in a translational fashion rather than rotational. Both of these new methods of implementation work well.

It was originally planned that no hold bars or push-down bars were to be implemented in the machine. Push down bars appear unnecessary in the select sequence, since only the desired card and its complement in the adjoining deck are pushed up and the gripper performs the "OR" selection. However, because of excessive card wear, hold bars have been designed and installed. Installation of the hold bars eliminates the need for a stacking bar which "stacks" (aligns) the cards before selection.

No read/write station has been implemented yet; however, it is planned to take existing read/write subassemblies —capstan, head support, belt support, etc.—and mount them on a new baseplate. The entry and exit tracks will be new designs which reduce the linear distance from the extract transport to the magnetic head and thereby reduce access time. An estimated saving of 25 milliseconds will result from this change.

Economical construction techniques, such as sheet metal stampings and match-drilled mounting plates, have been used in the design. Design techniques such as matched mounting surfaces and continuous card rest surfaces, were employed to reduce assembly and alignment time.

LOGIC DESCRIPTION

The logic in the Low-Cost Mass Memory system is designed to mechanically operate the system; it contains select and return sequences. No logic has been incorporated for read/write operations and the read/write operation format is a system decision.

The select sequence is broken down into five steps. These five steps are generated by three flip-flop circuits. The setting and resetting of these flip-flops is controlled by variable delays, which will allow setting of the optimum select time. The five select steps are as follows:

1) Bail over and hold, select bar over and hold, actuate hold bars "0" and "1".
2) Select bar up and hold, release hold bar "1" or "0", activate three other hold bars corresponding to card address.
3) Close gripper jaw and hold, release hold bars.
4) Release select bar up, actuate gripper forward.
5) Release select bar over, open gripper jaw, release bail over, reset state counter.

At present, two micro-switches are employed to inhibit continuance of the select sequence until the respective mechanical movement has been completed. The two mechanical movements are bail forward and select bar up. It is possible to remove these switches and rely only on timing of sequences.

The return sequence consists of five steps of operation:

1) Activate magazine gates and open transfer plates.
2) Activate lower channels and release magazine gates.
3) Activate upper channels.
4) Release transfer plates.
5) Release upper and lower channels.

The return sequence is initiated by a photocell on the recirculate assembly (when the read/write is installed in the capstan area). A second photocell in the return transport senses the card in the return channels. The remaining steps of the return sequence are again controlled by variable delays.

In addition to the select and return logic described above, a sequence stop and a variable function mode have been incorporated. The sequence stop will inhibit the select and return logic in any of the five select or five return steps described. The variable function mode will allow numerous operations to be selected as follows:

Continuous: Allows continuous selection and return of any card selected by the address switches.
Random Card: Randomly selects and returns the cards in a given magazine.
Random Magazine: Selects and returns a given card from random magazines.
Random Machine: Selects and returns random cards from random magazines.
Sequential Card: Sequences through the cards in a given magazine.
Sequential Magazine: Sequences through the magazines with a given card.
Sequential Machine: Sequences through the cards in a given magazine then steps to the next magazine.
Magazine Mates: Selects and returns a given card first from the right of the magazine then from the left of the magazine.

The variable function mode was installed in this machine for test and operational control purposes only; it would not appear in a production version.

An additional switch on the maintenance panel inhibits operation of the magazine gates. This allows removal of a particular card without opening the machine. Switches other than those previously described are provided to allow for addressing of cards and magazines.

At present there are approximately sixty-five logic boards of the RCA-301 computer type in the system for card handling. For a production-type model, this amount would be approximately fifty-five.

CONCLUSIONS

A machine has been built which has a storage capability of 70-million eight-bit bytes on 256 cards. Preliminary measurement of excess times with no attempt to optimize the select timing has yielded figures of 310 milliseconds. This was with the transport running at 365 inches/second, rather than at 400, and all electronic delays in the select sequence set at maximum. The minimum average access time measured was 185 milliseconds with optimum select sequence times. The fabrication cost of the machine on a one-quantity breadboard basis was approximately twice that allocated for production quantities, indicating that the allocated cost is realizable. Reliable operation has been demonstrated and preliminary indications are that the reliability goal can be readily achieved. Ease of assembly and maintenance appear superior to previous mass-memory designs due to the reduced size of the machine and the modular construction.

COMPLEMENTARY MOS INTEGRATED BINARY COUNTER

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KENNETH R. KELLER did his undergraduate work at Rutgers University in the "Physics Option Program" in the department of Electrical Engineering. He received his BS in 1961 and his MS in 1963 from the same university. In 1961 he joined the technical staff of RCA Laboratories where he has worked on lasers, in superconductivity in intermetallic compounds and design work using new semiconductor devices in television applications. Four years were spent using microwave ultrasonic techniques for the study of impurity scattering of phonons and for an investigation of the elastic properties of Nb_3Sn. In 1966 he transferred to the EC and D division of RCA to work in the field of integrated circuits. Mr. Keller is a member of the American Physical Society, IEEE, Tau Beta Pi, Eta Kappa Nu, Pi Mu Epsilon and Sigma Xi.

L. P. WENNIK graduated from The Pennsylvania State University in 1963 with a BSEE degree. He contributed to the logic design of an advanced multipurpose test system in addition to extensive evaluation of developmental ferrite-plane memories. Mr. Wennik participated in the development of a neuron model for neural networks, using silicon ntegrated circuit technology and has a patent pending for the circuit which was developed. Recently, Mr. Wennik has performed stability studies of thin-film field-effect transistors (TFT) and developed a sense amplifier for use with core memories compatible with silicon integrated circuit technology. Mr. Wennik was awarded a patent for the sense amplifier circuit. He also has completed logic, circuit, and topological layout design of an all-thin-film "Divide-by-N" array, using only TFT's. Currently, Mr. Wennik is involved in the testing and performance analysis of complementary metal-oxide-semiconductor (MOS) devices, MOS logic gates, and all-MOS digital arrays. He has just completed design and testing of an integrated twelve-stage complementary MOS counter and is presently designing a ten-stage complementary MOS shift register, using computer aids, which will operate at the highest frequency possible for a given area of silicon. Mr. Wennik is a member of Eta Kappa Nu, Sigma Tau, Tau Beta Pi, and the IEEE.

HAROLD BORKAN received the BS degree in Electrical Engineering with high honors from Rutgers University in 1950 and the MS degree from the same university in 1954. In 1950, he joined RCA Laboratories in Princeton, New Jersey, as a Member of the Technical Staff where he has done research on electronic devices and circuits. He has been concerned with circuit designs for, and analysis of, television camera tubes. From 1960 to 1965, he has been concerned with the measurement, analysis and utilization of developmental thin-film semiconductor devices and also with these devices integrated with thin-film passive components. In March 1965, Mr. Borkan transferred to RCA's Defense Microelectronics activity at Somerville, New Jersey, as an Engineering Scientist concerned with monolithic and thin-film integrated circuits. He is now Engineering Leader of the Integrated MOS Fabrication Techniques Group responsible for DME's effort in the development of MOS integrated arrays. Mr. Borkan is the author of over twenty technical papers and the holder of five patents in the areas of television camera tubes and semiconductor devices. He is a Senior Member of the IEEE, a member of Eta Kappa Nu, and is the recipient of two RCA Laboratories Achievement Awards. He is a member of the team that received an outstanding paper award from the 1964 IEEE International Solid State Circuits Conference.

A. KARL RAPP received a BSEE degree from Drexel Institute of Technology in 1954 and an MA degree in Applied Physics from Harvard University in 1955. In intervals during his undergraduate studies, he was employed as a Cooperative Student Engineer by the Philco Corporation. He joined the Research Division of Philco Corporation as a Senior Engineer in 1955. In 1956, he was promoted to Project Engineer and, in 1958, to group supervisor. There, he performed research in solid-state digital circuits, investigating high-speed logic and memory techniques based on semiconductor and magnetic devices. In 1963, Mr. Rapp became a Member of the Technical Staff of the Electronic Research Laboratory of RCA Laboratories. There he explored integrated digital circuits based on metal-oxide-semiconductor, field-effect transistors. He transferred to the Defense Microelectronics activity of RCA at Somerville, New Jersey in 1965, and in 1966 was promoted to Leader, MOS Circuit Development. Mr. Rapp is the author of nine technical papers. He has contributed chapters to two recent books: MOS Integrated Logic Nets, Symposium on Microelectronics and Large Systems, Spartan Books, Inc., 1965, and Applications of Field-Effect Transistors in Digital Circuits, Field Effect Transistors, Prentice-Hall, 1966. He received an Outstanding Paper Award from the 1961 International Solid-State Circuits Conference. He has been granted three patents and has six other patent applications filed. Mr. Rapp is a member of IEEE, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi.

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A TWELVE-STAGE binary counter, capable of arbitrarily low counting rates, has been developed as a monolithic array of *p*- and *n*-channel MOS transistors.* An outstanding advantage of such complementary MOS circuits is their extremely small power dissipation. The cofabrication of both types of devices requires that both *n*- and *p*-doped starting regions be available, a requirement which was met within a single silicon chip by utilizing a diffused isolation region as the local substrate for the *n*-channel devices[1] (Fig. 1).

Implementation of conventional Boolean logic functions with complementary MOS transistors requires a dual series-parallel connection as in the *nand* gate of Fig. 2a.[2,3] Instead, the four transistors can be connected as in Fig. 2b to yield a circuit with switchable data paths. This *transmission-gate* circuit utilizes the bilateral properties of MOS transistors to transmit either *hi* or *lo* logic levels via a single data path.[4,5] For some applications, transmission-gate circuits are most efficient logic elements than Boolean gates. Binary counting is one such application.

SIMPLIFICATION USING TRANSMISSION GATES

The considerable simplification that transmission gates can produce is demonstrated by the following comparison. An original design for the binary counter, based on multi-input gates of the type shown in Fig. 2a required 336 complementary MOS transistors to perform the basic 12-stage counting function. Seventy-two more transistors were needed for resetting the counter—a total of 408 transistors. By contrast, the application of transmission-gate techniques reduced the total transistor count to 196.

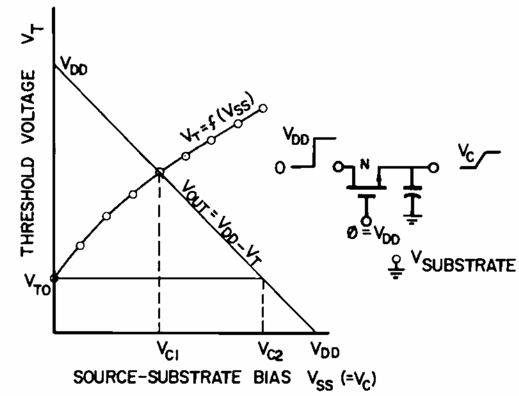

Fig. 3—Substrate-bias dependence of threshold voltage: effect on non-complementary transmission gate. Varying threshold causes transmitted V_{DD} level to be attenuated to C_{C1}. V_{C2} would obtain with constant threshold.

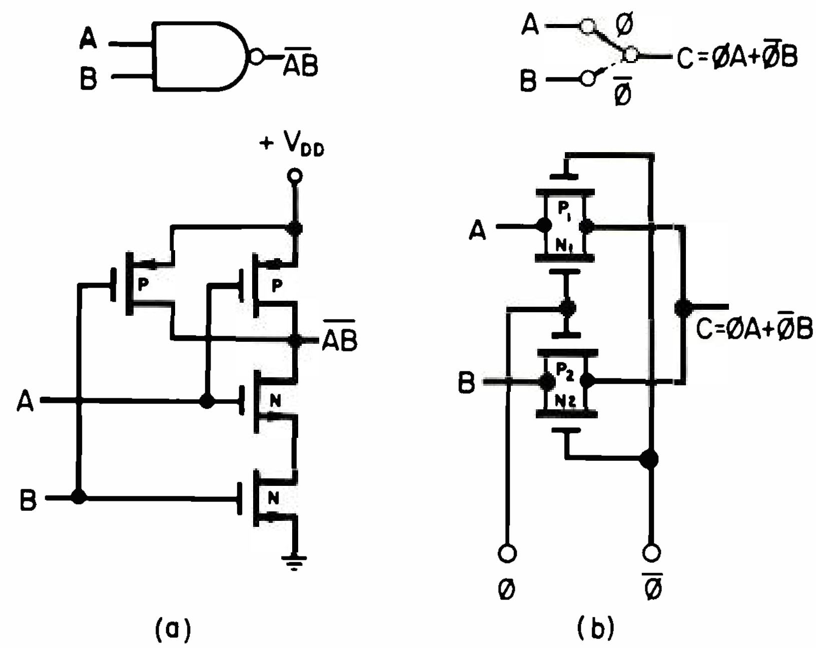

Fig. 2—Complementary MOS-gate forms (a) 2-input, positive-NAND gate. Requires dual series-parallel sections. b) Switchable data paths (transmission gates) A → C or B → C under control of θ. Approximate Boolean equivalent indicated.

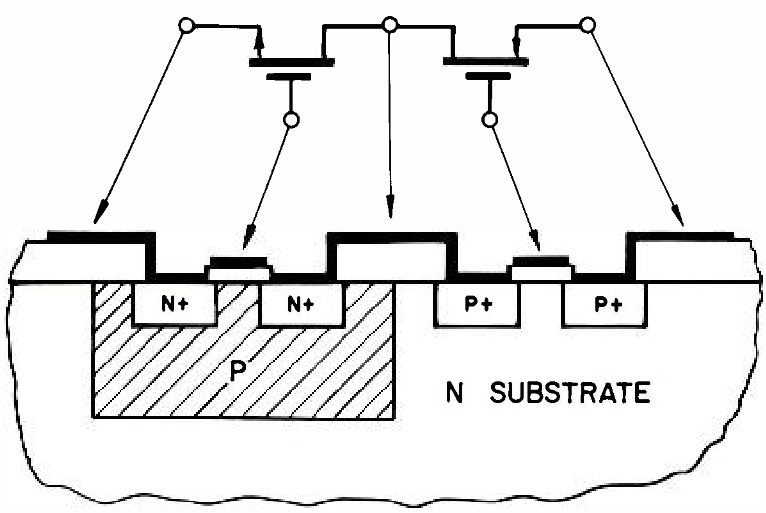

Fig. 1—Schematic cross-section of complementary MOS structure. Circuit symbols indicate corresponding metal regions of integrated circuit.

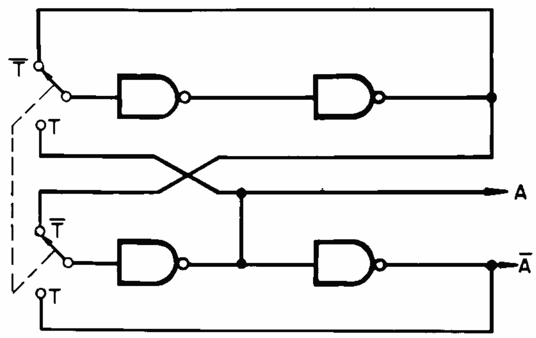

Fig. 4—Block diagram of counter stage. Inverted pairs are alternately latched into flip-flop. State is transmitted directly from upper to lower rank, inverted from lower to upper.

The transmission-gate circuit of Fig. 2b and the circuits in the binary counter utilize complementary transmission gates. Noncomplementary gates of the type described by Wood and Ball[4] would have further reduced the component count, but were found unsatisfactory for the following reasons:

Transmission-gate transistors operate either in a common-source or a source-follower mode, depending on the level transmitted. In the common-source mode, the level is transmitted exactly; in the source-follower mode, however, the receiving node can be brought only to within the transistor's threshold voltage, V_T, of the transmitting node. Moreover, V_T does not remain constant, but increases as the source voltage changes, because of a substrate-gating effect. Severe level attenuation then results, as illustrated in Fig. 3. The dependence of V_T on source-substrate bias occurs because the substrate acts as a second control electrode, modulating channel conductance by the junction-gate field effect, i.e., depletion-layer widening of a semiconductor junction. (The major portion of the channel of an MOS transistor is close to source potential and hence follows voltage variations of the source.) The resultant effect, reflected to the insulated-gate electrode, appears as a shift in V_T. The extent of the shift is related to the doping level of the substrate material, as described by Hofstein.[6]

BASIC BINARY-COUNTER STAGE

The basic binary-counter stage is formed by interconnecting two transmission-gate flip-flops,[5] as in Fig. 4, thus creating a type of two-count ring counter. With each cycle of the input signal, data are transferred unchanged from the upper to the lower rank and then back in inverted form from lower to upper rank. Two full input cycles thus are required for the output to return to its original state. The complete counter consists of twelve such stages plus two input-inverter stages. The inverter stages are required to generate the complement of the input signal and to control the input signal during reset.

Provision for resetting the counter to zero is achieved without additional transistors. The source of one *n*-channel transistor in each inverter-pair is tied to a common reset line (Fig. 5). During counting operation, the reset line is at ground potential and the inverter functions normally. Reset is effected by raising the line to supply potential (V_{DD}), thus forcing the inverter output level *hi;* however, the *n*-channel transistor operates as a source follower during this reset operation. Hence, it is subject to the signal-attenuation difficulties described above. By placing the *n*-channel transistors used for reset in their own *p* wells, however, these wells also can be raised to V_{DD} potential during reset. Proper reset thus is ensured.

Fig. 6 presents a photomicrograph of one of the counter chips. Preliminary counters have functioned well with supply voltages of 4 to 10 volts. Less than 100 microamperes total current is drawn at 8 volts. Reliable counting has been achieved with input repetition rates from DC to greater than 3 MHz.

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Fig. 5—Circuit diagram of counter stage. Reset is effected by raising local substrate (and source) of an N-Channel transistor in each inverter pair.

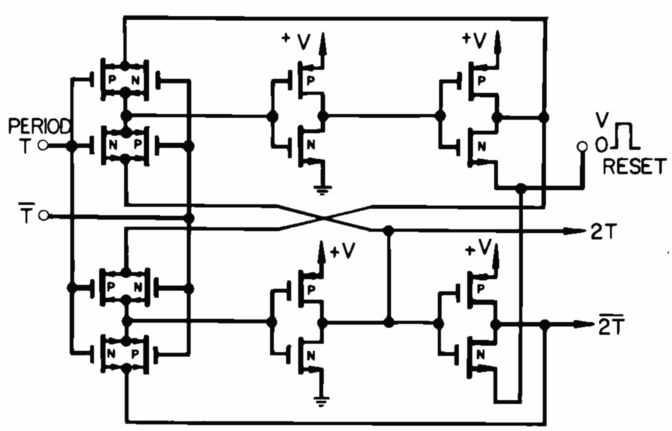
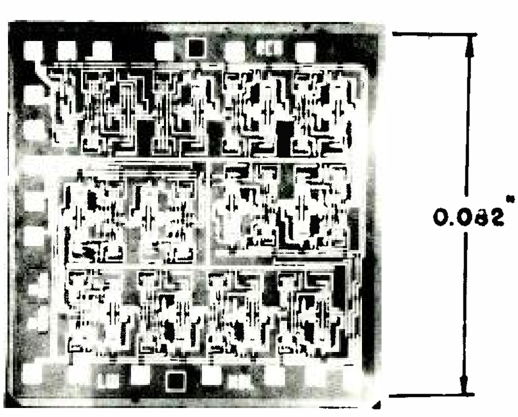


Fig. 6—Photomicrograph of complete, integrated, 12-stage binary counter. 196 MOS transistors (98 P- and 98 N-channel) are contained.



ELECTROFAX IN THE REPRODUCTION INDUSTRY

The reproduction industry, which includes office-copying, duplicating, and high-speed printing, is becoming aware of the potential benefits of electronic technology. The electronic and communications industry is also becoming aware of the contributions which it can make in this field. RCA, with its background in soft display and information handling, is in an ideal position to move into the hard-copy-reproduction area. A survey of the various reproduction systems is given with a description of RCA's Electrofax process and where it is now used. The office-copying market is currently the major user and is expected to continue its rapid growth. Many other areas appear promising for Electrofax applications, including non-impact printing for computer output, remote-station output devices for time sharing, multiple-copy reproduction for the duplicating field, and color printing. Continued research on the Electrofax coatings and toners and on new reproduction systems should provide products which can be exploited by the appropriate product divisions and by RCA's Electrofax licensees.

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The reproduction of graphic materials by copying or printing has been one of civilization's most profound technological achievements. While not as glamorous as space travel or other means of communication such as television, it is hard to imagine our present society limited to handwritten originals or soft CRT displays. Not only would we have lost much of our history but the dissemination of knowledge throughout the world would be limited or nonexistent. Printing or graphic reproduction is as important as any single element of our technology. Without it our present social structure would exist only with great difficulty.

RCA as a communications company is active in the production, transmission and presentation of real time information as in TV. It is also concerned with the creation, transmission, and presentation of information as non-real-time hard copy. Some of the methods used for hard-copy display are described below, together with RCA's current involvement.

MECHANICAL PRINTING

To reproduce large amounts of material cheaply we must have low priced masters which can be re-used many times and a method of transferring the information on the master to a cheap substrate. Contact printing on paper using liquid ink has been the answer but has required many innovations to reach its present state. Although hand carved wooden masters were used for reproduction as far back as 700 A.D., they were expensive and delicate to handle. Gutenberg is generally credited with being the first to use separate movable type around 1440. These could be assembled into page form to make the master. Once the master was used to print the required number of copies, the letters were removed from the "chase" and re-used. The master could be assembled by a printer instead of being the work of an artist.

While a simple concept to us today, the use of separate, movable letters was a major innovation and had far-reaching social implications. Once the spoken language could be reduced to printed form, order began to come out of the literature, and the widespread dissemination of new social and cultural ideas could become a reality. Language development became frozen once it was reduced to print.

The history of printing since Gutenberg's time has been mainly a series of mechanical innovations allowing the inked master to be used to produce copies at higher and higher speeds. Today's high-speed presses, the result of ingenious mechanical design, handle paper at speeds of up to twenty-five miles per hour. These presses use three basic types of master or plate to selectively deposit the ink on the paper. In a *letter-press* printing plate, the letters stand out about 40 mils above the base plate and are formed by a deep chemical etch of the substrate or by molding molten metal in a form. In *gravure* printing, shallow depressions up to 40 micrometers deep are chemically or mechanically formed on a smooth surface to pick up and hold the ink which is subsequently transferred to paper by contact. *Offset* printing makes use of the oleophilic properties of a surface to attract oil-based inks and the hydrophilic properties to repel the ink. The result is a flat printing plate. Each method has its particular advantages and disadvantages, and selection is based on the particular work to be done.

PHOTOCOPYING

In addition to the reproduction of material by mechanical contact, there is the equally important area of photocopying. This extends the technology beyond mechanical reproduction and includes all of the conventional and nonconventional

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photographic and optical methods for making an exact replica of an original. With it, copies may be made individually (as in office copying) or it may be used to form masters for duplicating (low-volume printing) or printing plates for high-volume reproduction. Photocopying is an important part of the printing field and is expected to become more important with the advent of computer composition and the need to convert electronic or optical serial output to parallel storage.

In photocopying, the image of the original is projected onto a photosensitive surface by reflection or transmission. The former is more convenient, since it places no demands on the substrate and the original may be printed on both sides. Ideally, each incident photon should be recorded as a separate event. Since the eye and most recording systems have a limiting resolution of about 1 micrometer, each photon should be recorded as a 1-micrometer grain or spot. Such a grain will contain about 10^{10} atoms. Since each photon will alter or effect only one or two atoms, some amplification is needed in the system. The ideal would be a gain of 10^{10}.

The second requirement of a photocopying system is the development and storage of the optical information. This may occur during a processing step, as in some photochromic systems; or, it may occur during the development step, in which case the latent image must be stable between exposure and development. In extreme cases, the information may be stored in some completely different form (such as magnetic tape) for later reproduction, with the amplification carried out by standard electronic systems onto a mechanically deformed surface which can be used as a printing plate.

The final requirement for a photocopy is its presentation. In photographic and office copying systems, this is done by altering the optical properties of the surface at the time of development to produce reflection or transmission images. In a magnetic system, presentation may be by a cathode ray tube for direct viewing or as a permanent copy by some secondary type of photocopy system. In printing, the image must be in a form which can be used to transfer the information on the photocopy master to ordinary paper. This may be by using the photosensitive surface as an acid resist for subsequent etching of the exposed areas as in gravure and letterpress or by altering the surface properties of the photosensitive surface to accept or reject ink, as in offset printing.

HISTORY OF PHOTOCOPYING

Silver halide photocopying is the oldest nonmechanical reproduction process. In 1839, Daguerre first demonstrated a practical photo process. In 1900, photostats were being made in this country and Europe; but they were slow, gave a white-on-black image, and were expensive. In the non-silver-halide area, Herschel demonstrated the blueprint in 1842. In 1920, it was shown that diazonium dyes exposed to ultraviolet light could be developed by ammonia vapor or alkaline solutions. This system is widely used for producing copies from transparencies, as well as a photosensitive coating for printing plates. It is slow and is seldom used for reflection copy, but has good resolution and is cheap.

Electrostatics also has an ancient history. Lichtenburg first produced patterns by electrical discharge in 1777. Ronalds made an electrographic recorder using a resin base in 1842. Swan showed[1] that insulating liquids could be repelled from charged areas to form images in 1897. (This latter method was "rediscovered"[2] in 1945, and is currently receiving much attention). Konig reported[3] on an electrostatic recorder in 1899 using a lacquer surface and a pointed stylus, and developed the images with a mixture of red lead and sulphur powders. One powder was negative and the other positive, and he was able to determine the direction of current flow by the type of toner which stuck to the image. The technical and patent literature is full of many novel applications of electrostatics in an age where instrumentation was so crude that our modern physicists and engineers would have been almost unable to work.

In the late 1930's, a number of these systems began to show promise for practical photocopying. Gevaert and Agfa in Europe, and Land in the United States, used diffusion transfer from silver halide films to produce copies. Carl Miller at the University of Minnesota (and now at Minnesota Mining & Mfg.) demonstrated thermography, which later became the basis of the Thermofax system. Chester Carlson received his original patent on electrostatic copying in 1938.

While few new machines or processes appeared during the 1940's, considerable effort was spent in research and development. There was particular interest in convenience copying—under 10 copies from the original—where the primary requirements were speed and simplicity.

During this period, the silver halide systems were modified and improved with respect to convenience and cost. These systems, using the diffusion transfer of undeveloped silver or the transfer of unexposed dyed gelatin, dominated the office copying market in the 1950's.

In 1954, Minnesota Mining & Mfg. introduced commercial machines using their Thermofax process. They were an almost immediate success, and within a year overtook and passed the silver halide systems in numbers of copies. Although the quality and spectral response was poor and special paper was required, the system was simple, clean, and foolproof. Thermography still has a substantial share of the office copying market, but its rate of growth is low compared to the electrostatic systems.

Battelle had undertaken development of Carlson's xerographic process in 1944. In 1947 Haloid began to support Battelle and subsequently purchased the rights to the process. The first commercial ma-

DR. DONALD A. ROSS received his B. Eng. degree in electrical engineering from McGill University in 1947. He worked with General Electric X-ray Corporation until 1950 doing application work in the medical and industrial X-ray field. In 1950 he joined the High Voltage Engineering Corporation where he worked on the design and use of high energy particle accelerators. From 1953 to 1957 he attended Yale University where he received the M.Sc. degree in 1955 and the Ph.D. degree in 1957 in physics. While at Yale he did work on radiation effects in biological and chemical systems using high energy electrons and gamma rays as well as work in nuclear physics using a high energy linear accelerator. Dr. Ross returned to the High Voltage Engineering Corporation in 1957 and was responsible for radiation applications in the medical, industrial, and radiation research fields. In 1958 he joined RCA Laboratories as Head of the Nuclear Reactor Group carrying on research work with the ndustrial Reactor Laboratory five megawatt nuclear reactor. In 1965 he became Head of the Electronic Printing Group (now a part of the Computer Research Laboratory) conducting research in novel methods of copying and printing by electrostatic and electromechanical methods. Dr. Ross is a member of the American Physical Society, Sigma Xi, and the American Association for the Advancement of Science.

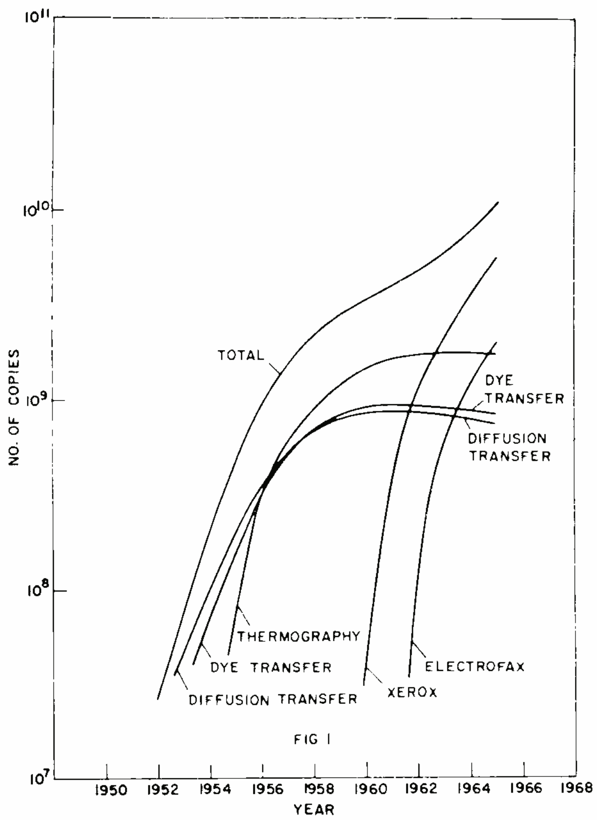

Fig. 1—Growth chart of Electrofax copies from 1950 to 1965.

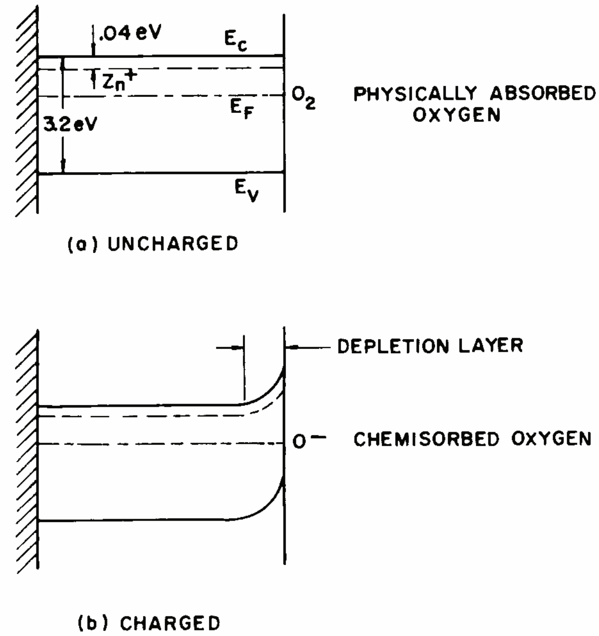

Fig. 2—Sketches showing the physics of the Electrofax layers; a, uncharged; and b, charged.

chines were produced in 1950 and during the next 10 years improvements were made in their operation. In 1960 the Xerox 914 was introduced and rapidly passed the other convenience copying systems in volume of copies per year.

Electrofax office copiers first appeared on the market in the early 1960's. RCA's interest in the office copying field came via facsimile. C. J. Young and his group had worked on facsimile systems for nearly 40 years. The early facsimile units used impact styli with carbon paper to produce the image. In the early 1930's, Young's group moved from Schenectady to RCA Camden. While in Camden they developed a wet electrolytic printing system which had many advantages over carbon paper. This was the system used for newspaper facsimile tests in the late 1930's and early 1940's when a full page of the New York Times was transmitted in a few minutes via a radio link. This was the "newspaper in the home," and while technically feasible, it never reached the market place.

The facsimile group moved to RCA Laboratories in 1942. In the late 1940's, Young's group began experimenting with electrostatic facsimile output systems. All of the systems then in use were slow, complex, and very large. It was felt that there must be a better way to produce dry copy electronically for high-speed facsimile. Since the image was to be formed optically, it required a photosensitive system. For simplicity, a photoconductive material should be in or on the paper. It should be white, nontoxic, cheap, stable with time, have a fast response to light, and produce permanent copy through external or built-in toners. In the early 1950's, H. G. Greig invented the Electrofax system[4] and a method to dye-sensitize the zinc oxide binder-layer used in the system so that it would respond to white light.[5] The initial description of the system by Young and Greig was published[6] in 1954.

As part of RCA's continuing research program, a number of prototype office copying units were built at RCA Laboratories to demonstrate the usefulness of the process and to serve as test vehicles for further technological developments. Many manufacturers recognized the merits of the Electrofax process. A number took out licenses and built machines for carrying out the process.

Commercial sales of Electrofax office copiers, together with Electrofax paper and other supplies, began in 1962. The growth of the use of this process has been as dramatic as Thermofax and Xerox. Fig. 1 shows the growth in numbers of Electrofax copies. The Electrofax machine population had reached about 85,000 by the end of 1965.

PHOTOCOPYING SYSTEMS

Of paramount importance in any photocopying system is the *gain*, defined here as the number of atoms affected by an incident photon. Secondly, the atoms should be fixed in their altered state so that the image is stable with time after final processing.

Silver halide is the highest-gain photocopying system in general use. The amplification is due to the chemical reaction between the developer and the silver ions. Each grain must absorb about 10 photons to form a nucleation site. The developer acts first at this site and eventually reduces all of the silver in the grain. Since a 1-micrometer grain contains about 10^{10} atoms, the gain in the system is about 10^9. Following development and fixing, the image is permanent. Either transparent or reflection copy can be produced and methods have been developed to couple dyes to the grains which selectively absorb white light and produce colored images. Unsensitized silver halide has a relatively wide bandgap and will respond only to ultraviolet light. Sensitizing dyes have been developed which can make the grain sensitive throughout visible spectrum. Because of the requirements of accurate process control, the coated paper is expensive, and development requires carefully controlled wet chemical processing.

A number of variations of this process are used for photocopying. Diffusion of unexposed silver halide is used to transfer the image from a light-sensitive negative master to an unexposed silver halide paper by wet chemical processing. Gelatin transfer is another process, developed by Eastman Kodak, which they call Verifax. The softened gelatin containing a dye is transferred to copy paper by contact after wet chemical processing. Multiple copies may be made from the master but fading may occur unless specially treated copy paper is used. These two systems dominated the office copying field until the introduction of the Thermofax process in 1954. Today they represent about 10% of the total office copier dollar volume.

Electrostatic Methods

The electrostatic systems use a photoconducting insulating layer as the light-sensitive element. In the Electrofax process, the layer is coated directly on the paper substrate. In the Xerox Corporation process, the layer is amorphous selenium deposited on a metal substrate. The layer is made photosensitive by charging it in the dark with a corona wire system. The charging unit consists of fine wires operating at 5,000 to 6,000 volts. The air around the wire is ionized and the ions migrate to the photoconducting surface where they are trapped. When fully charged, the layer has a charge density of about 10^{12} charges per square centimeter.

The Electrofax layer consists of a mixture of pure ZnO particles ranging from 0.1 to 1.0 micrometer in diameter laid down in an insulating binder. While other photoconducting powders can be used to form the layer, ZnO is an outstanding material for this purpose because it is white, photoconducting, bactericidal, nontoxic and cheap. The ZnO-binder mixture will work over a wide concentration ratio range and a wide range of thicknesses. For normal paper coatings, the layer is about half a mil thick and has a ratio of ZnO to binder of about 2.5:1.

Studies of the physics of the Electrofax layer were carried out in RCA's laboratory in Zurich as well as in Princeton.[7-10] A physical model which explains many of the experimental facts has been described by Amick[11]. It is considered to be a homogeneous *n*-type photoconductor with a bandgap of 3.2 eV and a carrier density of about 10^{14} cm^{-3} at equilibrium. The donors are considered to be interstitial Zn. In the unsensitized state, the bands are flat at the surface as shown in Fig. 2a. On charging with negative corona, the extrinsic surface traps (assumed to be adsorbed oxygen) are filled with electrons, and the resultant space charge forms a depletion layer at the surface as shown in Fig. 2b. The charge concentration on the surface is about 10^{12} cm^{-2} and the resistivity of the layer is about 10^{17} ohm-cm as measured by its decay-time constant.

On exposure to light, each photon with bandgap energy will form a hole-electron pair which will discharge one of the surface traps. For complete discharge about 10^{12} photons/cm^2 are needed. The quantum efficiency is believed to be limited to unity because of the blocking contact at the surface which prevents electron injection. The very short hole lifetime prevents effective hole injection at the paper-layer interface. Thus, no effective charge multiplication mechanism appears possible.[12]

ZnO has a band gap of 3.2 eV. Since high-intensity light sources with this energy are difficult to obtain, the ZnO is made sensitive to visible light of less than bandgap energy by adding sensitizing dyes to the layer. Since these dyes should not give the paper an objectional color, their concentration and the types used are limited. With these restrictions, it is not yet possible to make a white or near-white coating completely panchromatic, so that the effective quantum efficiency of the discharge process to white light is usually less than unity.

The real gain mechanism in electrostatic imaging systems is their ability to attract a very large number of atoms with a limited amount of charge. About 1,000 charges on a 1-micrometer toner particle are sufficient to make it adhere to the charged surface. Since a 1-micrometer particle has about 10^{10} atoms, the overall quantum efficiency—the number of atoms affected by a single photon—is about 10^7. This is confirmed by comparing the effective optical speed against a silver halide film of known ASA rating. Electrofax has an equivalent ASA speed of about 1. This is about 100 times slower than medium-resolution silver halide emulsions.

Organic photoconductors have been incorporated in an insulating matrix and used in the same way as the ZnO layer by charging, imaging, and toning[10]. They are currently more expensive than the ZnO binder system and more sensitive to the environment. There does not appear to be a real advantage to such systems for paper coatings at the present time, but they have potential since they would be lighter in weight than the ZnO layer.

The only other systems with a potential for high speed are those using chemical gain through free radical or polymerization chain reactions triggered by an incident photon. While much research is going on in this field, few commercial products have appeared. Control of the gain appears to be the problem. Techniques such as microencapsulation may help but it is doubtful if they will be competitive with existing systems in the near future.

A number of other photocopying systems which are now in use or have been proposed are listed below. All suffer from low sensitivity to light with gains of 10^3 to 10^4 compared to 10^7 for electrostatics and 10^9 for silver halide systems.

Thermography

Minnesota Mining & Mfg. has been the most active in this field. Their Thermofax process revolutionized the office copying field when it first appeared in 1954. An infrared or heat-sensitive paper is reflex-exposed, producing an image of the original. The gain is low because it is essentially a photochromic reaction, and only single molecules are effected by the incident photons. High-intensity heat sources are readily available however, so that the time per copy is relatively short. The method relies on local absorption of the infrared, which produces enough heat to develop the image. Since black copy absorbs most of the radiation while colored copy may absorb only a small fraction, the sensitivity to colors may be poor. In spite of these limitations, many Thermofax office copiers are in use and represent a sizable market.

Photochemical

Kalvar is a process developed by A. D. Little and Tulane University with the patents being assigned to the Kalvar Corporation. A thermoplastic film containing diazonium compounds is exposed to ultraviolet. The compounds decompose, releasing minute bubbles of nitrogen gas. When the film is heated the gas expands to form cavities about 1 micrometer in diameter producing an image due to scattered light. This process has been used to make contact copies of motion picture film and other types of transparencies. It is doubtful if it will be useful for office copying.

PIP (Persistent Internal Polarization)

This process was reported by Kalman and coworkers at N.Y.U. It makes use of light and electrical fields to produce polarization images. There are a number of variations in the process and it appears to have potential but so far little commercial use.

Photoconductive

Minnesota Mining & Mfg. uses a ZnO-binder coating on a conducting substrate which forms a resistivity pattern on exposure to light. The toner is electrolytically deposited to form the image. They have a color development process using this system as well as black and white. Exposures must be from a negative to produce positive copies.

Deformation Plastics

RCA, Xerox, and GE have been active in this field. The images are produced by sensitizing an insulating film, exposing it to light, and heating it to develop the image. The images appear in the form of ripples due to contraction of the softened surface or to crazing of the surface. E. C. Giaimo,[14] N. E. Wolff[15] and F. H. Nicoll[16] of RCA Laboratories have worked in this field. There are no commercial applications at the present time, although its use as a high resolution film is foreseen for video or data recording.

Photochemical

Diazo is a copying system where the incident photon causes the decomposition of a diazonium dye molecule. The image is developed and fixed by immersion in alkaline solutions or ammonia vapor. The speed is low since only the molecule where the photon is absorbed is effected. Since there will only be about 1,000 atoms per molecule the speed by our previous definition is only 10^3. Diazo is used extensively for engineering-drawing use where exposure is through a transparency. Enough light is available through the transparency to develop the image in a reasonable time but it is much too slow to be used for reflection type copying systems.

Photochromic

In a photochromic system the absorbed photon produces a change in the optical properties of the light sensitive molecule without a development step. If the activated molecule then absorbs light a direct image will be produced. There is difficulty in stabilizing the image, however. Continued exposure may cause the whole sheet to change color unless it is fixed. Systems have been developed where exposure to one wavelength of light will develop the image and to another will deactivate the unexposed molecules and fix the image. Photochromic systems have the potential of essentially molecular resolution and extreme versatility. Because of their slow optical speed, however, it is difficult to see their use in the photocopying field unless much more intense light sources in a suitable part of the spectrum become available. Lasers may solve this problem if it becomes possible to achieve adequate intensities in the appropriate spectral region at economical costs.

COMMERCIAL APPLICATIONS

Office Copying

Office copying is one of the most important uses of photocopying. It can be divided into two general areas; convenience copying where the demand is for under 10 copies and duplicating where anywhere from 10 to 10,000 copies may be required.

Convenience copying has been the area where major innovations have taken place over the past ten years. The total number of copies has increased[17] from about 500 million in 1955 to over 11 billion in 1965. The total dollar volume in 1965 was close to $550 million[17] and is predicted to reach $1 billion by 1969 or 1970. Fig. 1 illustrates the growth of the numbers of convenience copies over the past 15 years.[18] The rapid rise of the dye-transfer and diffusion-transfer system in the early 1950's is followed by the dramatic success of Thermofax in the mid 50's. The wet-chemical systems immediately began to lose favor. The introduction of the Xerox 914 in 1960 and Electrofax in 1962 were just as dramatic, and the electrostatic methods appear to be destined to take over the convenience copying field.

Duplicating

In addition to convenience copying for office use, there is the huge office duplicating field. As a means of comparison, over 11 billion copies were made in the convenience copying field in 1965 at a cost of about 5 cents each, totalling $550 million. In 1964, in the duplicating field, over 380 billion copies were made at a cost of about 1 cent each totalling $3.8 billion.[14]

No system has yet been able to offer major improvement over the presently used stencil, spirit, and offset processes. Electrofax coatings on paper and metal have been used to prepare offset masters, but the costs and convenience are not drastically different from the conventional diazo or dichromate sensitized plates. Xerox has made an attempt to cover both the convenience and duplicating field with an office copier capable of producing up to 500 copies of an original. It remains to be seen whether the higher cost per copy and the slower reproduction speed will be able to compete with the standard duplication methods. Minnesota Mining & Mfg. recently introduced a novel duplicating system called Adherography. Infrared light softens the surface of a master in the imaged areas, and minute amounts of an oil film are transferred to the copy paper. The oil film takes up an ink giving high quality black and white reproductions. Several hundred copies may be made from the master and its preparation is reported to be simple.

It is too early to say whether any of these systems will succeed in displacing the conventional processes. Each has its advantages and disadvantages. A great deal of research is being done to find the low-cost, low-volume printing system to revolutionize this market. To date it does *not* appear to be in sight.

High Volume Printing

At the high-volume end of the duplicating field, the area of true printing becomes of interest. The offset process is used in both areas, the main difference being the number of copies required from the plate and the type of press. Paper-backed Electrofax plates treated to make the background areas hydrophilic and the imaged areas oleophilic can make over 10,000 copies. The limitation in life is generally due to mechanical failure of the paper. Metal-backed Electrofax plates give longer life and are much faster optically than the conventional diazo or dichromate plates but are still in the development stage. They should give over 50,000 copies and have done so under controlled conditions. However, the advantage in optical exposure speed over conventional offset plates is offset by a slightly higher cost. Considerable development work is going on in this area. Successful Electrofax-coated plates which can be exposed in a process camera in seconds rather than requiring a full-size contact transparency and minutes of exposure could have a large market. Most small suburban newspapers are now printed by offset, and the demand for cheap, highly sensitive masters is bound to be large.

Letterpress plates are used for very-high-volume printing such as metropolitan daily papers. Electrofax coatings and toners have been developed which can act as acid resists and be used to prepare these plates. The advantage is the high optical speed (compared to other resists) which permits camera exposure and eliminates the contact transparency needed with current systems. The etching process still requires 10 to 15 minutes, however, and innovation in this part of the process is needed to compete with the conventional automatic hot-lead line-casting machines.

Gravure printing masters are usually cylindrical with shallow impressions of 10 to 40 micrometers which hold the ink. This process is the simplest, fastest, and (for very high volumes) the cheapest. The masters must be made to very high mechanical tolerances, however, and the process is only used for special runs. Since the need for speed in plate preparation is not as important as in letterpress for newspaper printing, conventional chemical resists are used and electrostatic resist coatings have limited use.

In addition to the mechanical printing systems, there are several electrostatic systems being used for special work. One reported by Stanford Research Institute uses a screen mesh through which electroscopic toners can be attracted. The surface to be printed lies between the mesh and a conducting plane. Since there is no contact, the process can be used to print on fabrics, and irregular surfaces such as glass or plastic containers.

A variation of this process has been developed by the Interchemical Corp. and the Battelle Memorial Institute where a gravure plate or roller has the impressions in its surface filled with a powdered ink which is subsequently charged by corona. When an electrical field is applied between the plate and the printing surface, the toner is attracted to the surface and is then fused by heat or chemical vapor. Again, this system has advantages for printing on fabrics and irregular shapes, but will require further development if it is to displace the more conventional mechanical methods for printing on paper.

The Gravure Research Institute has reported on the use of electric fields to electrostatically pull liquid inks from gravure plates. The process improves the transfer of inks from small grooves which might not otherwise make contact with the paper fibres.

SPECIAL USES OF ELECTROFAX

In addition to the uses described above for Electrofax systems, there are a number of special applications which may become commercially important in the future. These include color, high-speed reproduction of computer output using a special cathode ray tube, facsimile and multiple copy reproduction by transferring the image from the Electrofax master to ordinary paper.

The use of colored electroscopic toners was pioneered by RCA in the development of a system to reproduce maps for the U.S. Department of Defense.[19] Electrostatic images produced by transparencies representing different colors were made in sequence to produce multiple color maps. Subsequent development of techniques to make screened images by multiple exposure are being investigated for use as a proofing system for the color-printing industry. One system is already on the market and others will follow. The possibility of making continuous tone prints from color transparencies is also under active investigation.

Because of the limited optical speed of the Electrofax process, it is difficult to image directly from a conventional CRT. A special thin-window tube has been developed[20] which permits exposure of Electrofax paper at speeds of up to 20 inches per second for 8-inch-wide paper. This is much faster and quieter than possible with mechanical printers used for computer output and is much simpler than using silver halide emulsions.

The use of Electrofax for facsimile reproduction is old. However, there has always been the problem of image quality and the market for such systems. It is becoming evident that facsimile reproduction systems will be needed in a wide number of fields and Electrofax represents a simple, automatic output printer which can supply this need. Development work is continuing in this area.

One of the serious objections to the use of Electrofax for computer output has been the need for multiple copies. It has recently been demonstrated that dry powder toners, once deposited on a latent electrostatic image, can be transferred to ordinary paper by an opposing electrical field. This process can be repeated a number of times without destroying the original electrostatic image making it possible to produce a number of copies and still retain the optical sensitivity of the Electrofax process. In fact it is possible to remove the toner after the transfer process and re-use the Electrofax paper a number of times. With this technique, supply costs are no more than making multiple copies with carbon paper and the quality is much better.

These novel applications of Electrofax for reproduction purposes are still in the development stages. They hold forth the promise of providing the reproduction industry with systems which will provide hard copy in black and white or color from either digital or analog electrical input.

SUMMARY

The reproduction and printing industry is on the verge of major technological change. The ability to handle massive amounts of data electronically will alter the editing and composition function. Serial, real-time output from computers will be rapidly transferred to parallel storage in page form for proofing and editing. Some systems for such operations are now commercially available, such as in the convenience copying field. The next major area of innovation will be to find cheaper ways of getting the computer-generated information onto paper. It is felt that there are new and exciting uses of Electrofax in the rapidly expanding graphic reproduction field.

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HIGH-RESOLUTION DISPLAYS FOR PROCESSING AND DISTRIBUTION OF PICTORIAL MATERIAL

A Review

The type of high-resolution display technique to be employed is dependent upon the requirements for the display. "Hard" copy has been the preferred method of high-resolution display, but limitations of time and processing complexity are considerable, especially under conditions of continuous variation. Direct-view oscilloscope displays, while feasible, have not attained a high degree of refinement because of lack of a suitable market. This paper discusses various types of displays and the possibilities in several areas of high-resolution display devices.

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Two decades ago, television had tremendous and immediate impact in entertainment, news, and advertising, which in the last decade, has expanded into education and industrial applications. In general, the quality and standards for these applications are the same today as they were when television was introduced. Yet, the market can be expanded substantially if the quality can be improved without losing the inherent advantages of rapid and timely distribution of information. The most obvious new area is that of a distribution and display system as an accessory for computers and data storage. A more specialized and more demanding area is that of distribution, processing, and display of pictorial material. This is an area of special interest to RCA which will be discussed in detail in this paper.

Government agencies at all levels are the principal customers for high-quality pictorial systems. Military reconnaissance from aircraft and spacecraft has grown tremendously since World War II. Aerial photography is widely used by industry and by government at all levels for mapping and resource evaluations. The Federal Government is now seriously considering the development of a natural resources satellite to provide an inventory of crops, forest and geological resources, and other elements of national wealth. The Astro-Electronics Division (AED) pioneered in the development of meteorological satellites such as TIROS, now being used operationally. Imaging sensors are a most important tool in the early exploration of the moon and planets.

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In general, users have preferred photography to television because of its better quality, especially its high resolution. However, as the amount of the pictorial data has increased, transmission and handling have limited the utilization of the collected data. For example, in tactical reconnaissance, the targets are moving and the collected information is valid for only a short period of time. In other cases, the volume of data is sufficiently great to pose problems in the retrieval and transport of paper. There are techniques for the rapid processing of film and there are scanning devices to convert film information to video signals. Film recorders are also available. However, one begins to question the logic of such a system when it is compared with television, since this all-electronic system was designed specifically for sensing, transmission, and display in essentially real time.

RCA has responded to current requirements with the development of several high-resolution sensors. Dr. Otto Schade (of EC&D, Harrison) has demonstrated 8,000 TV lines with a 4½-inch return-beam vidicon (RBV) and AED is working with a 2-inch RBV having 4,000-line resolution. Developments are under way to produce 6,000 to 8,000 TV lines over the 1-inch-square format of the 2-inch tube. Over a period of six years, AED has developed dielectric phototape recording and demonstrated better than 80-cycles/mm resolution. This corresponds to a resolution of about 9,000 TV lines on a usable width of 55mm produced on 70-mm tape. A 35-mm dielectric-tape panoramic-slit camera has been built and space-qualified. Its sensitivity and dynamic range are comparable to those of good photographic film. These dielectric tape devices feature storage of information directly on the sensing element. Readout may be deferred for long periods and the readout rate may be tailored to fit within a communications bandwidth varying from a few hundred kHz to 20 MHz. Thus, TV sensing and electronic video transmission can be adjusted to satisfy a wide variety of requirements.

DISPLAY REQUIREMENTS

The wealth of pictorial data available is of no value until the information is transferred to a human being. Although pattern recognition and signal analysis techniques have been under investigation for many years, the only practical solution to date is a pictorial display that faithfully reproduces the scene. The display system, in addition to providing faithful reproduction, must accept information at sensor transmission rates and discharge information at rates compatible with the display device characteristics and with the demands of the user. In general, a buffer storage device is required for this purpose. This function can be performed by magnetic or dielectric tape. Hence, the display itself is the critical item.

In extracting information from a scene or display, a human interpreter performs four functions: scanning, detection, recognition, and orientation. Although a scene may contain a large amount of useful information, one interpreter is rarely interested in more than two or three things at any one time. To find these, the observer fixes on small areas subtending about 6 degrees of visual angle. Each fixation requires 0.2 to 0.3 second. It is apparent that a large area requires more time for scanning than does a small one. However, objects of interest are almost always associated with certain terrain features—boats are on water, vehicles are on or near roads, and so on. This tends to reduce the scanning time substantially as compared with the theoretical time required to scan a complete area. During scanning, the observer detects an object of interest and marks it for future analysis or immediately begins the analysis.

Recognition is somewhat more complicated, since the observer must determine shape and associate this with his background of knowledge. A reasonable approximation of the time required for detection (including scanning) and recognition is shown in Fig. 1. These times assume adequate resolution, brightness, and contrast to perform these operations with the unaided eye. (These factors will be discussed in some detail later, but we can note now that *detection* requires one or two resolution areas whereas *recognition of shape* requires from 10 to 100 distinguishable resolution areas.) Since the resolution capability of the eye is about one minute of arc, the recognition curve is displaced from the detection curve as indicated in Fig. 1. It can be seen from this graph that detection and recognition should be accomplished in about a minute for small images and in from 10 to 20 seconds for larger targets. In practice, photographic film interpretation usually requires more time primarily because film formats are too small and microscopes are needed to obtain a resolution observable to the human eye (i.e., the film resolution is greater than the capability of the unaided eye). Also, if the contrast in the vicinity of the image is insufficient, film processing may be needed to increase or stretch the gamma. Finally, since orientation is needed both to assist in recognition and to identify location relative to other objects in the scene, the display should be as large as possible for comfortable viewing at 12 to 18 inches distance. In summary, the viewing time per scene will be a few minutes nominally but may vary from 15 seconds to one hour.

It will be assumed that the resolution of the human eye is one minute of arc. This determination was made under a very specific set of conditions and hence, the value is not always accepted without question. Under some special circumstances, the eye can detect images subtending 30 seconds or less, while in others one minute is decidedly optimistic. Photo interpreters are demanding in their preferences, but they will accept one minute of arc limiting resolution for the unaided eye. This value subtends about 0.004 inch at one foot viewing distance, hence the display should have a resolution of 250 lines per inch. Only the central portion of the eye has this capability and for fixed viewing, the screen size should not exceed a 30-degree subtended arc. However, the viewer can move his head, and since a larger area will be required frequently for orientation, a viewing angle of about 60 degrees seems more reasonable. This results in a screen size of 14 to 16 inches square, providing 4,000 resolution lines in each direction. If it is assumed that most images of interest will be defined by 5 to 10 resolution lines, a screen of this size should provide sufficient additional information for orientation purposes.

Photo interpretation has been investigated primarily by the photographic community and hence some explanation is required to translate their standards into TV terminology. Resolution is usually measured by imaging black-and-white bar charts. Limiting resolution in cycles or line pairs per millimeter defines the spacing of bars in the finest pattern discernible by the eye or other measuring device. This is comparable, approximately, to the smallest sine wave pattern distinguishable on a display tube in one scan line. Each half-cycle is one resolution line. Kell (RCA Labs) showed that the number of resolution elements per unit length in the scanning direction must be less than the number of scan lines per unit length in the direction normal to a scan line by a factor of 0.7. Although this factor corresponds to the limiting resolution, picture quality is considerably degraded and hence a factor of 0.5 is a more conservative value. On this basis the raster should provide four times as many scan lines as there are cycles per scan. Finally, resolution is a function of brightness and contrast between the image and its immediate background. Ambient light is a part of the background, but since it can usually

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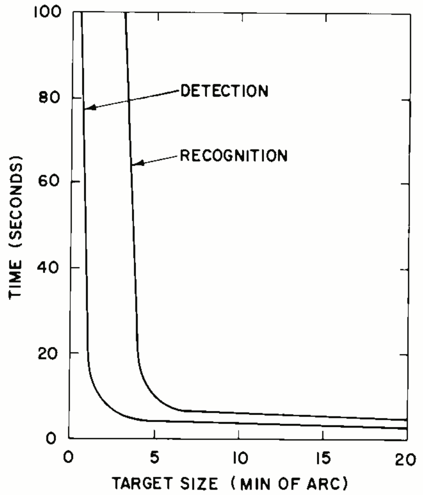

Fig. 1—Time factors for detection and recognition.

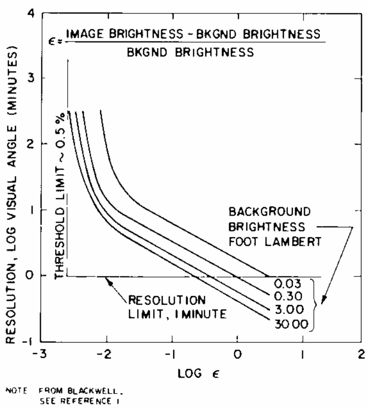

Fig. 2—Contrast threshold versus resolution for the human eye.

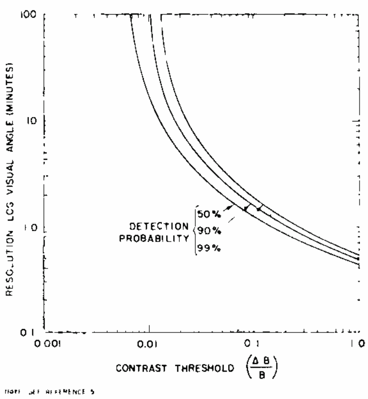

Fig. 3—Detection probability versus resolution and contrast threshold.

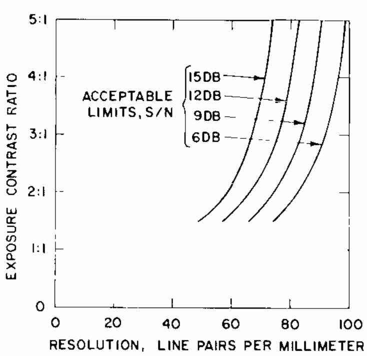

Fig. 4—Effect of signal-to-noise ratio.

be controlled to some degree, the ambient room light may be assumed in most cases to be 10 footcandles or less. Under these conditions background light in the vicinity of the display should not exceed about one footlambert and 30 to 50 footlamberts highlight brightness should be adequate.

Contrast requirements are considerably more complicated. Fig. 2 shows the relation between resolution and contrast thresholds at various brightness levels. Contrast thresholds are somewhat analogous to signal-to-noise. Schade has defined sensor limiting resolution as that resolution at which the signal-to-noise ratio is 3.5. This is approximately equal to 32 dB for large areas and it implies about 50 percent probability of detection for the smallest discernible area. Figs. 3 and 4 illustrate tradeoff values between contrast threshold, resolution limits, signal-to-noise ratio, and detection probability.

Finally, with regard to dynamic range, the eye senses the logarithm of light intensity. The range in a typical high-contrast glossy print corresponds to a reflectance ratio of 32, or ten equal $\sqrt{2}$ contrast steps. Electrically, this is a 31-dB range. Note that a 40:1 contrast scene, as viewed nearby on the ground, will not have more than 10:1 contrast from low aircraft altitudes and not more than 2:1 contrast from space altitudes. Hence, the display should have provisions for contrast stretch (that is, gamma manipulation). Magnification of 3 to 5 times is also highly desirable, since it is sometimes desirable to scan and detect at a lower resolution than that used for recognition.

Information retrieval time should be as short as possible. This applies whether the information is at a remote sensor connected to a display by a radio link, or located in a storage device near the display. However, a single 4,000-line picture of Kell factor 0.5 contains 16 × 10^6 cycles of information. With some allowances for margins, a minimum of 20-MHz bandwidth is required for retrieval time of one frame per second. It is reasonable to assume that retrieval times that are short compared with the viewing time would be acceptable. Thus, a 4-second retrieval time would bring the bandwidth within that commonly used in commercial TV. In some special cases, data-compression techniques can be used to reduce retrieval time or bandwidth by a factor of 5 to 10. In general, however, bandwidth and retrieval time are directly proportional and it is unlikely that retrieval times in excess of 5 seconds would be acceptable for a real-time display. High-resolution photographic recorders require 15 to 20 seconds for film development and the retrieval time is longer. The desirable characteristics of a high-quality display suitable for interpretation by the unaided eye can now be specified:

Area ....16 × 16 inches
Resolution ......250 TV lines/inch 70% response
......2,000 cycles/scan
......6,000 to 8,000 scan lines/square format
Brightness .....0.3 to 30 footlamberts
Retrieval time ...2 to 4 seconds for real-time system
...30 to 60 seconds for photographic reproduction
Viewing time ...Minutes normally
...1 hour maximum
Manipulation ...Gamma stretch
...5× magnification
Quality ....Free of flicker and shading error

STATUS OF DISPLAYS

Normally, a user is faced with the problem of selecting a few frames from a large file of information or a limited amount of data from a single frame. The advantages of a video display as well as a hard-copy record for these purposes appear to be obvious. When the desired information has been selected from a soft-copy display, a paper copy is often essential for filing and distribution. Thus, the ideal system should consist of a soft-copy display with a hard-copy reproducer attachment. Unfortunately, there is no high-quality soft-copy device.

A number of photorecording techniques have been devised for video recording; namely, facsimile, raster and line-scan kinescopes, laser recorders, and electron-beam-on-film recorders (EBFR). Excellent photofacsimile reproducers having the characteristics shown in Table I are available, and developments now in progress indicate that the preceding specifications (with the exception of input rates) could be met. However, these devices are electromechanical, and it is difficult to build into them flexibility in input rates and format. Raster kinescopes are available with the necessary resolution, but the brightness is barely sufficient for film recording. A line scan tube is available that has better resolution and brightness than the raster kinescopes but this device requires a precise film transport. The largest high-quality kinescopes have a 9-inch diameter, which provides about a 6-inch raster format. Optics are required both for the recording and for subsequent film enlargement. In general, copy lenses have a limiting resolution of 5,000 lines on axis with considerable distortion off axis and both resolution and linearity fall off at the edges of the kinescope. Thus full-format kinescope recording cannot meet the specifications.

For these reasons, high-resolution scenes have been segmented for recording and reconstructed in a photomosaic. This is undesirable, since considerable time is required to construct the mosaic but it does preserve the resolution over a large portion of the scene. Laser recorders may provide the best solution. These use rotating optics for scanning and a film transport for motion in the other direction. Recording should be possible up to a rate of 20 MHz. Since these devices are electromechanical, any specific design will be limited as to the range of rates and formats that can be accommodated. Also the rotating optics are difficult to acquire. The EBFR can be used in the line-scan mode or the raster-scan mode. When used in the raster mode, complete flexibility can be obtained in format and in rates in excess of 20 MHz. In this mode, the film and electron beam tube are contained in one vacuum enclosure. Users object to the time lost in degassing, but airlocks could be designed to minimize this objectionable feature. In the line-scan mode, the recording has been done through a Lenard window, apparently with some loss in resolution. In all film-recording systems, if the recording rate is greater than about 100 kHz, retrieval time is primarily that for film development. If high production rates are required, the first copy could be available in about one minute with subsequent frames being produced every few seconds.

No suitable direct-view kinescopes are available. There are a few 9- to 17-inch-diameter tubes capable of 1,500 TV line resolution with sufficient brightness and dynamic range to produce a good picture. To avoid flicker, the frame rate must be 40 to 50 frames per second or 30 frames per second interlaced. Thus, the beam modulation bandwidth is about 60 MHz and deflection circuits must operate about an order of magnitude faster than conventional TV rates. Circuits of this quality are being used with 1,500-TV-line tubes, but it is difficult to foresee how these rates can be increased by more than a factor of two. The more fundamental difficulty is that of brightness. As the resolution increases, the beam spot size must be reduced and the scanning rate must be increased. As a consequence, insufficient energy is transferred to fully activate the phosphor. It seems evident then, that some storage must be incorporated in the display tube. A phosphor persistence of about 4 seconds might be used, but available high-persistence phosphors have poor resolution and poor gray scale. Direct-view storage tubes retain the image on a mesh. They have the same limitations and, since there are some problems in mounting the mesh, the available tubes are made only in small sizes. There is no evidence to indicate that one or the other of these methods could not be used if an effort were directed toward the problem.

Photochromics appears to offer another potential solution. Some of these materials can be triggered with ultraviolet, viewed in ambient light, and erased thermally. The triggering energy is about 0.5 watt-second per square inch or about 150 watt-seconds for a 16-inch screen. If the retrieval time is two or three seconds, the power requirements become quite modest. However ultraviolet light sources are most inefficient (much less than 0.1%). Either filtered incandescent lamps or lasers are possible sources. Laser technology is relatively new and it may be reasonable to suppose that ultraviolet-laser efficiency can be improved.

Direct-view device development has lagged because of a lack of an obvious market, rather than because of any insurmountable technical obstacle. However, this market is growing. For the high-quality pictorial display discussed here, the government could use an estimated 1,000 units. This could vary by a factor of 10 either way, depending on price, size, and operational complexity. There is also a growing demand for a device capable of displaying text material generated at computers or remotely located sensors. For this purpose, an 8-by-10-inch, 100-line-per-inch display would be adequate. Since a system of this type has the potential of reducing a tremendous volume of filing, reproduction, and distribution, the market in this case is virtually unlimited.

CONCLUSIONS

High-quality hard-copy reproducers are within the state of the art. Early models of such devices are available now and continuous improvement may be expected in the near future, directed primarily toward greater convenience and reduced cost.

High-quality soft-copy devices are not available, but appear to be within reach technically. Although a substantial effort may be required for this development, equipment could be available within three to five years.

The market for *direct-view displays* is at least as large as the present one for office copying machines. If cost, size, and reliability are kept within reasonable bounds, it should be almost unlimited.

Although the pictorial reproducers discussed in this paper represent an extreme in quality, the competition in the direct-view display area will be keen and quality will be an important factor in determining sales levels.

TABLE I—Photo Recorders

	Facsimile	Kinescopes	Laser Recorder	EBFR
Resolution lines	800 to 8,000 line/scan	5,000 TV lines	5,000 to 10,000	5,000 to 10,000
Gray Scale, $\sqrt{2}$ steps	10	8	15	15
Format (square)	8½ inch	4 to 6 inch	5 and 9 inch	70 mm and 5 inch
Brightness	—	Very low	—	—
Retrieval time*	3 to 20 minutes	minutes	1 to 2 minutes	3 to 5 minutes
Manipulation	Gamma	Gamma magnification	Gamma	Gamma magnification
Problems	Low rates; inflexibility	Low brightness, format size, optics	Limited flexibility	Degassing

* Retrieval time includes exposure plus film development time.

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CONCEPTION AND USE OF SPECTRA 70 MULTILAYER BACK-PANEL WIRING

The heart of the Spectra 70/45 computer system is the multilayer printed-circuit back plane, or "platter." These platters provide the printed backplane wiring, controlled electrical impedance, and the necessary electrical shielding. They also house the printed-circuit logic cards and intraplatter cable harnesses required to connect all elements of the system.

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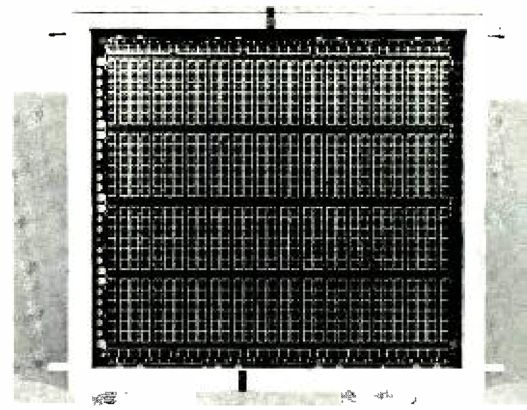

Fig. 2a—A basic platter before assembly.

THIS paper describes the various parameters of the multilayer platters, printed-circuit plug-ins, integrated circuit packages (ICP), connectors, and cabling interconnections used to package the Spectra 70/45 System. The basic system consists of the basic processing unit (BPU), the main memory (MM), the read-only memory (ROM), and the scratch-pad or fast memory (FM).

Of significant contribution to this design has been the use of the design automation programs; these and the use of existing computers have aided design engineers tremendously in designing the Spectra platters from basic ground rules to finished product. This was accomplished by output data for use by design engineering, manufacturing and testing groups.

The basic platter is used for all blocks of logic. The BPU, MM, ROM, and FM are all housed on individual platters and are arranged in modular-type building blocks. The basic platter (Figs. 1 and 2a) specifications are as follows:

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1) The size is approximately 17 x 17 inches x 0.100 inch thick.
2) There are approximately 16,000 plated-through holes available, of which 8,500 are typically used.
3) Printed signal lines are 0.010 ± 0.002 inch.
4) Plated-through holes are 0.040 ± 0.003 inch.
5) Two outside signal layers, orthogonal to each other.
6) Impedance = 100 ohms ±10%.
7) Three internal voltage and ground layers.
8) Houses 130 connectors; up to 104 for logic cards, and up to 26 for interconnection cables.
9) Voltage feed is by large plated-through holes, symmetrical on both sides of the platter.
10) Mounting is by insulated screws and hardware.

PLATTER FABRICATION

Figs. 2a-2d illustrate steps in platter fabrication. Fig. 2a shows a bare platter prior to assembly of components. The white markings indicate what positions are used for mounting connectors. The coded alphanumeric numbering is used for both an assembly aid and trouble shooting. Markings are on both sides of the platter. A solder resist (green pattern) coating is applied to the entire background surface except plated-through holes.

Testing

After fabrication and prior to assembly, the platter is 100% tested for continuity, opens, shorts, and grounds on an automatic platter probe tester. Here, a known platter of the same type is used as a standard and a comparison test is made between the two. If any discrepancies are noted, an automatic print-out is provided.

Assembly

The platter is now ready for assembly with connectors and blocks of terminating resistors as shown in Fig. 2b. There are two basic types of connectors. Type one is the basic logic plug-in connector, and type two is the harness connector used to interconnect platters. The connectors are mounted on ½-inch centers in four vertical rows containing 30 connectors per row. In addition, the top and

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Fig. 1—Author Gus Gaschnig holds a Spectra 70/45 multiplayer printed-circuit backplane (or "platter"), illustrating its appearance before IC plug-in boards are assembled to it. In his left hand is a typical IC plug-in. White outlines on platter are to guide plug-in assembly. In background are platters in place in a Spectra 70/45 rack.

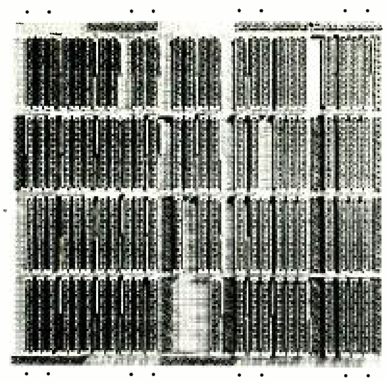

Fig. 2b—Platter assembled with connectors and terminating-resistor modules.

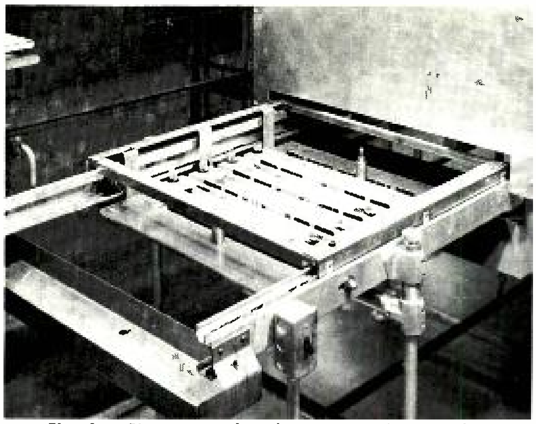

Fig. 2c—Platter entering the wave solder machine.

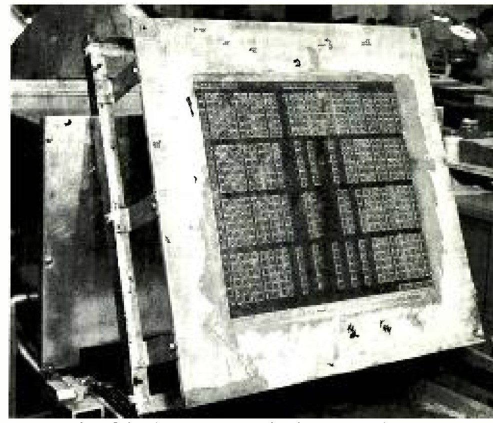

Fig. 2d—Platter at end of wave solder cycle.

bottom horizontal rows have 5 harness connectors each. Each row can have up to 26 logic connectors and 4 harness connectors, giving a total of 104 logic and 26 harness connectors. Mounted between connectors both vertically and horizontally are terminating resistor modules. Space for 156 is provided, and average useage is approximately 50 per platter.

Soldering

Originally, solder preforms were used to provide all solder connections. This was achieved using a solder preform setter plate and vibrator. When preforms were in place, a controlled stream of hot air was passed over the protruding connector pins and preforms and the solder joint made. This method has been replaced in production by an automatic wave solder operation. Fig. 2c shows an assembled platter ready to be soldered. The platter is passed through this equipment which provides pre-heating, soldering, washing, and drying. Solder is drawn up into the plated-through holes and leaves a thin coat on the connector pins. Fig. 2d shows a platter just after being soldered. Final inspection and touch-up is next performed and the platter is then ready for further testing.

Testing After Assembly

After assembly, the platter is placed on an automatic platter tester and checked using a paper-tape input provided by the design automation programs. Again the platter is checked for continuity, opens, shorts, grounds, and terminating resistors. An automatic readout device provides for recording of any discrepancy.

DISCRETE WIRING

Some platters require the addition of discrete wire over the printed wire due to printed wire density (Fig. 3a). Following a prescribed set of wiring rules, both single wire and twisted pair wire is used. A #26 AWG, thin-wall Teflon*, Nylon*-insulated solid wire is used. This is wired by wire-wrap techniques over the pins of the connectors, and dressed close to the surface of the platter, using a modified wrap.

After completion of wiring, the platter is again tested on the automatic platter tester.

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Approximately 90 to 95% of wiring is achieved by the printed lines and the balance by discrete wires. Some platters have no discrete wiring. Provisions are also available to make any changes by adding wires since the pins of the connectors can accept more than one wire-wrapped connection.

The completely wired and tested platter is then ready for mounting in the platter frame (Fig. 3b).

"Faston" voltage clips are next fastened to large plated-through holes on either or both of the edges of the platter. Normally, each of the four rows of platter connectors have voltage connections fed independently. The clips provide for a jumper wire to be inserted between the voltage feed holes of the platter and the DC voltage distribution bus which is mounted on each of the three platters. Each platter is then mounted in one of three vertical positions in the platter frame. Insulated hardware is used in mounting and the platter assembly is now complete, ready for insertion of logic plug-in boards and interconnecting cable harnesses.

Fig. 3a—Assembled platter with discrete wire added.

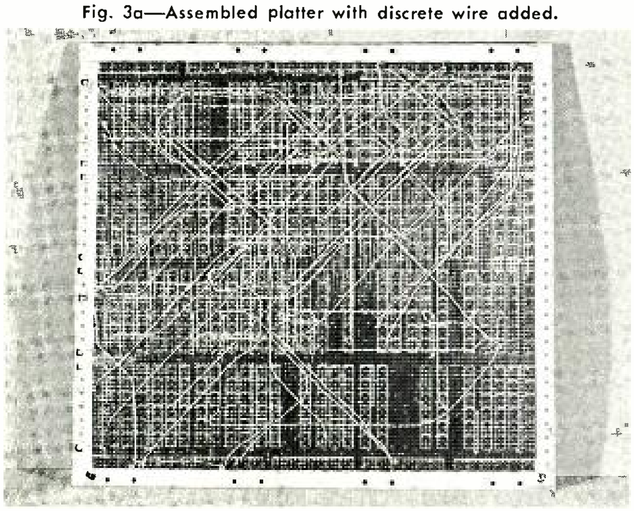
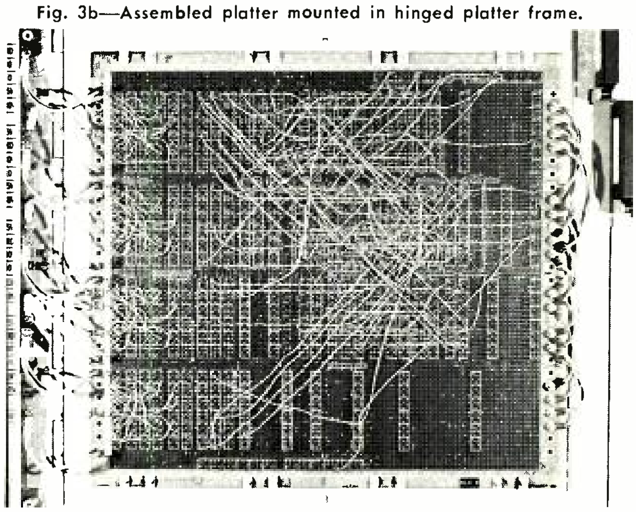


Fig. 3b—Assembled platter mounted in hinged platter frame.



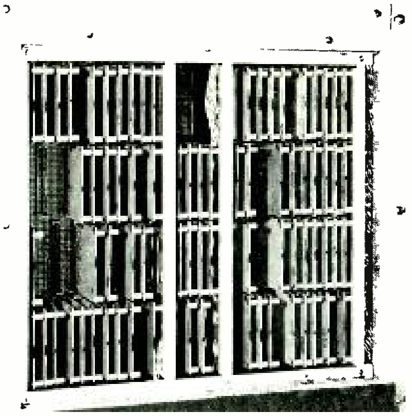


Fig. 4a—Platter mounted with plug-in boards in position.

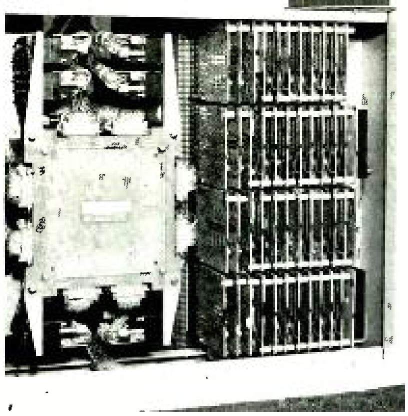


Fig. 4b—Main high-speed memory (MM) bank shown mounted to platter.

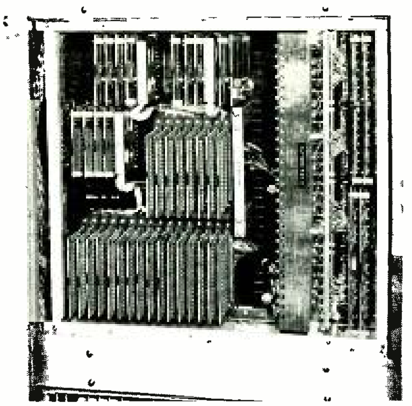


Fig. 4c—Read-only-memory (ROM) with circuitry mounted to platter.

MODULAR USE

Platter assemblies form the basic building block of the Spectra 70/45 system. The same basic size platter is used for all designs. Fig. 4a shows the plug-in side of a platter used in the BPU. Note that only plug-in boards are used in this assembly.

The MM uses plug-in logic platters similar to the BPU. In addition, a memory stack platter is used which houses both memory plug-ins and a magnetic-core memory stack (Fig. 4b). The memory stack is readily installed and removed from the memory platter by use of connectors. This unit is used to expand the memory size from 16.000 to 256,000 bytes.

The FM is similarly housed and provides for 512 eight-bit bytes. The read or access cycle is 120 nanoseconds, operating in a linear-select fashion, and has an overall cycle time of 300 nanoseconds.

The ROM (Fig. 4c) is also housed on a platter. Each ROM is composed of a set of two platters. ROM-E and ROM-O. Up to three sets of ROMS can be added to each 70/45 System. Again the versatility of the basic platter design is shown in this application.

One typical platter frame (Fig. 4d), therefore, has the capability of housing a variety of platter types in a subassembly three platters high. The 70/45 standard rack is 22 inches deep, 48 inches wide. and 62 inches high, and its internal structure accommodates 18 platter assemblies. Six platters are mounted in a central fixed frame assembly with access to both sides, and three platters are mounted on each of four swinging frames. Therefore. in a cubic volume of approximately 20 cubic feet, the entire 70/45 BPU and memories are housed.

Additional memory expansion can be accomplished by the installation of a standard half-rack measuring 22 inches deep, 24 inches wide, and 62 inches high or by extra full-size racks.

PLUG-IN BOARDS

The plug-in circuit logic boards are one of the basic building blocks of the Spectra system. The Spectra 70/45 system uses monolithic ICPs for all the basic logic functions. The plug-in board (Fig. 5a) measures approximately 3 x 4 inches and is 1/16 inch thick. There are two types of boards. One is a double-sided board; the other is a three-layer board having an internal ground plane. Both use plated-through holes for interconnections. Printed, gold-plated contact fingers are used to make reliable contact with the printed circuit connector. The plug-in is designed to accommodate up to 16 ICPs. Each ICP contains 2 gates; therefore, up to 32 gates per card are available. In addition, ICPs are used having other logical functions.

One of the main requirements was that ICPs had to be inserted to the boards in the same manner as conventional components and then wave soldered. After an unsuccessful survey of the field for an automated method of attaching ICPs, a design project was started to accomplish this. The project was completed; a prototype unit built, tested, and used to assemble boards for three prototype systems; and production equipment built.

Fig. 5b shows a typical semiautomatic tool used for cutting and trimming the leads of a standard 14-lead flat pack. The leads are trimmed in a back-to-back

Fig. 5a—Plug-in board with 16 ICPs mounted.

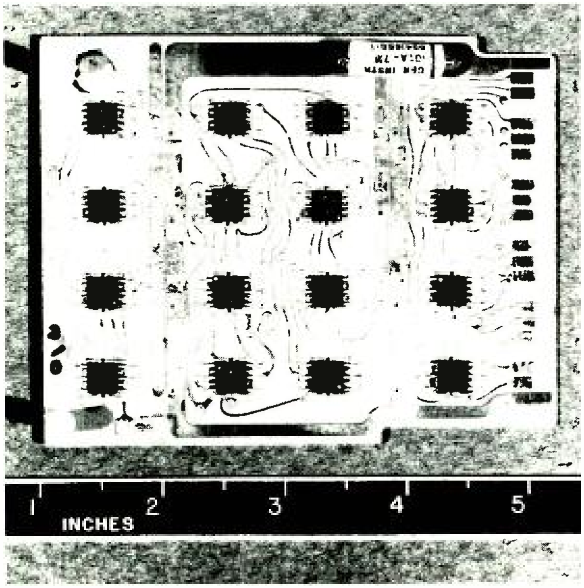
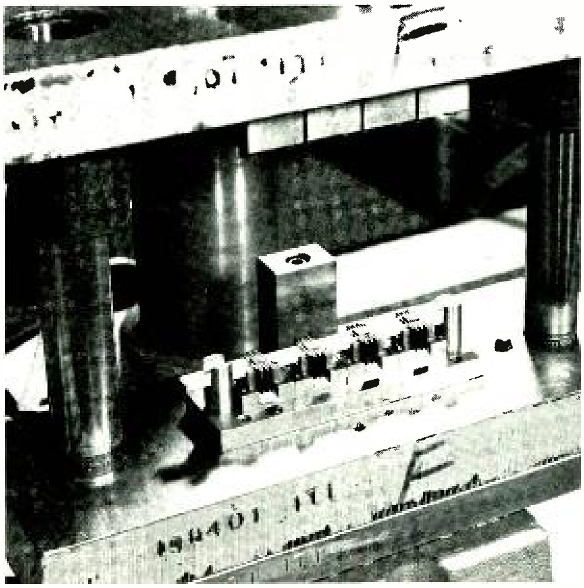


Fig. 5b—ICPs shown in cutting and trimming die after operation.



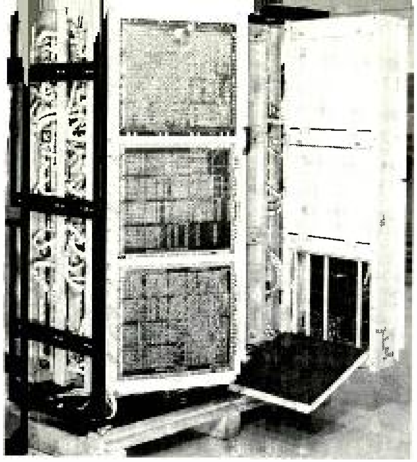


Fig. 4d—Typical hinged platter frame shown with one access door open.

configuration of 4 to 4 and 3 to 3. The trimmed flat packs are then inserted into a second tool (Fig. 5c) which bends the leads. A plug-in board is then inserted into place on this machine, a front lever activated, and the ICPs automatically raised up into the matching holes of the board and the leads wiped over. Fig. 5d shows a view with the board removed.

PLUG-IN CONNECTORS

A highly reliable, miniature connector was designed for use with the plug-in board. Exhaustive tests have proven the reliability of this approach. The contacts of the connector are designed using a welded gold ball as the interface between the connector and printed board. The gold ball provides low cost but still gives a gold-to-gold interface between mating units. The contact lateral force of 2 to 4 ounces was met initially and after 500 insertions. The contact design uses a preloaded design concept.

The contact extends through the Lexan molded body and is designed to allow two functions. First, the end is tapered, which permits easy lead-in when inserting into the platter. Pin-to-pin dimensions are held to the same tolerance as hole-to-hole spacing within a connector configuration on a platter. Secondly, the length of the pin was designed to accommodate up to three #26 AWG wires for use in prototype wiring, testing, and de-bugging. The connector is also designed so that if necessary, any pin may be removed from a completed platter assembly of over 4,000 pins. In addition to logic signals, pins are provided for connection to internal voltage and ground planes (layers).

Since the assembled platter is wave soldered, the pins of the connectors are coated with a thin coat of solder over the tin-lead plating. Exhaustive testing of wire-wrapped connections over solder-plated 0.020-by-0.030-inch rectangular pins under adverse environmental and mechanical conditions has proven this technique a success.

CABLING INTERCONNECTIONS

To interconnect any logical function on a platter to another in the system, cable harnesses are used. Fig. 6 illustrates a typical interconnection between platters on a hinged platter frame and the fixed platter frame. To accomplish this, a different platter connector called a *harness connector* is used. This design utilizes a two-piece connector, with half of it mounted on the platter around the periphery of the platter. This half has the interface contact in the form of a tuning fork design with the tail end approximately the same as the plug-in connector. The mating half of the connector houses a crimp-type, snap-in contact formed in a male blade. This half makes contact with the tuning fork contact. A maximum of 36 signals can be transmitted on any one of these connectors.

All harnesses are made up on an individual basis and pretested. The harnesses are then installed in the basic rack in a predetermined sequence, starting with the harnesses that contain multi-ended connectors and finishing with harnesses have a "one-to-one" connector configuration. A typical system may use up to 40 harnesses for a basic system plus an additional 40 for all optional features that can be added directly in the field at the customer's installation. All harnesses are designed to be readily expanded or changed by the use of separate, bundled wire. An impedance of approximately 100 ohms average is maintained over all harness wiring.

CONCLUSION

This paper has outlined the various parameters of multilayer printed circuit back panels, the hardware associated with them, their use in a system, and interconnections.

As computer speeds increase in the near future, packaging density becomes a bigger problem, and further advancements of today's known techniques are presently being pursued. The entire concept of interconnections presents a challenge to the design engineer, since to attain higher and higher speeds, packages become smaller and must be mounted closer together.

Present "state of the art" techniques in printed circuitry must be advanced so that tomorrow printed circuit concepts will be as common to manufacturing processes as are today's processes.

To achieve density such that three of the typical platters described in this paper will be compressed into one platter and still retain all features, is a near future challenge.

Fig. 5c—ICPs shown in position prior to forming operation.

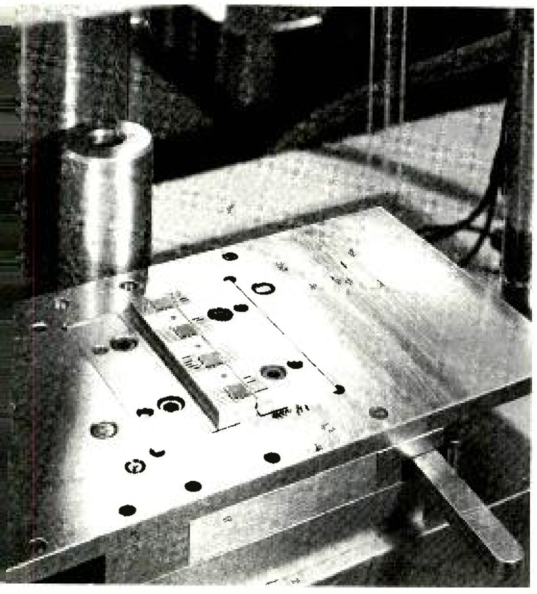


Fig. 5d—ICPs as they would appear just before inserted into a printed circuit board.

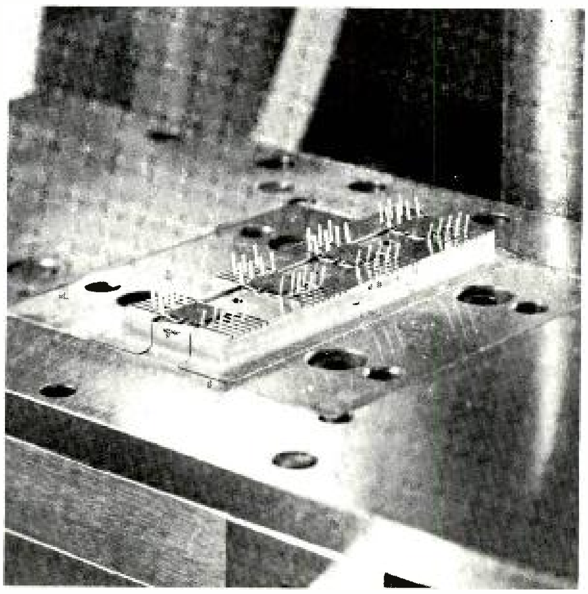


Fig. 6—Typical interconnecting cable harness between platter frames.

STANDARD MEMORY INTERFACE IN THE MULTIMODULE COMPUTER SYSTEMS ENVIRONMENT

A standard memory interface can ease the problem of future system growth in a multimodule computer. This is especially significant in view of the rapidly increasing demand of time-sharing technology. With such an interface, the processor and memory units are standardized, thus enhancing system maintainability and flexibility.

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In the growing technology of time sharing, computer systems are approaching a new stage in which faster processors and massive hierarchical memories will be integrated into a system hardware base. The demand for processing and storage capabilities of a computing system will be varied from various groups of users. In addition to the widely different demands in computing and storage capabilities, the users will expect to be served by highly reliable computer systems. These demands from the users can be best answered by a computing system with multiple module structure.[1] The multiple processing modules and memory modules in the future system architecture will provide system capability to accommodate multiple programming, multiple processing, and multiple response to multiple users.

STANDARD MEMORY INTERFACE CONCEPT

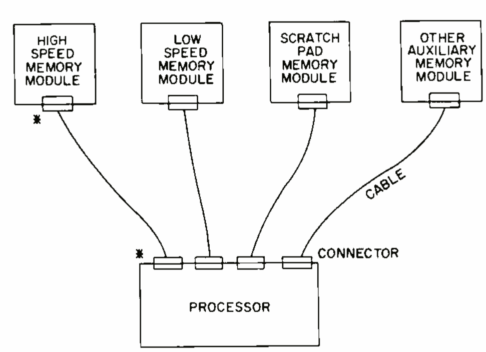
The multimodule approach in a computer system is a familiar one,[4,5,6] and there are almost as many variations in system modular configurations as there are multimodule systems.[2] However, the processing modules and the storage modules (memories) compose the heart of any computer system. Therefore, an effective communication must be in existence among the processing modules and memory modules. The existing operational interface of processing and memory modules varies from system to system. But with the increasing interest in multimodule systems plus the adaptation of standard input-output interface by several major computer manufacturers, the question of the necessity for a *standard memory interface* is a natural one. The standard memory interface provides a standard set of signals for the operation between any one processing module and memory module in the system. The processing modules and memory modules can be connected directly as shown in Fig. 1 or indirectly through a memory switching unit or units as shown in Figs. 2a and 2b at a standard memory interface. The acceptance of a standard memory interface provides many advantages:

From the customer's point of view, the advantages would be:

1) *Serviceability and Maintainability.* Technical training of service personnel can be minimized in the memory area as the relationship between the processor and memory units are standardized. This also leads to easier maintenance and direct labor saving.
2) *Factory Repair.* Complicated repair would not be necessary in the field. The individual processor or memory module becomes a black box and can be removed for proper attention in the factory.
3) *Upgrade or Downgrade of the Existing System.* As the customer's requirements changed, the standard memory interface offers the customer flexibility to change the elements in the system without having to go to a complete new system.

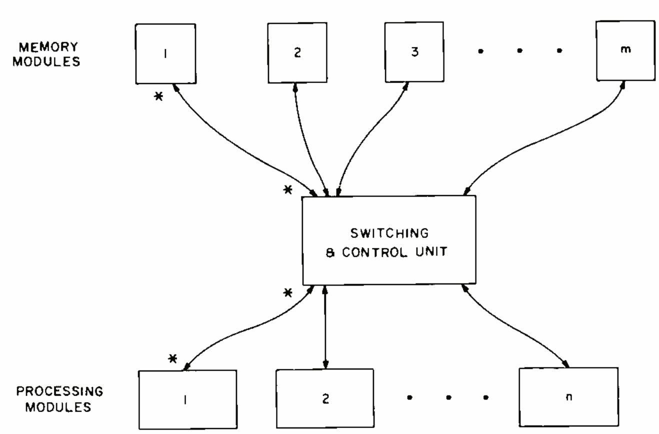
Final manuscript received March 15, 1967.

Fig. 1—Block diagram of computer system without memory switching unit.



* LOCATION OF STANDARD MEMORY INTERFACE

Fig. 2a—Block diagram of computer system with a memory switching unit.



* STANDARD MEMORY INTERFACE

From a marketing point of view, the advantages would be:

1) *System Configuration.* The system configuration can be changed to meet different customer's requirements, such as additional processing, memory or switching units.
2) *Replacement.* With standard memory interface, replacement of processor or memory unit would be greatly simplified.
3) *Product Reconfiguration.* Older or out-of-date products, can be used to form new configurations. This offers the advantage of extending the life of obsolescent products.

From an engineering point of view, the advantages would be:

1) With definite interface boundaries, the designers could optimize their design.
2) Uniform control logic could be derived from the Standard Memory Interface.

STANDARD MEMORY INTERFACE TRADEOFFS AND ANALYSIS

In order to establish a standard memory interface, the conceptual requirements were established as follows:

1) *Dynamic system reconfiguration*—proper and sufficient signals must be provided for operation in a multiple module switchable structure.
2) *The number of interface lines and signals must be kept to a minimum for both data and controls.* Multiple sets of Standard Memory Interface lines would be used to meet the switching requirement in the multiple module structure.
3) *Asynchronous operation*[3]—which could accept memory speed variation, processor speed variation, system cable variation, overlapping and simultaneous operation and switch and control variations.
4) *Concurrent memory module operation among multiple interfaces*—the Standard Memory Interface should not be the limiting factor in overlapping and simultaneous operation among multiple modules.
5) *Modular for data size variation*—the construction of Standard Memory Interface physically should be modular in structure for the maximum predetermined number of bits transfer.
6) *Adaptable for all data type of memories such as scratchpad, high or low speed memories etc.*—for some memory type, a subset of the total Standard Memory Interface signals might be used.

Trade-offs and analysis of the above system criteria involved an investigation in four conceptual aspects: Memory addressing, data transfer, switching and error detection.

MEMORY ADDRESSING AND DATA TRANSFER ASPECTS

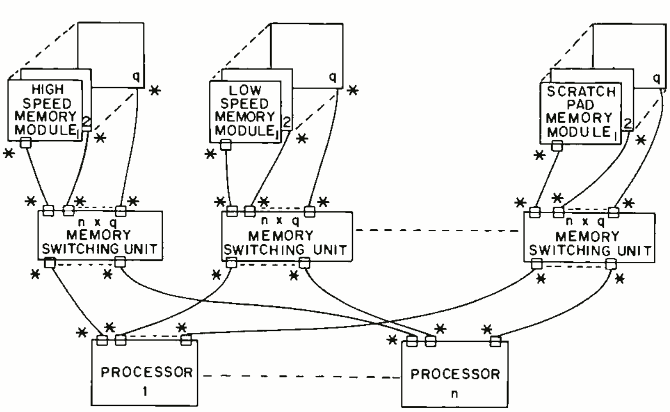
In order to analyze the memory addressing and data transfer aspects under the guide line of the above system criteria, two major questions must be answered: *system timing* and *interface configuration.*

System Timing

There are two approaches to the control timing in the standard memory interface signal; one is a constant-pulse-width approach, and the other a command-and-response approach. With well defined system components, the constant-pulse-width approach will be the most efficient in the processor cycle timing requirements.

However, efficiency will be decreased as the speed range of the various modules within the system increased. The command and response approach requires a longer period of the processor cycle timing, but it offers the advantage of asychronous operation and in error detection during transmission or switching. There are also mixtures of both approaches, with the result of processor cycle timing falling in between the two extremes. Therefore, before a standard memory interface can be established, a definite timing control approach must be established. In the study model analysis, the command and response approach is recommended, since such an approach will give a worst case timing delay for an assumed system configuration.

Fig. 2b.—Block diagram of computer system with several memory switching units.



* LOCATION OF STANDARD MEMORY INTERFACE

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Interface Configuration

The timing requirement and the complexity of the system controls between the processing and memory modules depends upon the memory addressing and data transfer operations; which in turn are functions of standard memory interface.

Three different standard memory interface configurations of the study model for memory addressing and data transfer operations are described in the following sections.

CONFIGURATION 1

Standard memory interface in Configuration I:

Data	α lines
Positional Control	β lines
Operational Control	γ lines
Total lines =	$\alpha + \beta + \gamma$

In order to describe the general concept of memory addressing and data transfer, a set of standard memory interface signals is assumed; they are presented in Table I.

When a memory unit is operable, the *available interlock* (AI) signal is true. Memory cycle starts when an *execute addressing signal* (EA) is received. The memory address is gated from the *processor data* lines (PD) into the MAR. Both *busy interlock* (BI) and *cycle in-interlock* (CI) go true. The memory operation begins the read-out phase of the memory cycle. The memory unit will not operate the regenerate phase until *execute regenerate signal* (ER) is received from the processor; at which time, the CI signal from the memory unit goes false as an acknowledgment of receipt of ER. Toward the end of the regenerate phase, the memory unit causes BI to go false and reset all internal controls to quiescent condition in preparation to accept another EA command.

The data movement in the memory unit is completely controlled by the processor. The memory at the start of the memory cycle, always assumes a fetch cycle. By the controlling commands the processor causes the memory unit to operate in a fetch or store operation.

In the store operation, the CI signals the processor to place the data on the PD lines and to generate the control signals SD and ER. Upon receiving the SD signal, the memory logic gates the data on the PD lines into the MDR, and generates the *store data interlock* (WI) signal to the processor to acknowledge receipt of the data. The regenerate phase starts when the *execute regenerate* signal (ER) is received and the read-out cycle is completed. The processor will generate a termination signal (TE) upon receiving the WI signal and ready to go into another memory access operation.

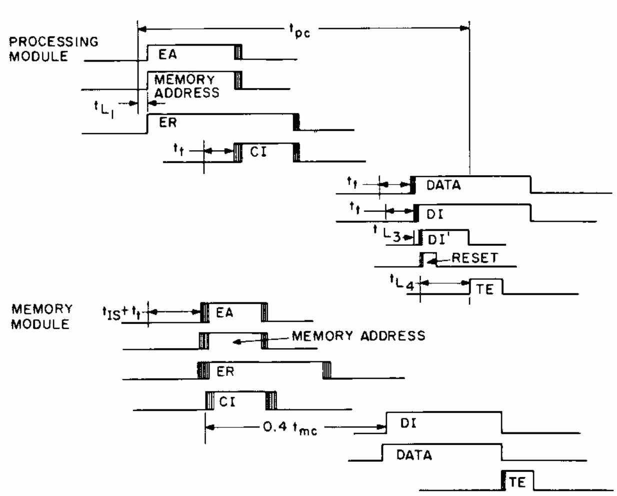
In the case of fetch operation, a *fetch data interlock signal* (DI) is generated by the memory unit when the data from the memory location specified by the MAR is firm at *memory data bus* (MD). Since the *memory data lines* (MD) are available to the processor at all times, DI is to signal the processor that the data from MDR is ready for the processor to use. The ER can be sent at any time and as early as the start of EA, but not before. (Memory logic inhibits the setting of regeneration flip-flop at the presence of EA by ER). Upon properly receiving the data for MD, the processor generates TE and prepares for another memory operation.

The above is a general description of the memory addressing and data transfer operations with the SMI configuration in Table I.

In the Configuration I, the data lines are time shared by the addressing information. The addressing information is sent to the memory module through the data line for the memory module selection before any data transfer is made. The size of α is a function of the system operational speed and the system storage capacity, therefore, it is the width of processor data or memory address whichever is larger. In cases where the circuit characteristic is unidirectional; a separate set of data lines have to provide for data transferred from memory to processor. The total number of Standard Memory Interface lines becomes $2\alpha + \beta + \gamma$. Positional control lines provide an additional option in store operation. With the existence of the positional control, the processing module can change any part of the complete data length α in one memory cycle without effecting the rest of the data. The size of β depends upon the resolution desired by the computer system (usually $\beta \ll \alpha$). Operational Control lines are necessary for memory access, operation, termination and error detection. The size of γ is usually in the order of 10 to 20 lines.

For the multiple module system, the repetition rate of memory operation is determined by the memory cycle time and the processor cycle time, whichever is longer. The processor cycle time is shortest interval possible between leading edges of successive execute addressing commands by the processor.

Fig. 3—Configuration I, timing chart of memory fetch operation.



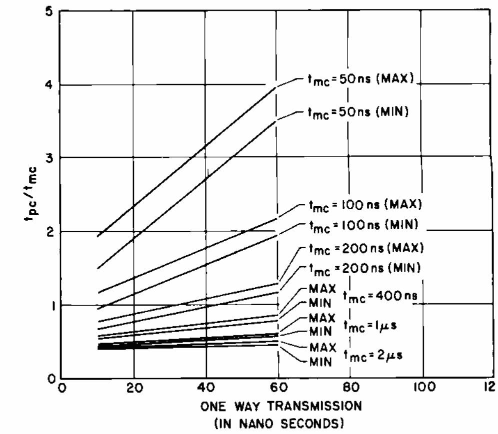


Fig. 4—t_{pc}/t_{mc} vs. one way transmission time in fetch operation.

The memory cycle time is in duration of the read-out phase, plus the regenerate phase.

From the timing chart in Fig. 3, the processor timing cycle t_{pc} in a fetch operation can be expressed as:

$$t_{pc} = t_{L1} + t_{Is} + t_t + t_{L2} + 0.4t_{mc} + t_t + t_{L3} + t_{L4}$$
$$= t_{Is} + 2t_t + 0.4t_{mc} + t_{L1} + t_{L2} + t_{L3} + t_{L4}$$

TABLE I—Standard Memory Interface Signals (Configuration I)

Name	Mnemonic	No. of lines	Processor/memory	Signal Relation
DATA		α		
Processor Data	(PD)		→	Timed
Memory Data	(MD)		←	Timed
POSITIONAL CONTROL				
Byte Control	(BC)	β	→	Timed
OPERATIONAL CONTROL		γ		
Execute Addressing	(EA)		→	Timing
Execute Regeneration	(ER)		→	Timing
Busy Interlock	(BI)		←	Timed
Available Interlock	(AI)		←	Timed
Cycle Interlock	(CI)		←	Timed
Fetch Data Interlock	(DI)		←	Timed
Store Data Interlock	(WI)		←	Timed
ROMAR	(RA)		→	Timing
RIMDR	(SD)		→	Timing
Termination	(TE)		→	Timing
General Reset	(GR)		→	Timing
Parity Error	(PE)		←	Timed
Cycle Error	(CE)		←	Timed
Processor Power	(PP)		→	Untimed
Memory Power	(MP)		←	Untimed

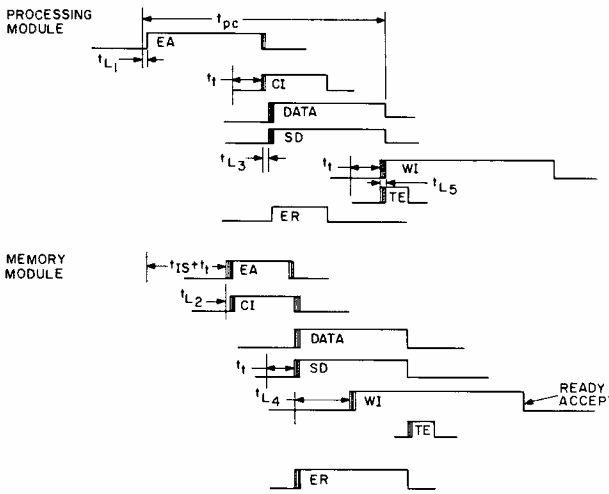


Fig. 5—Configuration I, timing chart of memory store operation.

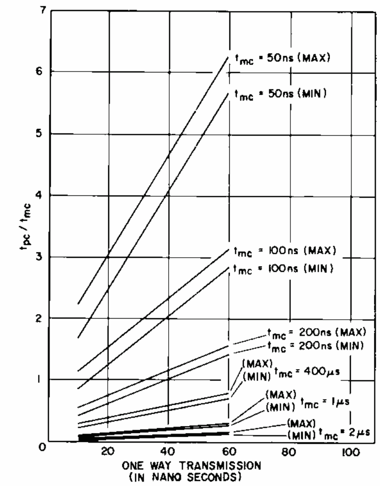


Fig. 6—t_{pc}/t_{mc} vs. one way transmission time in store operation.

where t_{pc} = processor cycle time in fetch operation, t_{mc} = memory cycle time (40% of which is read-out phase) t_{Is} = priority resolution and module selection time, approx. 2.5 pair delays (PD); t_{L1} = 1 pair gate delays, t_{L2} = 2 pair gate delays, t_{L3} = 2 pair gate delays, t_{L4} = 4 pair gate delays, and t_t = one way transmission time delay. Thus: $t_{pc} = 2.5\ \text{PD} + 2t_t + 0.4t_{mc} + 1\ \text{PD} + 2\ \text{PD} + 2\ \text{PD} + 4\ \text{PD}$
$= 11.5\ \text{PD} + 2t_t + 0.4\ t_{mc}$

Assuming maximum pair delay of the system circuit is 5 ns and minimum is 3 ns and cable as 2 ns per foot, the ratio of t_{pc}/t_{mc} is plotted against the one-way transmission delay time with various memory speed in Fig. 4. When $(t_{pc}/t_{mc}) = 1$, the time required for the processor to perform a fetch operation is the same as the memory cycle time. When $(t_{pc}/t_{mc}) > 1$, the processor cycle time is longer than the memory cycle time and the memory unit is not operating at its highest efficiency, the degree of idleness is in direct proportion to how much (t_{pc}/t_{mc}) is greater than 1. When $(t_{pc}/t_{mc}) < 1$, it represents the degree of availability for overlapping operation. An economic compromise in processor and memory speed will be when $(t_{pc}/t_{mc}) = 1$; however, the desirable compromise is when the ratio is below one. Fig. 4 offers a pictorial representation of the interrelationships of the memory cycle time, processor cycle time, and system transmission time. The specific point on the chart represents the operation characteristics of the system.

From the timing chart in Fig. 5, the t_{pc} in a store operation can be expressed as follows:

$$t_{pc} = t_{L1} + t_{Is} + t_t + t_{L2} + t_t + t_{L3} + t_t + t_{L4} + t_t + t_{L5}$$
$$= t_{Is} + 4t_t + t_{L1} + t_{L2} + t_{L3} + t_{L4} + t_{L5}$$

where t_{pc} = processor cycle time in store operation, t_{Is} = priority resolution and module selection time (approx. 2.5 PD), t_{L1} = 1 PD, t_{L2} = 2 PD, t_{L3} = 3 PD, t_{L4} = 4 PD, t_{L5} = 2 PD, and t_t = one way transmission time delay (cable and switching).

Thus:

$$t_{pc} = 14.5\ \text{PD} + 4t_t$$

Under the same circuit speed and cable delay assumptions, the ratio of t_{pc}/t_{mc} for the store operation is plotted against the one way transmission delay with various memory speed in Fig. 6.

CONFIGURATION II

Standard memory interface in Configuration II;

Data	α lines
Positional Control	$\frac{\beta}{2} + 1$ lines
Operational Control	γ lines

$$\text{Total} = (\alpha) + \left(\frac{\beta}{2} + 1\right) + \gamma$$

In configuration II, the memory addressing information and data of $\alpha/2$ bits long can be sent to the memory simultaneously on the α lines. If the data to be stored is only $\alpha/2$ in length, the processor cycle can be completed sooner by a significant amount. For data of α in length, the second half of $\alpha/2$ data will be sent for the memory after the first half is accepted by the memory. Thus, the operating speed will be approximately the same as in Configuration I. Due to the $\alpha/2$ data transfer, only $[(\beta/2) + 1]$ lines will be required which represents a savings of $[(\beta/2) - 1]$ lines from configuration I.

If it is only a single word store operation, the processor cycle can be completed sooner by a significant amount. For double word store operation, the data portion of the PD lines would be used twice, thus, the operating speed should be approximately the same as in Configuration I. This is shown in Fig. 7, the t_{pc}, can be expressed as follows:

$$t_{pc1} = t_{L1} + t_{Is} + t_t + t_{L2} + t_t + t_{L3}$$
$$= t_{Is} + 2t_t + t_{L1} + t_{L2} + t_{L3}$$

where t_{pc1} = processor cycle time in one-word store operation, t_{Is} = priority resolution and module selection time, approx. 2.5 PD, t_t = one way transmission time delay, t_{L1} = 1 PD, t_{L2} = 4 PD, and t_{L3} = 2 PD.

Thus:

$$t_{pc1} = 9.5\ \text{PD} + 2t_t$$

With the same circuit speed and cable delay assumptions, the ratio of t_{pc1}/t_{mc} for the one-word store operation is plotted against the one way transmission delay with various memory speed in Fig. 8. From Fig. 8, the processor can work with memory with higher speed and still retain $(t_{pc1}/t_{mc}) < 1$.

In case two full word store operation is required, the second full word (4 bytes) will be sent to the memory on the same path as the first full word upon receiving the *WI* signal. Since the second full word is transferred after the first full word, it takes in essence the same amount of time as Configuration I. Fig. 9 gives the timing chart of the two-word store operation, from which t_{pc2} can be expressed as follows:

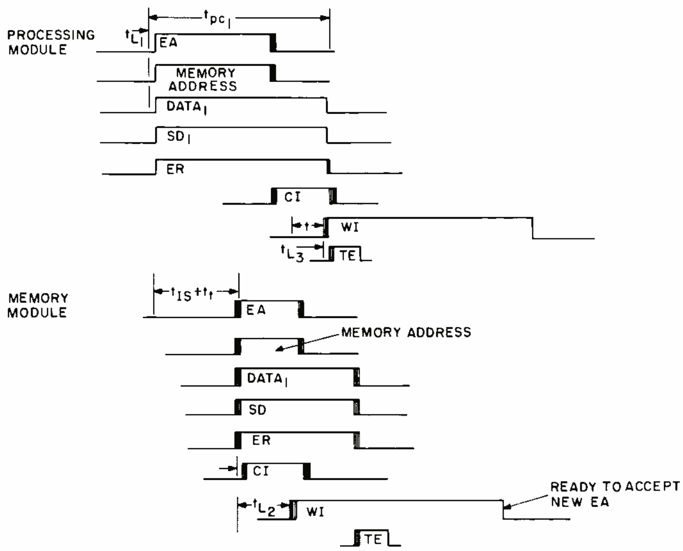


Fig. 7—Configuration II, timing chart of memory store operation of one-word transfer.

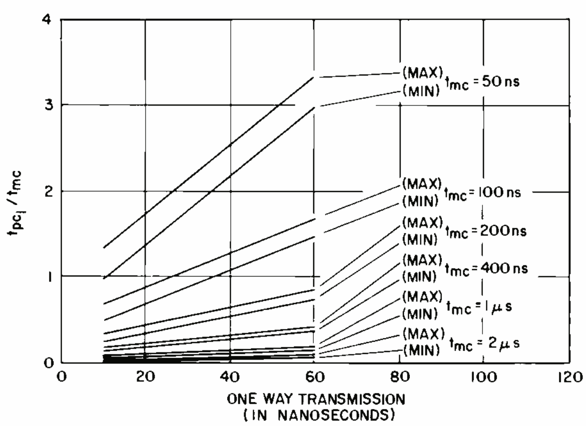


Fig. 8—t_{pc}/t_{mc} vs. one way transmission time in store operation.

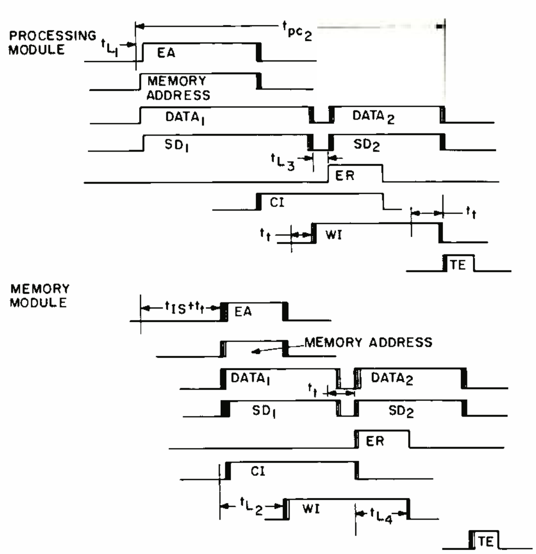


Fig. 9—Configuration II, timing chart of memory store operation of two-word transfer.

$$t_{pc2} = t_{L1} + t_{Is} + t_t + t_{L2} + t_t + t_{L3} + t_t + t_{L4} + t_t + t_{L5}$$
$$= t_{Is} + 4t_t + t_{l1} + t_{L2} + t_{L3} + t_{L4} + t_{L5}$$

where t_{pc2} = processor cycle time in two-word store operation, t_{Is} = priority resolution and module selection time, approx. 2.5 PD, t_t = one way transmission time delay, t_{L1} = 1 PD, t_{L2} = 1 PD, t_{L3} = 1 PD, t_{L4} = 4 PD, and t_{L5} = 2 PD.

CONFIGURATION III

Standard memory interface configuration III:

Data	α
Addressing	δ
Positional Control	β
Operational Control	γ
Total	$(\alpha + \beta + \gamma + \delta)$

Since memory addressing and processor data do not time-share the data lines, data of α long can be stored the same manner as $\alpha/2$ data in configuration II. It is the fastest data transfer of the three configurations for α long data store operation. However, it involves δ lines more than Configuration I and $[\delta + (\beta/2) - 1]$ lines more than Configuration II.

In all above three configurations, the time delay required for initial selection, which includes priority resolution and module selection, was added to the calculation to t_{pc}. For the first cut estimate, it is estimated to be 2.5 PD. This amount of time can be removed for normally dedicated connections such as in the case where the memory modules are program state memory modules. This will reduce t_{pc} approximately 10% and put the memory of 100-ns cycle time within operational range of $(t_{pc}/t_{mc}) = 1$.

Predominant factors in the immediate future seem to be the cabling and switching complexity and the number of signal lines is one of the more important considerations. The choice of a standard memory interface configuration depends therefore, upon solutions on these two factors. From the analysis of the three configurations, Configuration II seems to represent the best compromise in timing requirement and the least amount of cables.

MEMORY SWITCHING ASPECT

The memory switching is closely related to the standard memory interface, since the number of data lines to be switched, the number of control lines required in the memory access operations and the amount of time required are a prime concern of both standard memory interface and memory switching.

From the preceding section, t_{po} is a function of t_s and t_t. Since both t_s and t_t are the functions of the memory switching configuration of the system, any analysis of the standard memory interface must be involved in the analysis of system memory switching configurations. While there are many different types of memory switching configurations, the trade-off must be based upon the following areas:

Cable Sets

In a n processing modules by m memory modules computer system, the total number of set of standard memory interface cable depends upon the switching configurations. In the case of configuration shown in Fig. 2a, the total number of cable sets is equal to $(m + n)$ sets while in configuration shown in Fig. 10, is equal to $(m \times n)$ sets.

Total Logic Requirements

In Fig. 2a configuration, all the switching and control logic will be located in a centralized location. Therefore, it will require only one set of processor priority resolution logic, while there will be a duplication of priority resolution logic in each memory module in Fig. 10 configuration. In addition to the priority resolution logic, there will be only $2(m + n)$ sets of switching gates in Fig 2a configuration as compared to $2(m \times n)$ sets of switching gates in Fig. 10 configuration.

Therefore, from the total number of gates required in performing the switching and control functions in the $(m \times n)$ multimodule structure, the Fig. 2a configuration offers greater economy than Fig. 10. Configuration in the direct proportion to the number of modules in the system.

Additional Time Delay

In the case of Fig. 2a configuration where the switching and control function is located in separate unit, any signal transmitted from a processor to the memory module or vice versa must go through at least two sets of line drivers and receivers as compared to only one set in Fig. 10 configuration. Since the switching and control function is located in a separate unit, the packaging of the total system will require longer cable length in the Fig. 2a configuration. Therefore, from the time delay point of view, Figure 10 Configuration offers a system with smaller transmission time between operating modules.

Additional Power Supply

If the memory switching unit in Fig. 2a configuration is packaged together with the processors or memory modules, it usually can share the power supply with the other units in the system. In this case, the additional power supply requirements will be only the additional logic gates in the switching unit. Since there are less logic gates required in Fig. 2a configuration, the power supply required will be less.

System Availability

From the system availability point of view, the operation of the Fig. 2a configuration system will be completely jeopardized if the switching and control unit is out of service for any reason. However, one or more sets of switching and control logic in Fig. 10 configuration can become malfunction, the system still retains some operational capability, providing a fail-safe advantage.

The physical packages of the memory switching and control units presented in configurations Figs. 2a and 10 represent the two extremes in memory switching packages. There are also other combinations which fall somewhere in between. These are systems using several $n \times q$ memory switching units, where $q < m$ examples shown in Fig. 2b.

ERROR DETECTION ASPECTS

No interface architecture is complete without consideration of error detection. In the establishment of Standard Memory Interface, the following areas must be taken into consideration:

1) *Parity checks*—Parity checks must be provided for data and address from the processing module to the memory module in the store operation and data from memory module to processing module in the fetch operation. The amount of parity bits provided in the standard memory interface should be a system study trading off the number of additional lines in the standard memory interface and additional logic requirement against the required system reliability. Control signals must also be provided in the standard memory interface to communicate the detection of any parity error from the memory module to processing module and vice versa.
2) *Operational Sequence*—Definite memory operational should be established at the outset of establishing the standard memory interface. Any deviation from the established sequence should be detected immediately by one module and communicates with the other module through proper control signal provided by the standard memory interface.
3) *Power Supply*—Power supply failure in any form should be detected immediately; a control signal to indicate much failure should be provided in the standard memory interface.
4) *Diagnostic Provision*—The standard memory interface should provide sufficient number of control signals to allow diagnostic operations such as read-out memory address register content, snap-shot operation, diagnosis of one memory module by an un-related processing module etc.

CONCLUSION

With a well-defined standard memory interface, its effect on the future growth of computer systems can be significant. From the hardware point of view, it eases the system growth in modular manner to meet the ever-increasing demand of time-sharing technology. From the software point of view, it provides proper communications among modules for diagnostic programming and operating system.

ACKNOWLEDGEMENT

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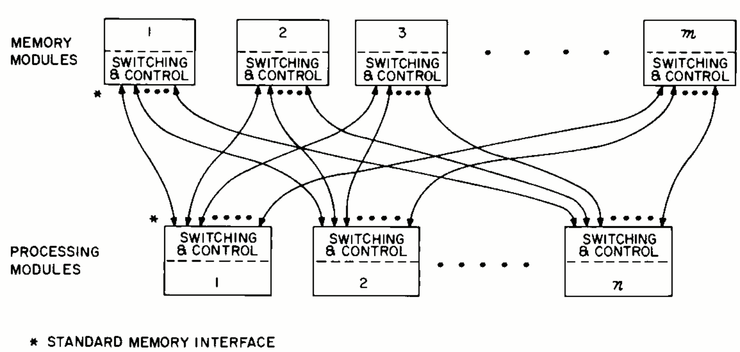

Fig. 10—m x n memory switching and control configuration.

PARTS SCREENING FOR HIGH RELIABILITY EQUIPMENT

Parts screening is a test or technique performed on 100% of a product to eliminate failures or potential failures. It is a cost effective and powerful tool for improving the reliable performance of inherently good component parts and, in certain cases, for controlling and significantly reducing factory re-work costs during equipment production. Such questions as when to employ parts screening on an equipment project, what it costs, and what it buys are discussed in this paper. An understanding of these and other parts screening concepts is mandatory since their application will have a significant bearing on the development, production, cost, and reliability of essentially every future military and space program.

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THE production of highly reliable equipment required for space, or any application where maintenance can not be provided during the equipment's useful life, requires that every part selected and its application be given the most expert attention and care possible to insure mission accomplishment. The best of systems concepts, circuit developments, and packaging designs are lost if the parts prove unreliable.

The parts program for any system must be subjected to the same constraints as the other phases of the program with respect to trade-offs between cost, time, and performance. The emphasis on weight, size, speed of operation, and environmental ruggedness has led to the use of many new and unproven parts developed especially for these requirements; yet at the same time, the sheer number of parts in the modern system requires an order of reliability on each part that approaches perfection.

Thus, the parts program should be implemented early in the hardware development stage in order that:

1) Maximum use is made of known and proven parts for which a great deal of performance data is available.
2) Designs do not become committed to an unavailable or basically unreliable part.
3) Time is provided to evaluate and qualify new and unproven parts.
4) Necessary controls and tests can be placed on parts going into the hardware.

Procedures for obtaining maximum confidence in parts utilized in these high-reliability systems are as diverse as the experience and judgment of the engineers involved and the needs of the particular program. Methods range from the detailed and rigorous program employed by the Bell Telephone Laboratories in selection of components used in undersea cable amplifiers to no-stress testing of individual parts with reliance on the environmental testing of the assembled equipment to reveal failures in potentially unreliable parts. A more usual approach, which may be varied to suit the confidence level desired or that can be afforded, is that of "screening".

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WHAT IS SCREENING?

Part screening refers to a series of tests conducted on a 100% basis under controlled conditions on finished electronic parts. The intent of such tests is one or more of the following:

1) To detect and eliminate initial and early failures.
2) To eliminate non-homogeneous parts from a lot (those which differ in performance from normal parts in a lot and, hence, are suspected as potential reliability risks).
3) To stabilize performance.
4) To increase confidence in the parts remaining.

The overall objective is to provide a group of specific parts for production use in which there are zero defects, or zero potential defects.

Some examples of tests used as screening operations are: high temperature storage, operational life, x-ray, current noise, shock, vibration, dew point, and electrical parameter measurements. Pre-conditioning, burn-in, and stabilization are other terms frequently used to describe a test that may be a part of the screening operation.

FACTORS DETERMINING SCREENING REQUIREMENTS

The tradeoffs between costs, time, and increased reliability actually obtained are presently far from an exact science for which specific standards can be established and followed without exercising a great deal of judgment—as will be evident from the following considerations.

The test that will reveal potential failures early or indicate unstable units must be tailored to each type of component. In addition, the same type of component produced by different vendors may require different tests, depending on its design and production process. The parts engineering specialist must work very closely with a parts manufacturer in the development of meaningful screening tests, taking into account his test data, sampling plans, etc. Good judgment is required based on a knowledge of failure modes, and criteria must be subjected to continuous change as additional experience is acquired. Such techniques as cycling, overstress, noise and thermal measurements, and observation of parameter change are being developed and are proving increasingly more valuable in the selection process, but must be applied with understanding and caution.

The duration of screening tests can often be approximated from previous data available, but each project is different in regard to time and money available and the degree of assurance required. Observation of data readings at intervals will indicate when and if leveling off occurs and when additional time fails to produce significant additional data on which to make further selection. This is a point where objective thinking needs to be applied, tempered by time and cost considerations.

Screening costs are determined by the volume of parts handled, extent of the test decided upon, cost of the facilities employed and number of batches to be run. Where possible, large savings can result by screening enough parts for the entire equipment program at one time, rather than running tests on small batches for one equipment at a time. The number of items on test is not as significant an item of cost as would be the repeating of the tests for each of several lots. Frequently, the cost of testing far exceeds the cost of the product, and this may or may not be a wise expenditure. On the other hand, the lack of any screening would permit defective devices to get into the equipment, which could cause delays, expensive rework, or mission failure.

The selection of which parts to screen and the relative emphasis to be placed on them requires a system approach in order that the effort be directed to those areas where the greatest benefits can be obtained. The trade-offs between time or costs and benefits are complicated by the inability to quantitatively measure the benefits. The analysis requires the participation of Engineering parts specialists, who are fully knowledgeable of the failure modes, working with the system project and reliability engineers to develop an initial testing program. Implementation of a screening program continues to require skilled technicians under engineering direction to protect the integrity of the part, to ensure that there is not more harm than good done, to interpret the data taken, and to recommend modifications in the testing program that may change emphasis and costs. Except possibly on very large programs involving a high volume of parts, this type of screening effort can not be standardized to the point that it becomes a normal incoming inspection type of test.

In addition to the parts screening, there is need for the complete equipment operational tests to further insure that the parts selected have been properly installed, without damage, and work together to perform the equipment function. It can be argued that equipment operational tests could be conducted so thoroughly as to make part screening unnecessary. However, equipment operational tests, in general, do not measure individual part performance nor do they subject parts to maximum stress and, therefore, are not sensitive enough to provide data for elimination of potential failures. Furthermore, if excessive failures are encountered in equipment testing, the failures and repairs can lead to further damage to interconnections and other parts so that the overall quality of the equipment is degraded by the rework. Also, this may be very late in the time schedule to discover the need for a replacement. It is important, therefore, that the number of replacements in the finished equipment be minimized. Properly applied part selection methods help accomplish this.

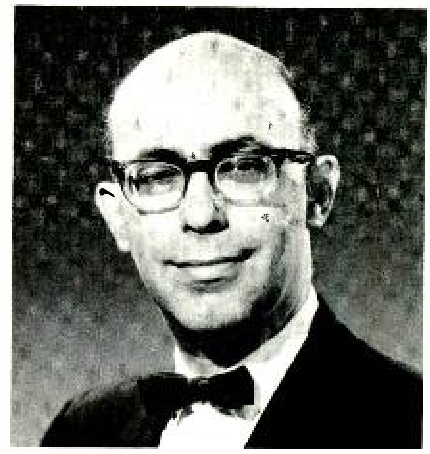
It has been possible in the past to procure screened parts from part manufacturers where high usage of individual part types was involved. In many current cases, however, involving relatively low quantities of a broad variety of part types, and more sophisticated tests, vendors are now reluctant, and in some cases are refusing, to supply screened parts. In other instances, quoted part manufacturer prices are excessive due to the facilities and engineering time required, and the delivery times are often totally unacceptable. Poorly conceived screening requirements can, of course, contribute to these difficulties, which again points to the need for the best judgment possible in determining the most effective screening requirements to invoke.

WHEN TO SCREEN

The basic factors which determine when parts screening should be invoked as a project requirement are:

1) The reliability/safety requirements and degree of assurance necessary to meet these requirements.
2) Repair considerations relative to initial production or field maintenance.

Although a cost effectiveness analysis must be considered for either of these factors, reliability requirements in certain cases dictate the need for screening essentially independent of cost. This is particularly the situation wherever the mission functions must be carried out at an absolute minimum risk; for example, where personnel safety is involved in manned space flight, or in the case of certain weapon-systems applications. The primary reason for the mandatory screening requirement in these cases is that there is no known practical alternative approach for obtaining the needed reliability assurance. Furthermore, parts screening is the only technique that has been successfully demonstrated in prior equipments; for example, the underwater transatlantic cable system and numerous space equipments.



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In the case of the repair factor, an estimate of the comparative repair and maintenance costs should be made considering the use of screened versus unscreened parts based on achieving the same operational effectiveness. It is not an easy matter to carry out such a cost-trade analysis, since many of the factors are not readily determinable. However, this type of analysis has been performed on systems in the past and should be considered particularly where large quantities of equipments or parts are involved. In several cases at RCA, it has been found that an order of magnitude reduction in factory line repairs occurred when screened parts were used in place of normal military types.

The utilization of parts screening as a production tool (and the degree of such screening) must be established on an individual program basis since it will have a significant impact on equipment cost. However, for guidance purposes, the following rules of thumb are pro-

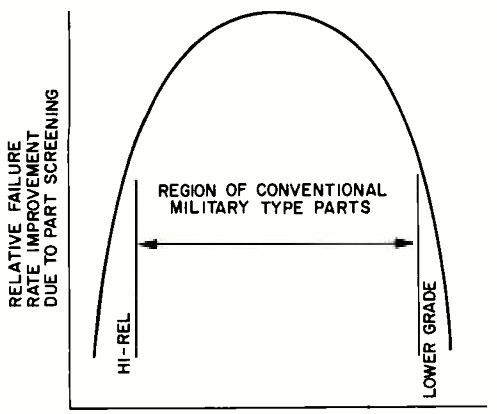

Fig. 1—Relative Failure Rate Improvement due to Part Screening.

vided as to when screening is generally applicable:

1) For space equipments.
2) Where the required average part failure rate for the equipment is less than 0.1 failure per million hours.
3) For equipments having a contractually specified MTBF in excess of 1,000 hours.
4) Wherever repair or maintenance costs may be excessive; for example, sealed or encapsulated assemblies or remote location maintenance.

PART TYPES TO SCREEN

When required, screening should be performed on those part types most critical to equipment mission success, to "state-of-the-art" types, and to non-standard types. Power, linear, close tolerance, or high electrical stress devices are those which should be given maximum consideration. In general, the best effectiveness is achieved by screening the following part types: semiconductors, integrated circuits, relays, and capacitors.

EVALUATION OF SCREENING EFFECTIVENESS

The question often raised is, "What is gained by screening?" The determination of what screening achieves in terms of improved reliability on a numerical basis is complicated by many factors and probably has never been satisfactorily established. To establish such a number, it is necessary to consider the specific part type, lot-to-lot variation, vendor-to-vendor process differences, applicable failure mechanisms, the particular screening technique, the specific applications of the part, and methods for measuring part reliability. The variables are not only numerous but essentially uncontrollable. Furthermore, the economics of failure-rate measurements are so great that they preclude the establishment of the numerical improvement in failure rate due to screening on a direct basis.

To attack the problem of screening effectiveness, one must resort to an indirect approach. Before proceeding with such an approach, it must be recognized that there is not a fixed failure rate applicable to any part type (contrary to widespread belief) but a range of failure rates. Furthermore, there is extensive evidence that this range can be quite large and cover several orders of magnitude. That this is so, is evident by the fact that the same part is generally constructed differently by different vendors and each vendor's fabrication process not only has variability, but is changed from time to time. In addition, laboratory and field data show widely differing failure rate values for the same part type.

A second important factor, which indirectly provides an indication of potential improvement available, is the degree to which conventional military type specifications provide for reliability assurance. Reliability guaranties for most electronic parts are either nonexistent or practically meaningless based on the test requirements of most military-type specifications. This is not an oversight but is due to the prohibitive cost of specifying such requirements. Typical failure rates guaranteed by conventional military specification acceptance tests range from about 100 to 1,000 failures per million hours. For high reliability specifications, acceptance test guaranties range from about 1 to 100 failures per million hours. On the other hand, equipment reliability requirements normally demand failure rates on the order of 0.001 to 1.0 failures per million hours. The incompatibility of the part and equipment specification requirements is quite evident.

Correlation between known failure mechanisms and techniques to detect defects related to these failure mechanisms is another factor that provides an indirect measure of screening effectiveness. In general, electrical and environmental stresses are related to existing or potential defects in parts. For example, over-voltage is used to identify defects in capacitor dielectrics; voltage and temperature are used to detect semiconductor contamination defects. There are numerous types of defects and associated screening techniques to cull these defects. It is apparent then that the application of a reasonably well-designed screening will reduce the number of defects in a group of parts and, hence, yield an improvement in the reliability of the remaining group.

In summary, there are three key factors that substantiate a basis for improvement in device reliability (failure rate) through screening. These are as follows:

1) A failure-rate range is associated with each lot of part types, and unless a means of eliminating the higher failure-rate portion of this range is provided, there is little assurance that this range will not, in fact, be experienced in any particular equipment.
2) Conventional military-type specifications (for practical cost reasons) incorporate failure rate requirements that are orders of magnitude poorer than are actually needed to meet high reliability equipment requirements.
3) Failure mechanisms as well as tools for detecting them are known for most part types.

Therefore, the application of a well-designed screen, which can detect failures and potential failures, can readily achieve improvements of many orders of magnitude over that for comparable unscreened parts. The specific improvement to be achieved can only be determined on an individual part type basis considering such factors as part failure mechanisms, application conditions, and the specific screening used.

In general, it can be expected that improvement will also be some function of the inherent quality or reliability level of the part, and that for extremely reliable as well as relatively poor part types, the improvement would not be

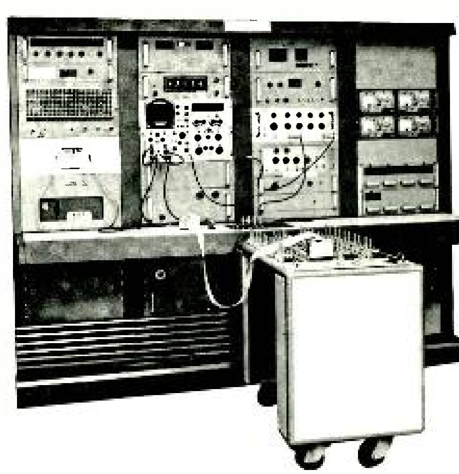

Fig. 2— Automatic Integrated Circuit Test Set.

as large as for what might be considered basically good parts. This point is shown in Fig. 1 and in Table I.

TABLE I—Failure Rate Improvement

Nominal Failure Rate	Estimated Best Final Failure Rate After Screening	Estimated Improvement Due to Screening
(failures/10^6 hours) .001 — .01	(failures/10^6 hours) $\leq$ .001	1 — 10^2
.01 — .1	$\leq$ .001	10 — 10^3
.1 — 1.0	$\leq$ .001	100 — 10^4
1.0 — 10.0	$\leq$ .1	100 — 10^3
10.0 — 100.0	$\leq$ 1.0	10 — 10^2

The particular improvement achievable due to screening must be determined or estimated on an individual part-type basis dependent upon the specific circumstances. However, for guidance purposes, the following are considered conservative estimates of reliability gain due to screening applicable to conventional military part types:

1) For nominal screens: 10/1 improvement.
2) For more stringent screens: 100/1 improvement.

AVAILABILITY AND COST OF SCREENED PARTS

The specialized requirements of screening on an individual part-type basis combined with the relatively small quantities required in space applications make part screening a non-production type operation. As a result, part suppliers are unwilling to supply screened parts or quote excessive prices and delivery times (16 to 29 weeks). Where high volume is involved for an individual part type, screened parts can generally be obtained from part manufacturers. Therefore, compliance with part screening requirements necessitates the availability of an RCA in-house capability.

Screening costs vary quite widely and are a function of the following parameters.

Number of part types,
Complexity of part types,
Quantity per type,
Number of lots to be handled per type,
Types of screen specified, and
Need for special test fixtures.

Although the screening costs for any particular project can be established only by an evaluation of the specific program requirements considering the above factors, the cost information in Table II is provided *for guidance purposes:*

TABLE II—Average per Part Screening Cost (To be added to basic part cost)

For small quantity requirements, variety of part types, numerous lots, relatively extensive screening	$15.00
For high quantity requirements of common part types:	
Reverse-bias bake and electrical tests	$0.30 to $1.00
Operational life and electrical tests	$1.00 to $3.00
Environmental tests, operational life, and electrical tests	$5.00

DEP SCREENING EXPERIENCE

Although screening has been utilized by RCA for many years as a production tool (for example: burn-in of tubes), in more recent years, starting about 1959, screening has been employed successfully for reliability purposes on numerous space and military projects. Since the latter date, DEP experience has included the screening of over 15 million electronic parts of all types, including integrated circuits, to a variety of screening specifications. Screening techniques employed have encompassed high temperature storage, reverse bias bake, operational life, x-ray, temperature cycling, centrifuge, dew point, gross and fine leak seal tests, monitored vibration, over voltage, and power stress tests. Some of the equipments used for screening tests are shown in Figs. 2, 3, and 4. Some of the projects on which screening was extensively employed include: RELAY, RANGER, MINUTEMAN, TIROS, NIMBUS, OGO, LUNAR ORBITER, GEMINI, plus several classified space and military projects. These projects have been unusually successful to date with respect to reliable and long-term performance. The screening of the parts used is considered a vital factor in these successes.

An analysis of Central Engineering screening data covering 45,000 parts showed that an overall average of 15% were rejected for equipment use with the typical range of rejection rates being from 1% to 42%. Where screening is performed in-house, these percentages are indicative of the extra quantity of parts that must be procured to meet equipment production requirements.

ACKNOWLEDGMENT

The Author is indebted to R. C. Willman, Manager, Central Engineering, for his technical support and direction in the preparation of this article.

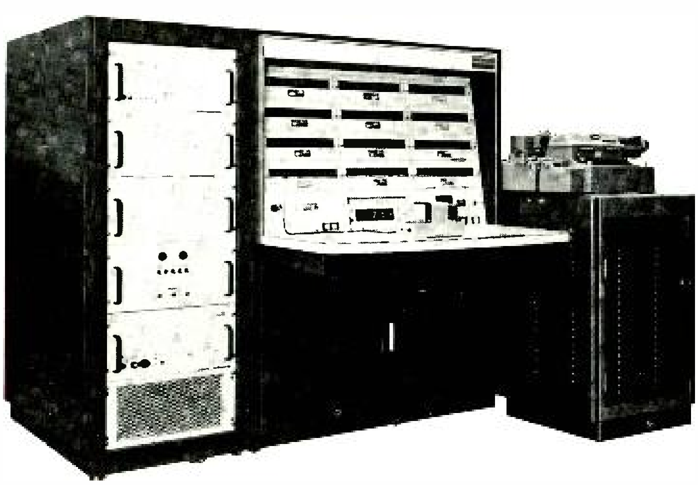

Fig. 3— Automatic Semiconductor Test Set.

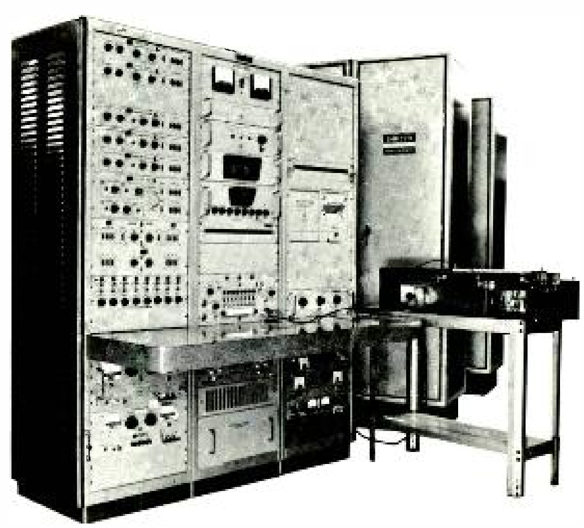

Fig. 4—Automatic Semiconductor Test Set and Burn-in Racks.

THE RCA-USAF VARIABLE INSTRUCTION COMPUTER

System Description and Reliability Aspects

This paper is intended to show how the unique features of the Variable Instruction Computer (VIC) make it valuable for applications requiring high reliability. By careful choice of components, use of error checking circuits, and selected application of redundant hardware, the basic unextended reliability of the VIC is comparable with the state-of-the-art. This is verified by a standard MIL-HDBK-217 type of analysis. The variable instruction technique is briefly described by use of a block diagram. The method for extending reliability by use of variable instructions is explained and an example is given. The concept of algorithm change to achieve controlled graceful degradation is discussed. An analysis of a typical application of this technique is given and extensions of the variable instruction concept to more advanced reliability requirements are discussed.

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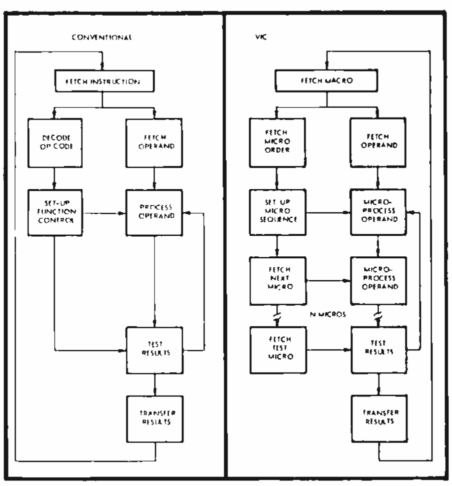
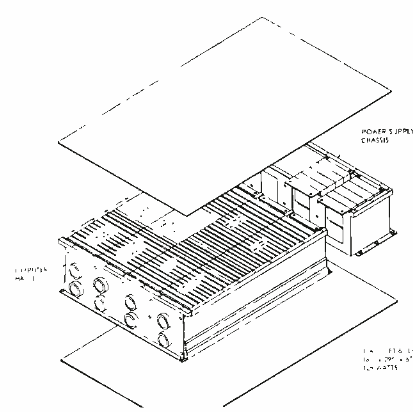


Fig. 1—Concept comparison

- General purpose, 36 bit parallel, stored program
- 1 and 2's complement, fixed point sign and magnitude, hexadecimal floating point
- 67,000 average operations per second
- Up to 128 duplex variable instruction locations
- Two 256 x 38 bit word 0.6 microsecond high speed memories
- Two (to eight) 4096 x 38 bit word 3.0 microsecond main memory modules
- Four input and output channels (1-36 bit, 3-8 bit)
- 200 Kc parallel input/output rate

Fig. 2—VIC—36A specifications

Fig. 3—Central processor unit



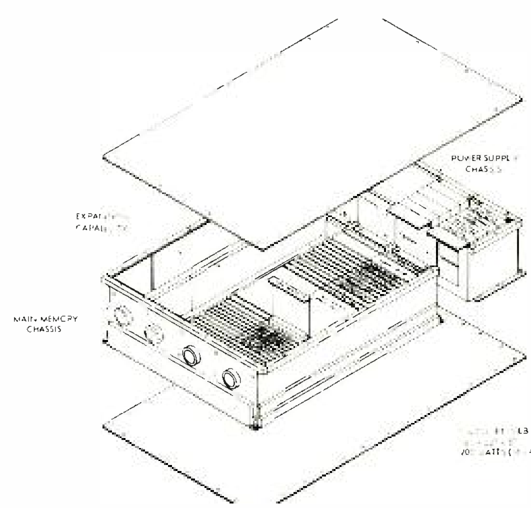


Fig. 4—Main memory unit

E. H. MILLER received the degree of Electrical Engineer in 1952 at the University of Cincinnati; he has completed numerous graduate level courses at the University of Pennsylvania, California and Northeastern. He joined RCA in 1947 as a co-operative student working in advanced development of navigational aids, radar and television systems. As a development engineer, Mr. Miller has worked on electro-static storage devices for automatic-track-while-scan systems, and the application of semiconductors to defense communications equipment. Mr. Miller was promoted to design engineering leader of the Memory Devices Group which designed and developed core memory systems for the Air Force Ballistic Missile Early Warning System. Mr. Miller is currently responsible for planning and execution of advanced systems required in the areospace environment. Such systems process realtime data gathered from sensors, communications and system components to be analyzed and displayed for the purpose of command and control action. Mr. Miller is a registered engineer in the State of Ohio, and a member of the IEEE and ACM.

THE Variable Instruction Computer (VIC) is a joint RCA and USAF development which provides the aerospace computer user with a high degree of flexibility, modularity, and reliability. Under an R&D program AF 33-(615)-2588 sponsored by the Avionics Laboratory, Wright-Patterson Air Force Base, RCA was funded to build a research model which would demonstrate some of RCA's VIC concepts. This paper describes that research model and discusses the reliability aspects of the VIC.

VIC CONCEPT

First, what is the variable instruction concept? The key word is *variable*, which means within a single order class the variations may include:

1) the source of the information
2) the function performed on this information
3) the destination of the results.

The variable instruction tool provides the programmer with the hardware flexibility to combine, in many possible ways, the variations in information sources, functions, and destinations. This flexibility is in contrast with the conventional computer which forces the programmer to use the instruction set wired into machine. The result is a compromise which is usually less than optimum for the application. Fig. 1 compares the steps involved in a conventional computer with those used in the VIC. In the VIC, the *macro*-order specified a *micro*-order sequence and modifies the source and destination of the data. The micro-order sequence is a series of discrete steps which sets up transfer paths, assigns registers, controls shifts, sets patterns of logical operations, controls arithmetic operations, set counts and tests.

Final manuscript received January 15, 1967.

RCA-USAF VIC-36A

The work to build a research model of the VIC began in the spring of 1965. The objective was to demonstrate the VIC concept by utilizing off-the-shelf components wherever possible. To complement the unique reliability aspects of the VIC approach, integrated circuits, organizational modularity, and checking features were built into the model.

Fig. 2 summarizes the VIC-36A specifications. A key feature is the flexibility which provides the user with several different number systems. For reliability, the variable instructions are stored in the redundant high speed memory modules. To provide for future growth, the main memory is expandable in 4,000-word modules up to 32,000 words. The four

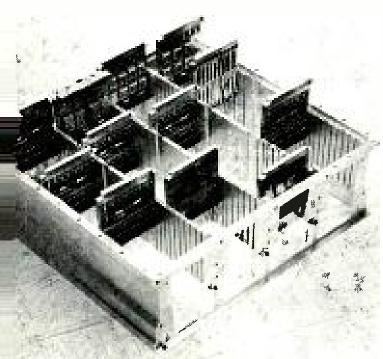


Fig. 5—Main memory assembly

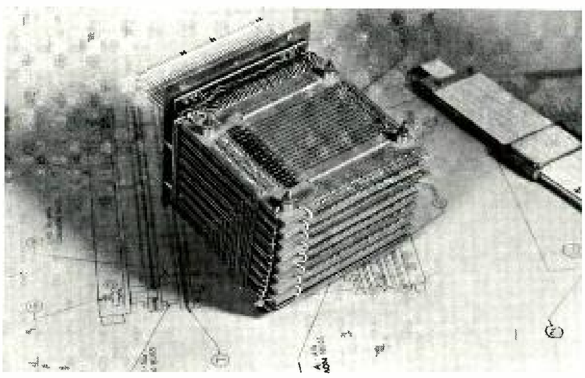
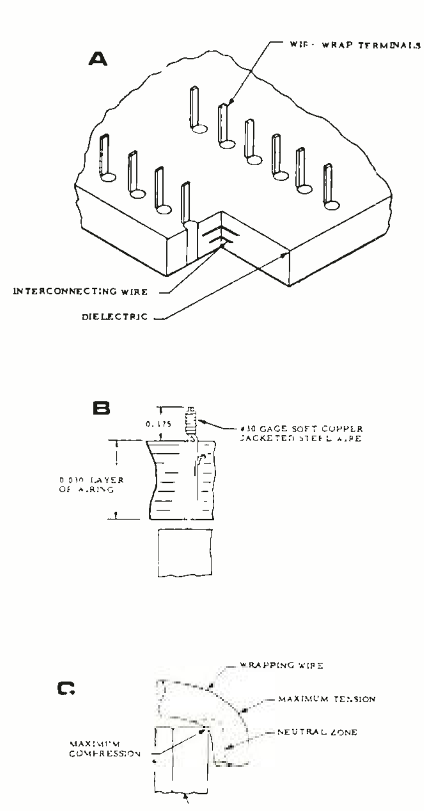


Fig. 6—High-speed memory stack

Fig. 8—Spit pin wiring wrap—wiring module



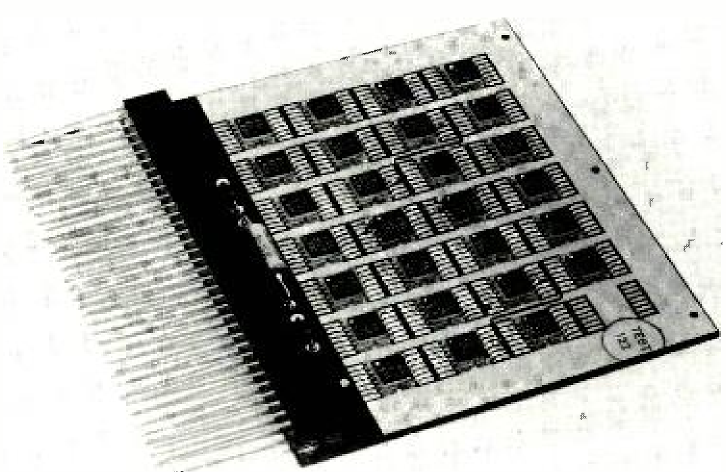


Fig. 7—Logic card

independent input-output channels are built into a traffic control system having four levels of priority.

The physical configuration of the VIC central processor unit is shown in Fig. 3. Each subassembly may be removed for repair including the power supply modules and the high speed core memory stacks. Cooling is achieved by metal thermal conductive paths from the silicon semiconductor to a cold plate mounting surface. The size, weight, and power figures include the duplex 400-cycle AC power supplies. Fig. 4 shows the main memory unit with only two of the four 4,096-word main-memory modules installed. The size, weight, and power figures include the full 16,000-word complement. Connectors are provided for connecting a second 16,000-word main-memory unit. With the full complement of 32,000 words of storage, the expanded 36-bit parallel-word VIC-36A is 4.4 cubic feet and weighs 175 lb. These size and weight figures include all of the reliability features and redundant circuits described in this paper.

The objectives of this paper are:

1) to describe the VIC-36A at the block diagram level,
2) discuss its intrinsic reliability features, and
3) show how the VIC concept extends the basic reliability by means of algorithm change in order to achieve multiple levels of graceful degradation.

Fig. 9—MTBF analysis

	FAILURE RATE λ*	ARITHMETIC UNIT		CONTROL UNIT		INPUT-OUTPUT		HIGH SPEED MEMORY		POWER SUPPLY		4K MAIN MEMORY		MAIN MEMORY PS	
		n	nλ	n	nλ	n	nλ	n	nλ	n	nλ	n	nλ	n	nλ
DIGITAL I.C.'S	0.10	774	77.4	950	95.0	500	50.0	266	26.6			222	22.2		
ANALOG I.C.'S	0.30							45	13.5			40	12.0		
HYBRID CIRCUITS	0.40							104	41.6			53	21.2		
TRANSISTORS	0.06							4	0.2	32	1.9	4	0.2	22	1.3
DIODES	0.03							116	3.5	84	2.5	512	15.4	41	1.2
CAPACITORS	0.02			19	0.4	9	0.2	93	1.9	66	1.3	63	1.2	21	0.4
RESISTORS	0.002							166	0.3	120	0.2	111	0.2	58	0.1
TRANSFORMERS	0.20									9	1.8			8	1.6
SOLDER JOINTS	5.0×10^{-4}	7700	3.8	9500	4.8	5000	2.5	4900	2.5	750	0.4	4600	2.4	350	0.2
WELDS	2.0×10^{-4}	2300	0.5	2800	0.5	1400	0.3	800	0.2			700	0.1		
WIRE WRAPS	4.0×10^{-5}	2100	0.1	2400	0.1	1260	0.1	1680	0.1	780	—	1540	0.1	280	—
STACK	1.6							1	1.6			1	1.6		
CONNECTORS	(0.001/PIN)					70	0.07			20	—	70	0.07	20	—
	TOTALS		81.8		100.9		53.3		92.0		8.1		76.7		4.8

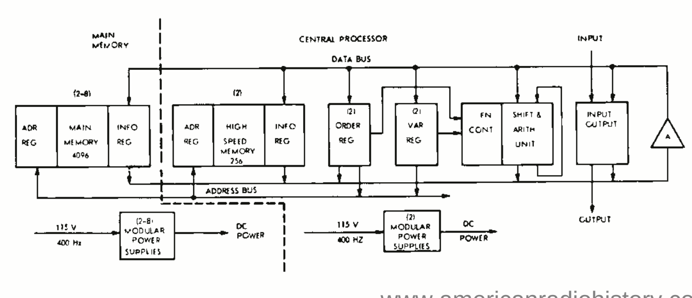
* λ = FAILURES/10^6 HRS.

Fig. 10—Effects of redundancy of MTBF

	mλ	SINGLE THREAD				DUPLEX HSM VR, CR & PS				DUPLEX HSM & PS			
	F/10^6 HRS	4K	8K	16K	32K	4K	8K	16K	32K	4K/8K	8K/12K	16K/20K	32K/36K
CENTRAL PROCESSOR													
ARITHMETIC	81.8	81.8				81.8				81.8			
CONTROL	90.9	90.9				90.9				90.9			
CR AND VR	10	10				•							
INPUT-OUTPUT	53.2	53.2				53.2				53.2			
HIGH SPEED MEMORY	92.0	92.1				•							
POWER SUPPLY	8.1	8.1				•							
TOTAL CPU		336	336	336	336	236	236	236	236	236	236	236	236
MAIN MEMORY													
4K + PS	81.9	82				82				•			
8K + PS	163.8		164				164				98		
16K + PS	327.6			328				328				180	
32K + PS	655.2				655				655				347
TOTAL mλ		418	500	664	991	308	390	554	881	236	334	416	583
MTTF = mλ/10^6		2400	2000	1500	1000	3200	2550	1800	1100	4200	3000	2400	1700

* INSIGNIFICANT BY VIRTUE OF REDUNDANCY.

Fig. 11—Organization



COMPONENTS AND CONSTRUCTION

The VIC design utilizes integrated circuits in order to benefit from the high reliability afforded by fewer components and interconnections. In Fig. 5, three of the main memory data register cards are shown in the column on the left. Note the 8 monolithic-silicon integrated sense amplifiers and the 8 DTL flip-flop register flatpacks. The two cards in the last row in the upper right hold 8 dual hybrid switch-circuit packages and the associated decoding logic flatpacks. The remaining card in the last row holds the four main current-driver cordwood modules required for one of the 4,096-by-38-bit main-memory modules. The large heat-conducting flange assures that the heat generated by the drivers is conducted to the heat sink. The driver card and the load resistor card in the rear column, next to last row, are the only assemblies besides the power-supply modules which do not contain integrated circuits.

Each card is guided by tracks in the metal column separators. The metal strips at the top edge of each card make intimate contact with the cold plate which covers the unit. Each card is secured to the column separators by a screw at each end of the metal strip. The total thermal drop from the active component junction to the cold plate surface is less than 25°C.

Tests performed on this type of construction have proven its ability to withstand environmental hazards encountered in both air and spacecraft. For maintainability, each card is directly accessible and its planar construction allows component test and repair with simple test equipment and shop tools.

Memory Design

In choosing the memory approach for VIC the goal was reliable operation over a 125°C temperature range with minimum susceptibility to stray magnetic fields and power supply transients. To meet these requirements, the device selected was the closed-magnetic-path toroidal core, made of wide-temperature lithium ferrite, developed by RCA Electronic Components and Devices at Needham, Mass. Its characteristics are essentially flat over any 100°C temperature range below the curie point. Operation is extended to 125°C by modifying the interrogate current as a function of core stack temperature.

Fig. 6 is a photograph of the VIC high-speed memory stack which operates on a 600-ns cycle. The four modes in which the memory operates are: *clear/write*, *read/restore*, *read/modify/write*, or

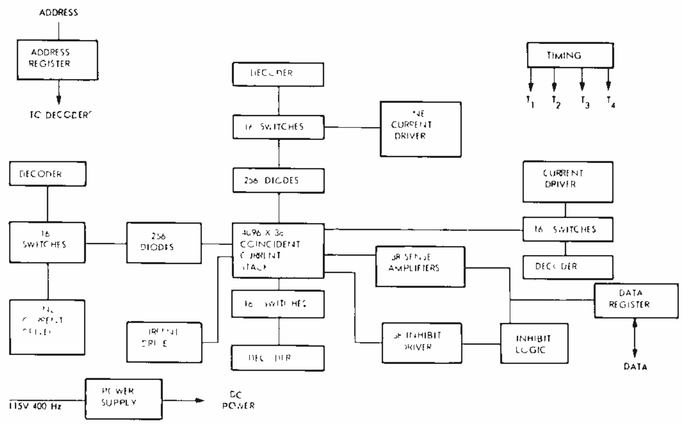


Fig. 12—Main Memory

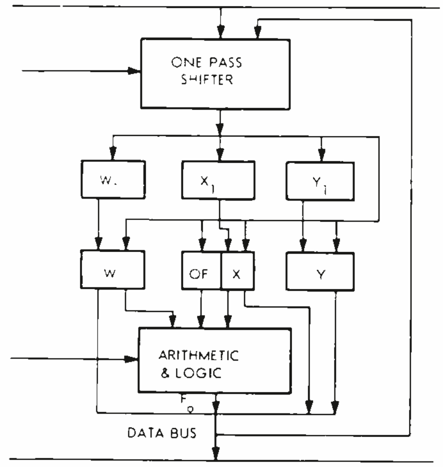


Fig. 13—Arithmetic unit

read/count/write cycle. The high-speed memory is organized as a two-core-per-bit linear select memory. It provides 325-ns parallel access to any of the 256-by-38-bit words. A 30-mV bipolar readout from the two 20-by-12-mil cores provides an extremely reliable readout signal.

The main memories employ 30-by-18-mil lithium ferrite cores operating in a coincident-current mode. They provide a 3.0-μs *clear/write, read/restore*, or *read/modify/write cycle* time and an access time of 650 ns. A typical readout signal is 60 mV and the sense amplifier threshold level is greater than 10 mV at −55°C and greater than 30 mV at +100°C.

Both memories utilize monolithic-silicon integrated-circuit sense amplifiers. The current switches are hybrid integrated circuit units which utilize thin-film interconnection techniques. Each switch is transformer-coupled and two circuits are packaged in a single 0.75-inch-square hermetically sealed package.

Logic Cards and Interconnections

Fig. 7 illustrates a typical logic circuit card. Each card is 3.75 by 3.5 inches and can accommodate up to 32 integrated-circuit packages. The cards are either 4-layer built-up plated circuit cards or 3-layer welded-wire matrix assemblies.

Both types utilize the same 70-pin connector. The long beryllium-copper pins on the connector are designed to pass through a multi-layer welded matrix backplane as shown in Fig. 8a. After the card is inserted in the backplane, the long connector pin is adjacent to a similar pin which is welded to the wires within the backplane as shown in Fig. 8b. The adjacent pins are then wire-wrapped together to produce an extremely reliable connection which can withstand extremes of shock, vibration, and temperature. At the point of maximum compression, as shown in Fig. 8c, the metals recrystalize and fuse into a very low impedance connection at four points in every turn of the wrap. As a result, the resistance of a wire-wrap connection is only 0.0007 ohm, compared to 0.006 ohm for a typical solder joint and 0.01 ohm for a typical connector pin. The wire wraps may be removed and discarded and new wraps may be installed as often as required.

The Vic interconnection technique also provides the reliability of a solid-encapsulated welded-wire backplane. The backplane is built layer-by-layer from welded wire matrices which are individually inspected and tested. These are assembled and welded to pins in a step-by-step process with inspections and tests at each step. The entire assembly is then encapsulated in a solid unit.

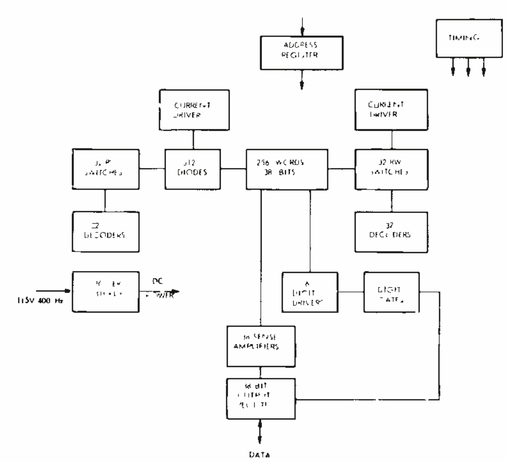
BASIC RELIABILITY PREDICTIONS

After that introduction to the Vic, its components and construction, the next step is to determine the basic reliability factors based on component counts and straightforward redundancy. Fig. 9 shows the Vic-36A failure rate analysis

Fig. 14—Arithmetic and logic unit functions

CODE	FUNCTION	REMARKS	CODE	FUNCTION	REMARKS
000000	W OR X		010000	C(X)-1	DECREMENT X BY 1
000001	$\overline{W}$ AND $\overline{X}$		010001	(C(X)-1) $[\overline{Y}_{35}]$	DECREMENT X BY 1 IF Y_{35} IS $\underline{0}$
000010	$\overline{W}$ OR X		010010	$\lvert\overline{C(X)}\rvert$ + 1	COMPLEMENT MAGNITUDE OF C(X) AND INCREMENT BY 1
000011	W AND $\overline{X}$		010011	$\lvert\overline{C(X)}\rvert$	COMPLEMENT MAGNITUDE OF C(X)
000100	W OR $\overline{X}$		010100	C(X) + 1	INCREMENT X BY 1
000101	$\overline{W}$ AND X		010101	(C(X) + 1) $[Y_{35}]$	INCREMENT X BY 1 IF Y_{35} IS $\underline{1}$
000110	$\overline{W}$ OR $\overline{X}$		010110	DIVIDE STEP	
000111	W AND X		010111	MULTIPLY STEP	
001000	W ⊕ X	EXCLUSIVE OR	011000	SPECIAL ADD	TWO'S COMPLEMENT ADD $X\Sigma_2W$ WITH FORCED CARRY
001001	$\overline{W \oplus X}$		011001	$X\Sigma_2W$	ADDITION TWO'S COMPLEMENT
001010	$\overline{X}$		011010	$X\Sigma_1W$	ADDITION· ONE'S COMPLEMENT
001011	X		011011	$X-_1W$	SUBTRACTION: ONE'S COMPLEMENT
001100	$\overline{W}$		011100	$X-_2W$	SUBTRACTION: TWO'S COMPLEMENT
001101	W		011101	SPECIAL SUBTRACT	SUBTRACT: $X-_2W$, NO CARRY IN
001110	$\underline{0}$	ALL ZEROES	011110	$X\Sigma_{sm}W$	ADDITION: SIGN, MAGNITUDE
001111	$\underline{1}$	ALL ONES	011111	$X-_{sm}W$	SUBTRACTION: SIGN, MAGNITUDE

Fig. 15—High speed memory



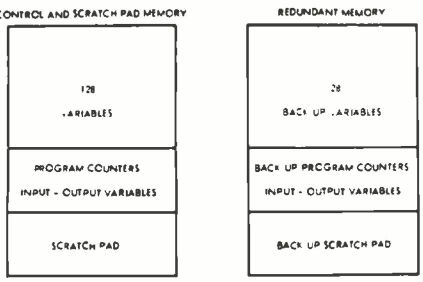


Fig. 16—High speed memory allocation

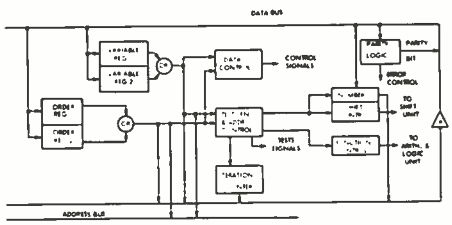


Fig. 17—Control unit

for each section of the computer. The part failure rates are typical of those utilized on the LUNAR EXCURSION MODULE (LEM) program. The rates fall between those used for military equipments and those required on the MINUTEMAN high reliability program. Interconnection techniques improve as they progress from solder to welding to wire wrap. In each case, rigid NASA procedures and tests verify the workmanship. Connectors are the least reliable, as their failure rate indicates, and the effect of their virtual elimination in the VIC and the effects on reliability are significant.

With the data derived in Fig. 9, it is now possible to determine the improvements attained by the use of simple redundancy in VIC. Fig. 10 shows the effects of redundancy on the MTBF of VIC, assuming that no repair is possible during a simple mission.

The first four columns of Fig. 10 show the MTBF for a single-thread VIC of 4,000, 8,000, 16,000, and 32,000 words of main memory to be 2,400, 2,000, 1,500, and 1,000 hours, respectively. In the next four columns, as a result of having duplex high speed memories, control registers, and central processor power supplies an improvement of from 30% to 10% in MTBF is gained, depending on the amount of main-memory capacity. In the last four columns, as a result of having a spare main memory and its associated power supply, an improvement of from 75% to 70% is gained over the single-thread case, depending on the amount of main-memory capacity required. The hardware cost in terms of size or weight for the 75% improvement in MTBF was only 20%, while for the 70% improvement in the 32,000-word machine it was only 12.5%.

These basic reliability predictions show the effects of employing integrated circuits, core memory devices, and advanced packaging techniques to yield good basic reliability in VIC. The use of switchable redundant modules was discussed to show how VIC's basic MTBF can be effectively improved simply by a nominal increase in hardware. A discussion of what unique additional reliability features accrue from the use of the variable instruction technique follows.

VIC MODULAR ORGANIZATION

The VIC has an unusual modular organization as shown in Fig. 11. Each major functional unit is as nearly independent of other units as possible. For example, each of the main-memory modules has its own independent address register, information register, local control and power supply. Each of the two high-speed memory modules has the same independent features. There are two independent power supplies in the central processor either of which can serve the entire processor. The two pairs of order and variable registers, whose function will be described later, are also independent of each other. There are four input-output channels, each separately addressable and independent of each other. The function control, shift, and arithmetic units will be treated later.

As indicated in Fig. 11, the VIC is organized around two busses, one for data and the other for address information. Each of these busses is unidirectional and, thus, a single set of amplifiers can service all data transfers. Test data on a large number of monolithic integrated DTL circuits of the type used in the VIC shows that 95% of the failures in these circuits occur in a condition where all circuit impedance is removed from the input or output terminals. Thus, a condition in which the VIC bus "hangs up" and cannot be switched by the surviving circuitry is highly improbable.

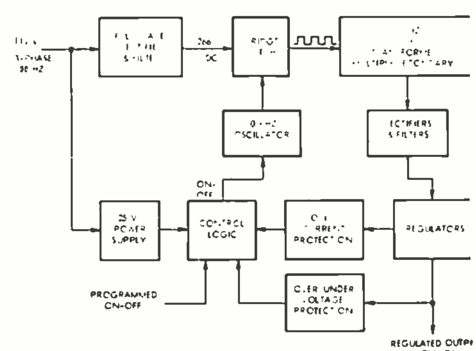
Fig. 12 shows all the circuits in one main-memory module. All of the essential circuits are included; in addition, a parity generator in the central processor generates a parity bit for every word as it is sent to memory. When either the main- or high-speed memory is accessed, a parity check is performed in the central processor. Thus, a failure of any component in a memory module will be detected when the affected location is accessed.

The arithmetic unit is shown in Fig. 13. The data bus interface is indicated at the top and bottom of the diagram. Two control lines are shown coming in from the left. The arithmetic unit is organized in a vertical slice so that two bits of each of the three double-rank registers and two bits of the arithmetic and logic section are all on a single card. This card is the one shown in Fig. 7. There are eighteen of these cards in the full 36-bit arithmetic unit.

The variable instructions control the arithmetic unit. All the shift, arithmetic, logical, and interim storage functions are controlled by discrete bits in the variable-instruction word. Fig. 14 lists all of the functions which can be performed in the arithmetic and logic unit. Each of these functions is independent and separate from the others and may be called out by the mirco-orders in a wide variety of ways. Making each of these operations as simple and basic as possible gives the programmer complete freedom to design an almost unlimited set of macro-orders.

Fig. 15 shows all of the circuits in one of the high-speed memory modules. The failure of a component in either module will be detected by the check on parity as every affected word is read out of the module just as with the main-memory modules. One high-speed memory module is a duplicate of the other, as shown in Fig. 16. Note that half the memory is

Fig. 18—VIC power supplies



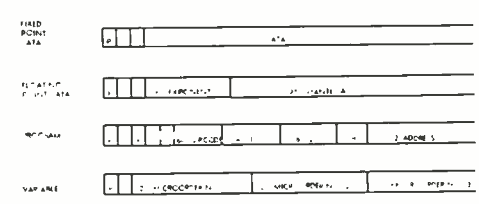


Fig. 19—Word formats

devoted to variable word storage, a quarter to program counters and input-output control, and a quarter to scratch-pad storage. In normal operation, only one of the high-speed memory modules is interrogated at one time. If an error is detected, the second module is interrogated. If the second module is read incorrectly, a diagnostic routine is called in, and information may be restored from a nonvolatile backup store, if necessary. Whenever the information in a scratch-pad or program-counter location is changed, both modules are updated simultaneously.

Fig. 17 shows the VIC control unit. The redundant order registers receive the macro-order from the main memory. The redundant variable registers receive the micro-orders from the control memory. The bit content of these two registers is decoded in:

1) the data control to set up the data transfer paths in the machine; and
2) in the test, function and address control to set up the number of shifts, the functions to be executed, the number of iterations and the type of tests to be performed.

The signals thus generated go to the transfer gates, shift unit, arithmetic and logic unit, program counters, and input-ouput variable-storage locations.

VIC is unique in that it is an asynchronous machine and there is no central clock source which is critical to the operation of the separate functional units. Such clock sources are usually nonredundant and involve a few components which are heavily loaded by drive-current power requirements. Central clock sources are also heavily dependent upon the reliability of interconnection techniques and freedom from local electromagnetic interference sources and power-supply transients.

POWER SUPPLY FEATURES

There are two types of AC to DC power supplies in the VIC. One is for a 4,096-word main-memory module, and one is for a high-speed memory module and the central-processor unit. Both types have the same block diagram (shown in Fig. 18). The 400-Hz input power is rectified, filtered, and then chopped at a 10-kHz rate. The 10-kHz square wave drives a small power transformer with multiple secondary windings. These develop the various input amplitudes for a set of rectifiers, filters, and regulators for each of the DC output voltages required. The regulator outputs are sensed for overcurrent, overvoltage, and undervoltage. These *go/no-go* signals are used to initiate a fast-stop action in the 10-kHz oscillator control logic. This control logic also enables the programmer to turn off excess memory capacity during certain phases of the mission. This increases the longevity of the memory modules and enables them to survive excessive temperature and radiation extremes.

VARIABLE INSTRUCTION TECHNIQUE

Now that we have described the circuits, construction, organization, and standard reliability aspects of the VIC, we can discuss the unique reliability features of the VIC. Fig. 19 shows the word formats used in the VIC. The program or macro instruction operation code is, in part, the address of the first variable word in control memory. The variable word contains three 12-bit micro-orders which control the discrete micro-operation of the VIC.

The way in which the program and variable words are combined to control the step-by-step operation of the VIC is illustrated in Fig. 20. The bits of the order register and variable register are decoded to generate specific data address and control operations. At least one (and sometimes four or five) variable words are required for each order. Since every variable contains three micro-orders, a macro-order may have 12 or 15 micro-orders. Because of the great flexibility of the VIC transfer paths, arithmetic, logical and shift operations, a macro-order can be formulated from micro-orders in a wide variety of ways. *Herein lies the fundamental advantage of the* VIC *from the standpoint of reliability.*

Given this most flexible set of computer parameters, a programmer can find a great many ways to execute a particular macro-order. With this flexibility it is possible to substitute alternative ways to execute an order and circumvent the failure of some portion of every register and control path in the machine. A comprehensive set of diagnostics can be formulated which can detect failures in basic algorithms and then determine which secondary or even tertiary algorithms can be substituted.

Suppose, for example, that the second bit of the adder logic has suffered a permanent fault. Then the data can be treated as two half-words, and the addition can be performed in two steps in the good half of the arithmetic unit. Alternatively, the words to be added can be converted to their complement, subtracted, and the result recomplemented. Even though these alternatives will require more time, the computer can continue to operate. The micro-order routine for the *add* operation would be permanently altered so that every time a macro-order calls for an add operation the altered micro sequence will be used.

It is reasonable to consider a 36-bit parallel arithmetic unit as three 12-bit units which normally operate in parallel. If one, or even two, of these 12-bit bytes have failed, it is still possible to continue operating on a 12-bit byte. This is sometimes called "graceful degradation" or the *multithreading* approach to reliability.[1] The analysis given in Reference 1 shows that this approach has particular merit where high meantime before failure goals are required and repair is not possible.

CONCLUSIONS

A model of a variable instruction computer has been built which demonstrates the ability of the variable technique to enhance reliability by means of controlled graceful degradation. The features built into the VIC include independent memory modules, redundant control memories and registers, asynchronous operation and independent input-output channels. In addition, the variable-instruction technique provides a means for on-line algorithm substitution to achieve multiple modes of operation each at successively lower levels of degradation (see Fig. 21).

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1. See, for example, R. P. Hasset and E. H. Miller, (RCA), "Multithreading Design of a Reliable Aerospace Computer," Supplement to IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-2, No. 6, Nov. 1966, pp. 147-158.

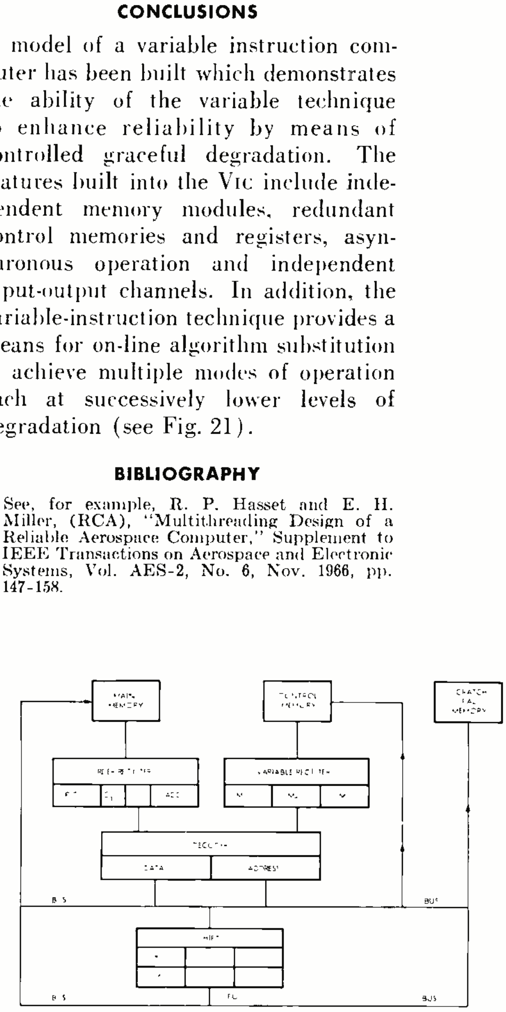
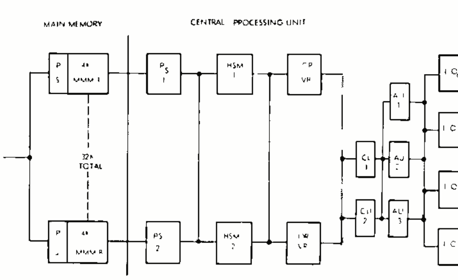


Fig. 20—Instruction flow

Fig. 21—Reliability block diagram



COMPUTERS AS ENGINEERING TOOLS FOR FILTER AND NETWORK DESIGN

During the past six years, the Microwave and Industrial Television Engineering Department of the Broadcast and Communications Product Division in Camden has used special digital computer programs in the design of precision filters and networks for multiplex telephone and data systems. A major application for such filters and networks was in the design of the Solid-State CV-600 Frequency Division Multiplex equipment.[1] These filter designs have ranged from those with relatively simple requirements to high-order complex networks with stringent requirements on transmission performance. This paper will present a condensed review of some of these programs for filter design and analysis.

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The filters and networks considered here are ladder structures, composed of passive RLC elements. These networks are considered only for their steady-state characteristics of input immittance, and transmission magnitude, phase, and envelope delay.

The major objectives in using computers in this design work can be summarized as follows:

1) To reduce engineering design time;
2) To determine expected performance of design before constructing models;
3) To free design engineers from tedious and error-prone numerical calculations;
4) To allow high-order complex designs to be accomplished;
5) To determine or predict the sensitivity to element tolerances of a particular design.

All of these objectives are aimed at improving design efficiency in terms of lowered production cost, improved design performance, and minimum overall design cost.

The computer programs to be described all follow a similar format in planning, as shown in Fig. 1. For each program, certain data describing the particular problem is required in punched-card form. The main program decks include the necessary mathematical relations in numerical programmed form, as well as the logical processing operations for the program flow. The computed output can then be prepared on tape or cards for off-line listing, or can be automatically printed on-line.

Table I is a condensed listing of a small "library" of computer programs covering the areas of network analysis; conventional filter design; modern insertion-loss synthesis filter design; network transformations and coil designs; and evaluation of network-function polynomials. The following paragraphs describe some of the programs listed in the Table.

NETWORK ANALYSIS PROGRAM

The ladder analysis program, written in FORTRAN, is based on the recurrent relations of voltage, current, impedance, and admittance in the alternate series and shunt branches of a ladder network. As shown in Fig. 2, a unit output current at a given frequency is assumed, and the branch voltages and currents determined, working from the load back to the source. All currents are complex quantities, with the exception of the output current which is assumed to have a zero phase angle. Once all the branch voltages and currents have been determined, the input immittances and transfer characteristics are computed and printed.

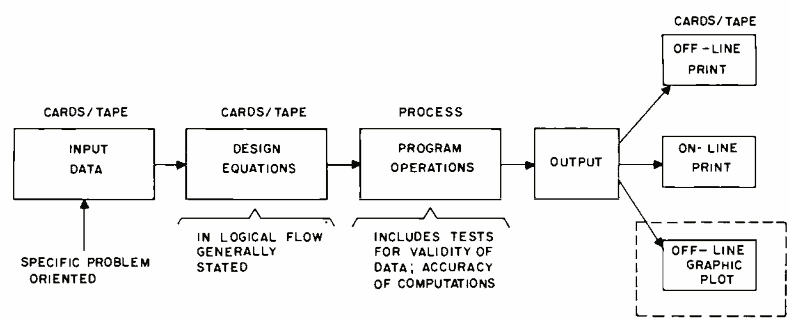


Fig. 1—Typical program flow.

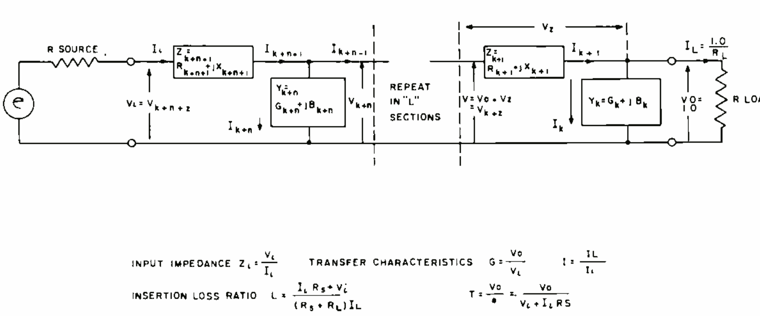


Fig. 2—Ladder network analysis.

Final manuscript received September 15, 1966.

FREQ. HZ	IL.DB	PHASE DEG.	R IN	X IN	REFL. MAGN	REFL. PH. DEG.
.24000000E 05	73.846	205.336	.000	134.433	0.99999994E 00	154.742
.24100001E 05	73.779	205.855	.000	137.285	0.99999999E 00	154.224
.24200001E 05	73.727	206.395	.000	140.251	0.10000000E 01	153.687
.24300001E 05	73.693	206.955	.000	143.338	0.99999994E 00	153.128
.24400001E 05	73.680	207.537	.000	146.554	0.10000000E 01	152.548

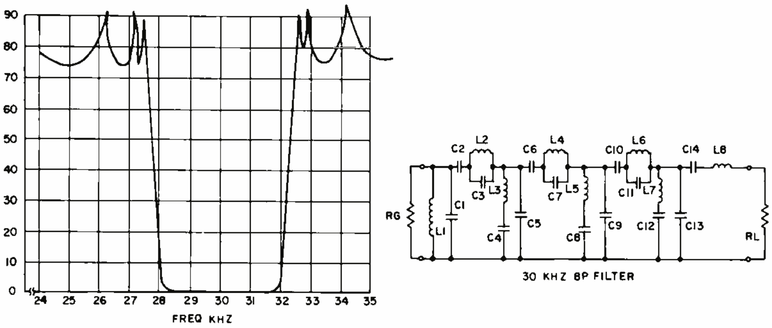


Fig. 3—Sample output of ladder analysis, 30 kHz bandpass filter network.

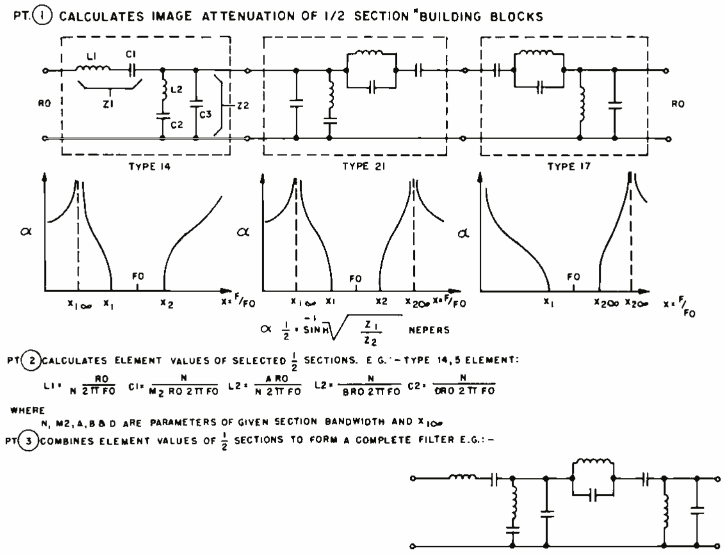


Fig. 4—Image parameter bandpass filter design.

The procedure is then repeated at the next given frequency. A coded description of the series and shunt branch configurations, in terms of RLC elements, is included in the input data, together with the frequencies at which the analysis outputs are required. These outputs are normally insertion loss in dB, insertion phase shift in degrees, input impedance, input reflection coefficient, and return loss.

A sample output for an analysis of a 30 kHz symmetrical BPF ladder network is shown in Fig. 3. Execution time on an RCA-301 computer for this 16th-order (8-coil) network was: read-in, 30 seconds; execute and print, 3 seconds per frequency.

IMAGE PARAMETER BPF DESIGN PROGRAM

The image parameter BPF design programs include a set of three programs as shown in Fig. 4. The first calculates the summed image attenuation of any given number of BP half-section "building blocks", at any given number of stopband frequencies. The BP half-sections can be selected from a table of 21 different types, including constant-K and m-derived 4-, 5-, and 6-element types. Information as to the BP center frequency, the cut-off frequencies, and the number and type of BP half sections must be entered as input data.

The second program calculates the element values for each of the given BP half-sections, and the third program

TABLE I—Analysis and Design Program Sets

Title	*Purpose*
Network Analysis Program (ladder, lattice, networks)	Analyzes these networks for steady-state transmission and input/output characteristics.
Image Parameter BPF Design	Calculates element values for Image Parameter band pass filters.
Ladder Network Realization	Realizes an open circuit driving point impedance function as an LC ladder network.
Synthesis Programs	Given the transfer or characteristic function for a four-terminal network, generates the open-circuit driving point impedance functions.
Filter and Section Transformation Programs	Transforms normalized LP networks to LP, HP, BP networks at any freq. range or impedance. Provide impedance transformation sections to adjust element values in networks.
Coil Winding Design Program	Determine turns for bobbin-wound pot-core coils, including tolerances.
Evaluating Network Functions	Evaluates network function polynomials for magnitude, phase, and delay.

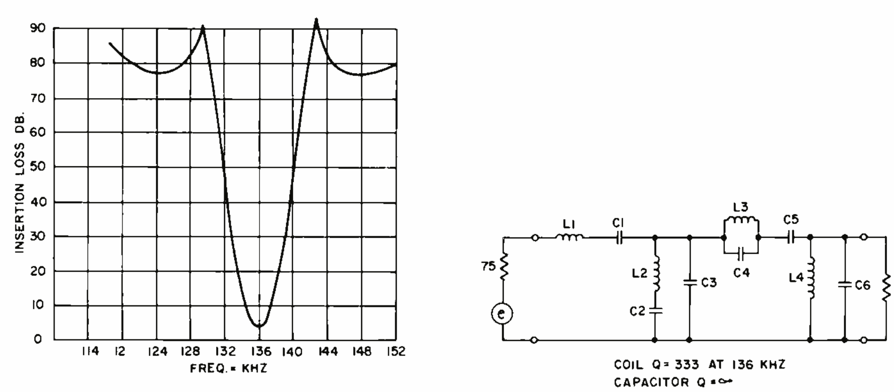


Fig. 5—Image parameter BPF design example, multiplex carrier select filter.

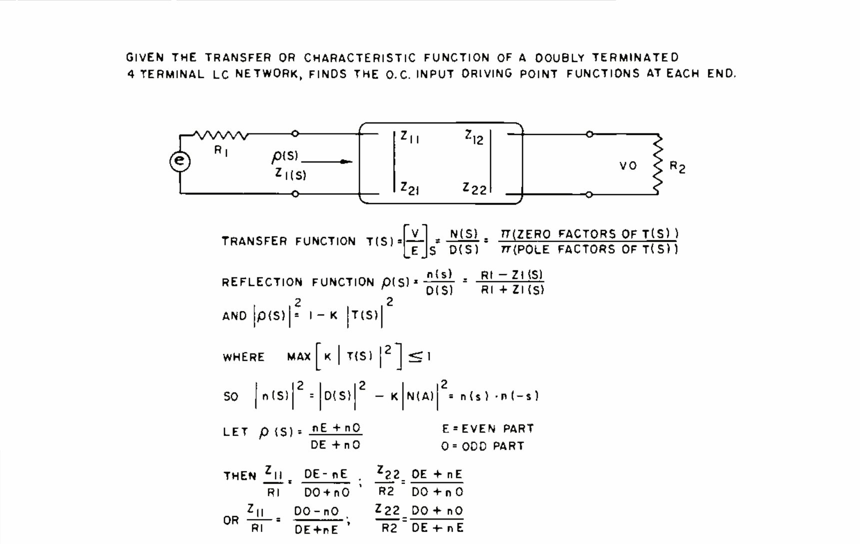


Fig. 6—Synthesis program.

combines these elements to give the complete ladder network.

An example is shown in Fig. 5 of a multiplex carrier select BPF design using three half sections. The attenuation characteristics shown are those computed by the ladder analysis program for this network with coil Q's of 333 at 136 kHz. Execution time for this design on an RCA-301 computer was:

- Part 1—read-in 20 seconds, execute 2 seconds per half section per frequency;
- Part 2—read-in 30 seconds, execute 4 seconds per half section;
- Part 3—read-in 30 seconds, execute 2 seconds per half section.

These programs produce conventional image parameter BPF designs which do not consider the effects of section and termination mismatch and reflection loss, or the effects of network element dissipation, etc.

MODERN NETWORK SYNTHESIS

For precise, complex designs meeting stringent pass and stopband requirements with a minimum number of elements, network synthesis procedures must be used. Insertion-loss filter design by modern synthesis techniques can be divided into three main problem areas:

1) The *approximation* problem: A suitable describing network function must be generated, as the ratio of two polynominals in complex frequencies, which approximates (in some acceptable sense) the required transmission performance on the $j\omega$ axis.

2) The *synthesis* problem: The network-describing function must be manipulated to obtain a driving-point immittance function of a physically realizable network.

3) The *realization* problem: This driving-point immittance function must be manipulated and expanded so as to allow RLC elements or RLC "sections" to be extracted. For a ladder realization, this extraction proceeds until there is no remainder left from the original immittance function.

Because of numerical accuracy problems, large numbers of significant digits must be carried in these manipulations if 3- or 4-place accuracy in the final element values is desired. For networks up to the 16th order, 16 significant digits may be required in all numerical calculations. Coupled with a large amount of arithmetic calculations, algebraic manipulations, and polynomial factoring, this dictates the use of digital computer programs for filter synthesis design. The realization and synthesis programs have been previously described by T. G. Marshall.[2] For the approximation problem, we have successfully used an unique potential analog plane[3] and network function evaluation programs.

SYNTHESIS PROGRAM

A brief outline of the synthesis program is shown in Fig. 6. Given a transfer or characteristic function of a doubly-terminated four-terminal network, this program finds the open-circuit driving-point functions for the network. The transfer function must be given as the ratio of two polynomials in s (factor form). Numerator and denominator polynomials up to the 16th order have been successfully handled. The transfer function poles and zeros can be (uniformly) predistorted to allow for known element dissipation. The program forms the squared magnitude of the input reflection coefficient function numerator from the given transfer function, and then factors this function. Suitable factored roots are then selected and the complete reflection function formed. From the odd and even parts of the numerator and denominator of the reflection function, the two nor-

Fig. 7—Ladder realization program.

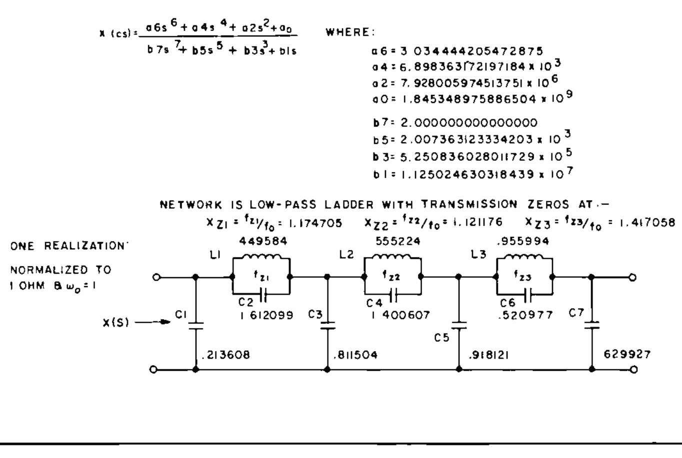
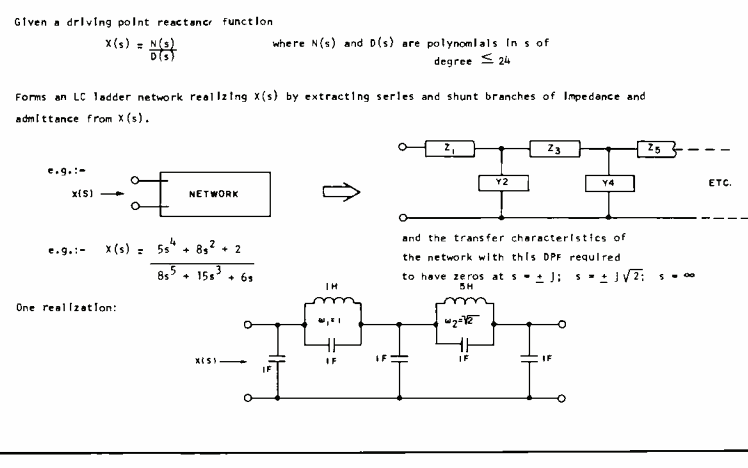


Fig. 8—Ladder network realization example.



malized open-circuit network input impedance functions are then determined. All calculations are carried in 16-digit notation. The factoring routine used is based on a modified Bairstow procedure prepared by N. L. Gordon at the RCA Laboratories.

LADDER NETWORK REALIZATION PROGRAM

For the realization problem, a ladder realization program has been prepared (some details of this program are shown in Fig. 7). This program computes the element values of an LC ladder network which realizes a given open circuit driving-point impedance function, expressed as a ratio of two polynomials in s. These numerator and denominator polynomials can be up to the 24th order. The program proceeds by extracting series and shunt branches of impedance and admittance from the driving-point function, using the section extractions given by Saal and Ulbrich.[4] The program also extracts branches forming specified transmission zeros, and normally does this in an automatic procedure which selects that sequence of transmission zero removal which minimizes the probability of producing non-realizable elements in succeeding sections. The final realization, of course, is not unique. Many different structures and sets of element values can be derived by different sequences of section removals; by partial section extractions; and by removing the transmission zeros in different orders.

Fig. 8 shows an example of a LP ladder network realization for a 7th order structure. Note that the coefficients of the $Z(s)$ numerator and denominator are given with 16 digits. This program was written in Bell L1-650 language. Machine time on an IBM-650 computer for this example was approximately 10 minutes.

An example of the use of both the synthesis and realization programs is shown in Fig. 9. A 16th order BP network was designed to pass the band 12 kHz to 59.4 kHz, and provide stop-band attenuation over 40 dB from 60.6 kHz to 180 kHz, and over 70 dB from 180 kHz to 228 kHz. The network shown was realized to have unequal terminating resistances. The analysis shown is for the complete network with average coil Q's of 375 at 60 kHz. This program was written in Bell L1-650 language, and execution time on an IBM-650 computer for this example was approximately 65 minutes for synthesis and 30 minutes for realization.

FILTER AND SECTION TRANSFORMATION PROGRAM

Many filter requirements can be most economically met by designing networks which provide a "standard" type of transmission response, such as Chebychev, Butterworth, or elliptic function types. Computer-derived tables of normalized ladder element values are available in the literature[5,6] for networks which provide the LP form of these "standard" functions. Programs for automatically scaling and transforming such normalized tables of element values to LP, HP, BS, and BP filters at any specified frequency, bandwidth, and impedance level then provide useful design tools.

Two such programs are briefly outlined in Fig. 10. These programs are written in FORTRAN, and allow scaling and transforming of up to 20th order, all-pole, or 13th order, m-derived, LP networks. As an example of a 7th-order elliptic function LP, the execution time on an IBM-301 was: read-in and compile, 2.5 minutes; execute and print, 7 seconds. For a 5th order Chebychev LP-to-BP example, the execution time was: read-in and compile, 1 minute, 50

FRANK M. BROCK graduated in 1950 from the University of Alberta, Canada, with a BSEE. He received his MSEE from the University of Pennsylvania in 1962. Following graduation in 1950, he worked one year on the G.E. Test Course with the Canadian General Electric Co. in Canada, and then joined the Electronics Dept. of C.G.E., working on radar and microwave communications equipment. In 1953, he joined the Microwave Engineering Dept. of RCA in Camden, N. J. to participate in the design and development of frequency division multiplex communications equipment and systems. From 1954 to 1957, Mr. Brock contributed to the original development program for the AN/GRC-50 radio relay equipment, in the areas of local service telephone system practices and circuits, and feedback amplifier design. From 1957 to 1961, he contributed to the design of custom voice and data multiplex equipment, intermodulation noise test sets, and special communications systems wave filters. Since 1961, he has acted as Project Engineer for the development of the CT-42 solid state FSK telegraph data equipment; the development of precision filters and networks for the CV-600 voice multiplex equipment; and for advanced development studies in network synthesis and data communication systems. Mr. Brock is a Registered Professional Engineer of the Province of Ontario, and a member of the IEEE and the IEEE professional groups on Circuit Theory, Communications Technology, and Computers. He holds three U.S. patents.

Fig. 9—Synthesis design example, 12 to 60 kHz bandpass filter.

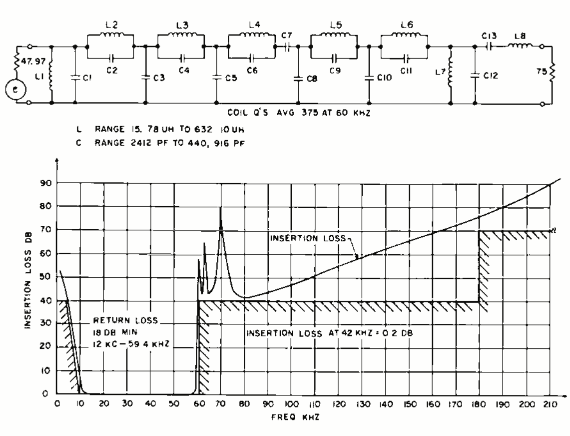
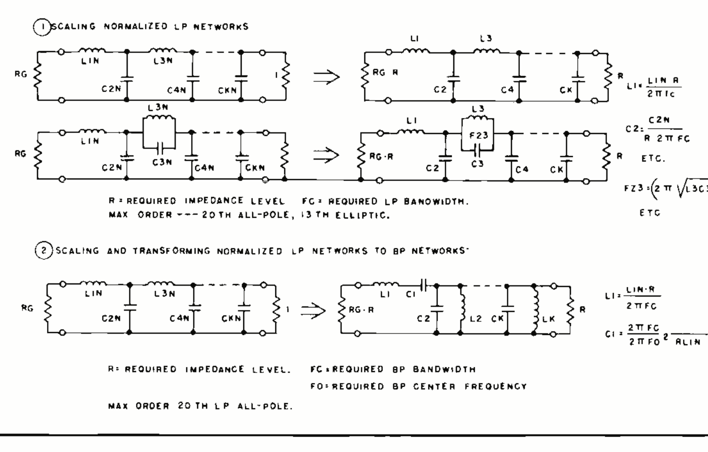


Fig. 10—Network transformation programs.



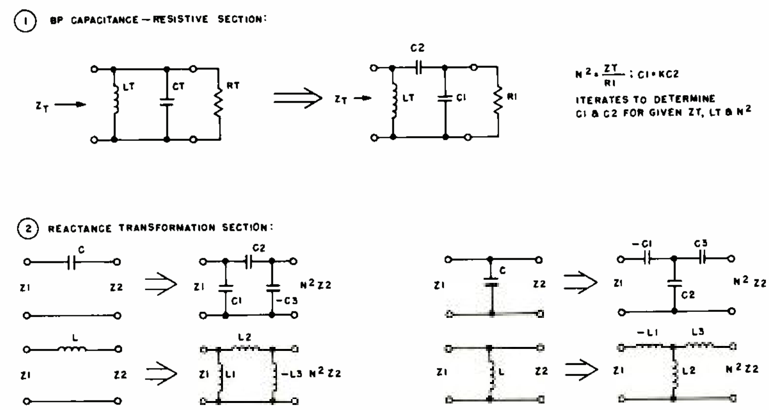


Fig. 11—Section transformation programs.

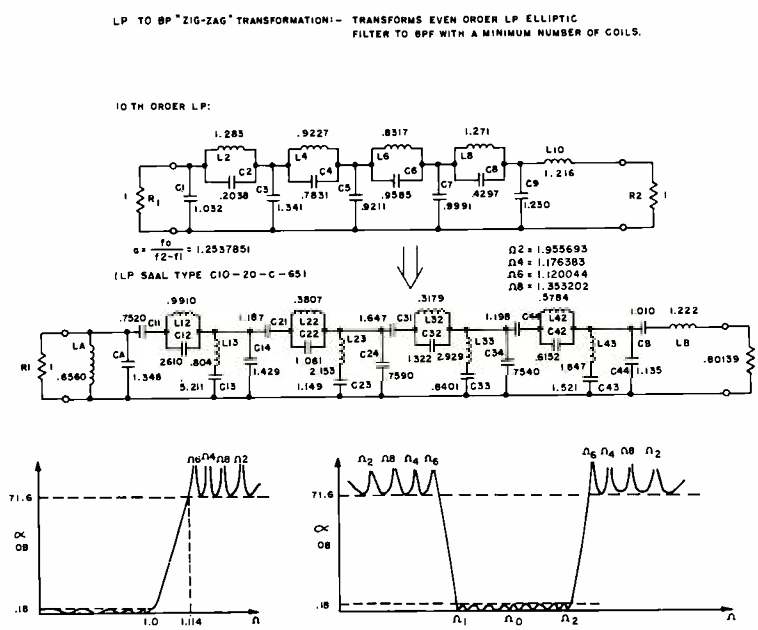


Fig. 12—Minimum inductance network transformation program.

seconds; execute and print, 7 seconds.

Given network structures can frequently be improved for production by applying impedance transformation sections. These sections can be used to eliminate wound transformers; make element values more acceptable for production; and sometimes to eliminate elements. Fig. 11 shows some details of two FORTRAN programs for transformation sections used for BP networks. These programs require a minimum of input data (one card per problem); read-in and compile in less than 2 minutes on 301, and execute and print in less than 5 secs. per problem. Any number of sections can be run sequentially, allowing a family of transformation levels to be quickly determined for design purposes.

COIL WINDING DESIGN PROGRAMS

In transforming LP networks with finite zeros of transmission into BP networks, the usual LP to BP transformation applied to a LP network with N reactive elements results in BP networks with N coils. The number of coils in BP networks derived from even order elliptic function LP networks can be minimized by using section-by-section transformations, such as the "Zig-Zag" transformation.[7] A description of this transformation is given by Saal and Ulbrich.[4] This transformation, when applied to elliptic function LP networks of even order n (and $(3n\text{-}2)/2$ reactive elements) produces BP designs of order $2n$ with n coils. This is a % reduction in coils of $100\ (n\text{-}2)/(3n\text{-}2)$. The reduction in coils is obtained at the price of additional capacitors in the BP network. Fig. 12 shows an example of a 10th-order LP elliptic network with four finite transmission zeros, transformed to a 20th-order BP network with ten coils. The designs shown assume lossless elements. The BP network has a transmission characteristic geometrically symmetrical about the center frequency. Execute and print time on an RCA-301 for this example was approximately 40 seconds.

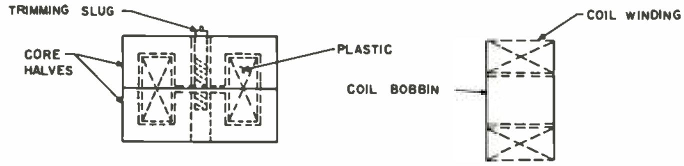
These filter designs have all been constructed with polystyrene and mica capacitors, and ferrite pot-core inductors. These high-Q ferrite inductors provide many desirable features for use in precision filters. The coil windings are bobbin wound in single or multiple sections. A FORTRAN program has been prepared for determining the coil turns for such windings, for a guaranteed minimum inductance range centered on the nominal inductance design value. Core nominal permeability (and specified tolerance), trimming slug range, and bobbin winding factors, are included and taken into account in calculating the required coil turns to the nearest one half turn. Fig. 13 shows an outline of these relations. This program reads and compiles in 2 minutes, 10 seconds; executes and prints in 2 seconds per coil, on an RCA-301 computer. Any number of coil windings can be calculated sequentially.

EVALUATING NETWORK FUNCTIONS

An important operation in the network synthesis procedure is the checking of the network function derived for the approximation problem. This transfer or characteristic function must be evaluated for steady-state magnitude, and perhaps also phase or delay, on the $j\omega$ axis to verify its acceptability in meeting the required transmission. Such an evaluation program has been written in FORTRAN for network functions given as pole and zero factors, as shown on Fig. 14. The program will handle up to 50th-order numerator and a 50th-order denominator. Fig. 15 shows, in some detail, an example of an 8th-order BP transfer function, evaluated in the pass-band region from 2.945 kHz to 3.005 kHz. The program will automatically compute up to 999 frequency points, commencing at a given starting frequency and incre-

Fig. 13—Coil winding design program.

Ferrite pot-core inductors for filters:



Core inductance factor   Al = (henries × 10^{-9})/($turns^2$)

Basic inductance relation: $L_{uh} = \frac{(turns)^2}{10^3} Al$

Winding factors:

- Inductance trimming range = DELTAL
- Minimum trimmer effect = DELMIN
- Core permeability tolerance = ± UTOL
- Coil factor = CF   (effect of partial bobbin filling)
- Req'd. inductance adjustment range = ± RANGE

Coil winding design relations:

$$\text{Coil uh min.} = \left[\frac{(turns)^2\, Al(1+CF)\,(1+UTOL)\,(1+DELMIN)}{10^3}\right] \le \left[\text{coil uh nom. } (1-RANGE)\right]$$

$$\text{Coil uh max.} = \left[\frac{(turns)^2\, Al(1+CF)\,(1-UTOL)\,(1+DELTAL)}{10^3}\right] \ge \left[\text{coil uh nom. } (1+RANGE)\right]$$

Program computes and checks coil turns to nearest ½ turn to meet above.

Fig. 14—Program for evaluating network functions.

$$F(S) = H\left[\frac{\prod_{i=1}^{10}(S+\sigma_{oi})\prod_{i=1}^{20}(S+S_{coi})(S+S^*_{coi})}{\prod_{i=1}^{10}(S+\sigma_{pi})\prod_{i=1}^{20}(S+S_{cpi})(S+S^*_{cpi})}\right]$$

$$= H\left[\frac{\prod_{i=1}^{10}(S+\sigma_{oi})\prod_{i=1}^{20}(S^2+2S\sigma_{coi}+\sigma_{coi}^2+\omega_{coi}^2)}{\prod_{i=1}^{10}(S+\sigma_{pi})\prod_{i=1}^{20}(S^2+2S\sigma_{cpi}+\sigma_{pi}^2+\omega_{coi}^2)}\right]$$

EVALUATES:

MAGNITUDE db = $20 \log_{10} |F(j\omega)|$

PHASE = $\theta = \tan^{-1}\left(\frac{ImF(j\omega)}{REF(j\omega)}\right)$

ENVELOPE DELAY = $\frac{d\theta}{d\omega}$

} FROM POLE-ZERO LOCATIONS OF F(S)

WHERE:

- H = CONSTANT MULTIPLIER NOT EQUAL TO ZERO.
- σ_{oi} = REAL ZERO IN R.P.S.
- σ_{pi} = REAL POLE IN R.P.S.
- σ_{coi} = COMPLEX CONJUGATE ZERO PAIR REAL PART IN R.P.S.
- ω_{coi} = COMPLEX CONJUGATE ZERO PAIR IMAGINARY PART IN R.P.S.
- σ_{cpi} = COMPLEX CONJUGATE POLE PAIR REAL PART IN R.P.S.
- ω_{cpi} = COMPLEX CONJUGATE POLE PAIR IMAGINARY PART IN R.P.S.

Fig. 15—Example of bandpass transfer function evaluation.

Given Roots of T (s):-

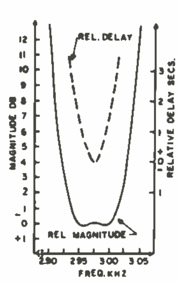
No zeros at D.C.
No complex conjugate zeros.

8 PAIR COMPLEX CONJUGATE POLES:

$P_1 = -1.889479\times10^2 \pm j\,1.8271502\times10^4$
$P_2 = -1.889479\times10^2 \pm j\,1.9309201\times10^4$
$P_3 = -2.024568\times10^2 \pm j\,1.8409732\times10^4$
$P_4 = -2.095694\times10^2 \pm j\,1.8579378\times10^4$
$P_5 = -2.024568\times10^2 \pm j\,1.8836989\times10^4$
$P_6 = -2.024568\times10^2 \pm j\,1.9012918\times10^4$
$P_7 = -1.889479\times10^2 \pm j\,1.9082033\times10^4$
$P_8 = -1.846377\times10^2 \pm j\,1.9138582\times10^4$

SAMPLE OUTPUT:

FREQ. HZ	MAGN DB	PHASE DEGR.	DELAY SECS.
0.29450000E 01	-0.30103000E 00	-0.15821180E 02	0.21238350E 01
0.29550000E 01	0.52740000E-01	-0.10266900E 03	0.12119190E 01
0.29650000E 01	0.70760000E-01	-0.50178040E 02	0.42695300E 00
0.29750000E 01	0.00000000E-99	0.24000000E+02	-0.50000000E+05
0.29850000E 01	0.22160000E-01	0.49862910E 02	0.27394200E 00
0.29950000E 01	0.42460000E-01	0.10181334E 03	0.10893330E 01
0.30050000E 01	-0.21501000E 00	0.15701479E 03	0.20390640E 01



menting by a given frequency increment. The program will also compute the magnitude (dB), phase (degrees), and envelope delay (seconds) relative to those values at a given reference frequency. This is convenient when only relative variations in a given frequency range are of interest. The example shown, executed on an RCA-301 computer was read-in and compiled in 2.5 minutes, and executed with on-line print at 2 seconds per frequency.

SUMMARY

A number of useful computer programs for filter design and analysis have been briefly described. These programs, along with others, have been used as design tools during the past six years in the design of over 60 different filter networks of varying degrees of complexity. Many of these designs could not otherwise have been accomplished except by the expenditure of considerably greater engineering design effort, and then only for designs with more elements and therefore higher production cost. In all types of designs, these programs have reduced model construction to a bare minimum, and have insured that numerical design errors were also held to a minimum.

With the availability of high speed, large memory, computing systems in RCA facilities, arranged for efficient engineering design access, it is hoped that these programs can be improved, expanded, and integrated to further increase filter and network design capability.

ACKNOWLEDGEMENTS

These computer programs were developed during the network design phase of the CV-600 Carrier Multiplex equipment development, directed by Mr. H. F. L. Cameron. Special acknowledgement is given to J. F. Parker for programming assistance, and to T. G. Marshall for the circuit theoretic and programming work on the synthesis and realization programs.

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NEW COLOR TELEVISION MOBILE UNIT

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A REVIEW of the television networks' experience with mobile equipment shows that following the period 1948-1954, when there was great activity in building monochrome units and a few isolated color units, a lapse of several years occurred before interest was again stimulated to produce more color mobile equipment. It is most interesting to note that during this interval an ever increasing percentage of live programming was being produced with mobile units. Operational experience with some of the more spectacular events, such as political conventions, inaugural ceremonies, as well as all types of sporting events of national and international importance, forceably brought to the attention of programming and engineering managements the inadequacies of existing equipments. It is also true that the majority of the early mobile units, compared to today's standard, had minimum technical facilities and in almost every instance, once the equipment was installed and tested, it was painfully realized that there was barely none for program personnel and client enough room for technical personnel and representatives.

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The "novelty" days of programming from the field are over; today it is not uncommon to find field production requirements in excess of those of a studio. Not only is there the demand for more cameras, but additional facilities to process camera signals, insert titles, intermix video tape for instant replay, genlock to other remote locations, and many other features are required for the simplest type of field production. Consideration of all these factors, and the rapid expansion from monochrome to color operations dictated an entirely new concept of mobile unit design. Therefore, new NBC mobile units have been designed and constructed to conform with the following criteria:

1) Highest standards of technical performance;
2) Allocation of adequate and comfortable space for all personnel;
3) Provision for interior comfort over a wide range of outside temperature;
4) Esthetic attractiveness; and
5) Minimum transport delay caused by engine or power train failure.

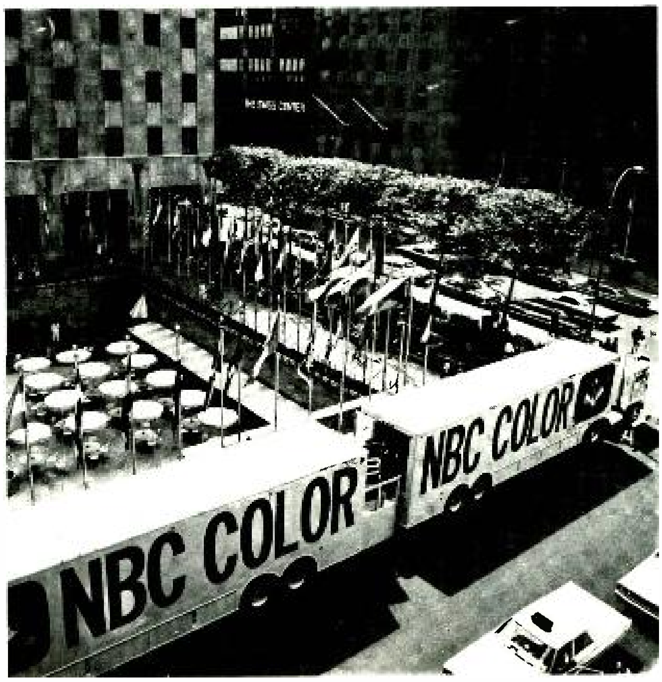
In September 1965, NBC put into service the first of a series of color mobile units designed to these specifications, in August 1966 a second series, and a third series is scheduled for delivery August, 1967.

VEHICLES

An NBC color mobile complex is comprised of three air-ride 40-ft tractor-driven trailers, designated: *A*, equipment unit; *B*, control or production unit; and *C*, carryall. Fig. 1 is a photograph of the units built in 1966. The trailers are custom built and incorporate many special features, including 2 inches of insulation on all walls and top, underfloor cable trenches, and recessed lighting and air conditioning distribution. The first two units, *A*, and *B*, are equipped with adequate ventilation, heating and cooling to provide comfortable interior conditions over a range of outside temperature from +10°F. to +100°F. These vehicles comply with all legal and safety requirements in all states, and equipped are loaded to approximately 75% axle capacity.

Two very important vehicle design features included in this complex are tractor drive and air suspension, which warrant

Fig. 1—Photos of units in rockefeller plaza.



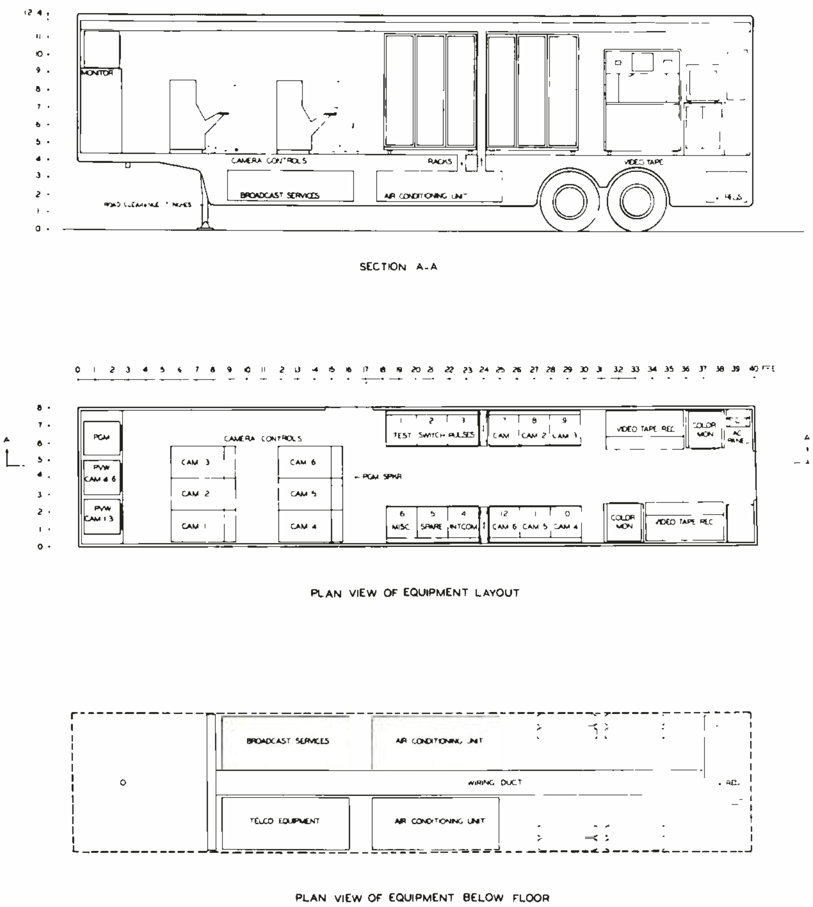
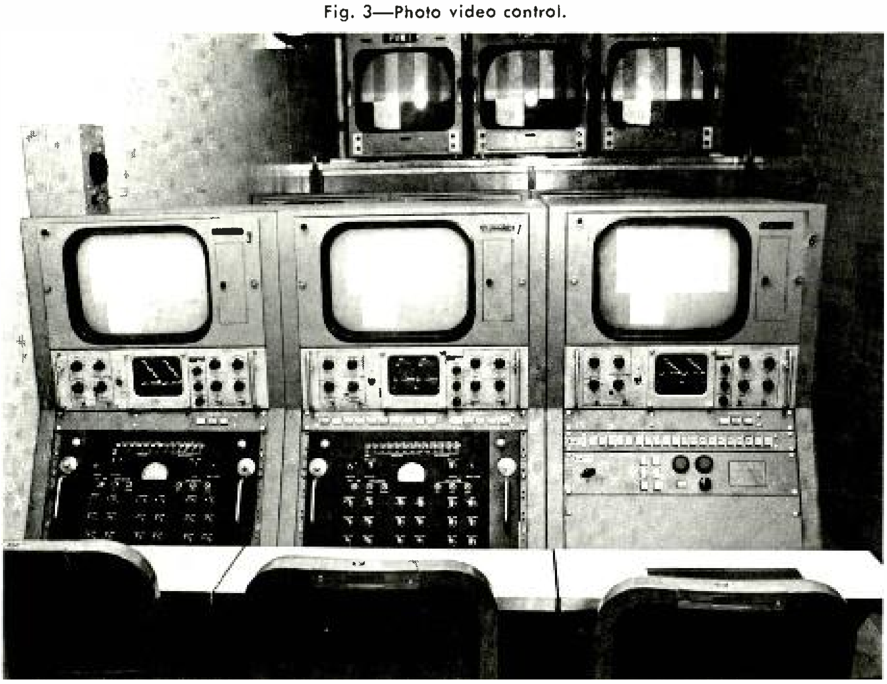


Fig. 2—Diagram of "A" unit.

Fig. 3—Photo video control.



further explanation. Tractor drive offers greater reliability of transport than a self-powered vehicle because any relatively simple engine breakdown or other mechanical failure of a self-powered vehicle may cause a delay of several days, whereas a faulty tractor can be replaced in every part of the country within 2 to 3 hours. Furthermore, the all too common problem of an overloaded self-powered vehicle can be avoided. Air suspension was selected in preference to conventional leaf springs because of higher efficiency isolation to road shock. Thus, by having the mass of the entire vehicle shock-mounted, the use of individual equipment mounts was unnecessary, saving valuable equipment mounting space. as well as being more economical.

POWER

Power required to operate the mobile complex may be either 208-volt-AC 3-phase 4-wire, or 230-volt-AC single-phase 3-wire, and the total current drain with all technical equipment and air conditioners operating is 230 to 250 amperes per phase. The *A* unit is equipped with two 4-ton air conditioners and the *B* unit with two 2-ton units. These units represent a substantial part of the total power load and are operated on 230-volt-AC single-phase 3-wire power. The design of the power distribution system would have been less complicated and more efficient with a 3-phase 208-volt-AC 4-wire source. However, there are many areas, particularly in nonindustrial districts, where only a 230-volt single-phase 3-wire source is available. Voltage regulators are provided in the *A* and *B* units for technical equipment only. Other elements, such as air conditioning units, general lighting and convenience outlets, are supplied with unregulated power.

TELCO EQUIPMENT

The *A* and *B* units have permanently installed telephone facilities with a number of private line extensions in each unit. This equipment was installed by the telephone company in accordance with NBC specifications, and like any other phone has a monthly rental charge. The advantages gained from this type of installation are:

1) The instruments are always in the same location;
2) Connections to external telco lines are made in an underfloor compartment, eliminating the disturbance and confusion caused by an installer fastening wires all over the inside of the vehicle;
3) The time required to establish telephone communications is reduced to a minimum with the resultant economy in job setup time.

CAMERA OR EQUIPMENT "A" UNIT

The equipment or camera vehicle referred to as the *A* unit shown diagramatically in Fig. 2 combines into one vehicle the functions of camera or video control, pulse generation and distribution, transmission, test and video tape. Starting at the front of the unit and proceeding to the rear is the following equipment: three color monitors used for camera balancing and program monitoring; six video consoles, five for TK41 three-image-orthicon color cameras, and the sixth for a monochrome insert camera (see Fig. 3); a group of 12 equipment racks containing the equipment associated with the color cameras, pulse generation and distribution, video transmission, test equipment, and the intercommunications system. (See Fig. 4). Moving further toward the rear are two color video tape recorders with monitoring and tape storage facilities, and at the extreme rear right is the power panel equipped with metering for line voltage and current and branch circuit distribution of similar type to that employed in any central plant system. Opposite the power distribution panel is a coat closet for the crew. Air conditioning controls are located on the wall about the midpoint of the vehicle. In addition to the normal thermostat these controls include switching for ventilation, heating or cooling, and, as a special precautionary measure, Magnehelic gauges are installed in the supply ducts to indicate air velocity. Because the air conditioning is a closed system, any obstruction in either the supply or return ducts can be detected by a change in the indication of the Magnehelic gauge, thus preventing abnormal or damaging operation of the air conditioning units.

Fig. 4—Photo of rack equipments.

CAMERAS

The camera chains are basically the standard RCA TK41 Image Orthicon color units, except for the repackaging of the console equipment into one 22-inch console employing a 14-inch monochrome camera monitor, a 529 CRO, and the addition of a "cable stretcher" to permit cameras to work with as much as 2000 ft of cable. A variable six-step 0-to-1.2 neutral-density filter system was also added to each camera. The cable stretcher is a variable horizontal-pulse-delay multivibrator which produces early pulses. The feeding of these early pulses to the camera will effectively cancel the increased total video path from control unit to camera and return. The variable neutral density filter system is used by the cameraman to compensate for changes in total ambient light level, such as those changes which occur during the progress of an afternoon football game.

PULSES

The pulse distribution system consists of two synchronizing generators with an emergency automatic changeover feature, two black burst generators and individual isolated pulse feeds to each camera chain. The "sync" pulse is added to video in the colorplexer to obtain composite video output. In normal operation "sync" generator No. 1 feeds the pulse distribution system supplying all cameras and a black burst generator. The horizontal and vertical outputs from "sync" generator No. 2 are terminated; blanking, burst flag, "sync", and subcarrier are fed to the second blank burst generator. This configuration of the No. 2 or standby synch generator feeding the second black burst generator provides a steady state composite video reference for synch generator No. 1 when operating in the genlock mode. A typical example of this operation would be to assume that cameras are being fed from synch generator No. 1 which is genlocked to generator No. 2 until it is required to switch to a nonsynchronous video source. Prior to the technical director switching the program bus from the local camera to a nonsynchronous source, the input to synch generator No. 1 can be switched from black burst generator No. 2 to the incoming nonsynchronous video signal. The local camera, while "on the air," will take a slow rate of vertical lockup, and, when vertical and horizontal coincidence have been established, any type of switching or special effects can be performed between the two signals. Coincidence of the local and the nonsynchronous signals is indicated by a tally light located on the technical director's console. The synch comparator circuit which delivers information to the synchronous tally indicator also inhibits the accidental mixing of any two nonsynchronous video signals until coincidence has been established. The method of mating synch generators and black burst generators not only achieves fast genlock operation, but also provides a very convenient method of synch generator testing because it eliminates the old procedure of requiring the discontinuance of pulse feeds to cameras when switching generators.

COMMUNICATIONS

The local communications system provided with this mobile complex actually consists of three separate and distinct systems:

1) IFB (Interrupted feedback);

2) Headset interphone;

3) Engineering command (squawk box).

The IFB system used by NBC is exactly what the name implies, program monitoring feedback to all local and remote locations which can be interrupted by the program coordinator for verbal instructions. This system is used primarily by

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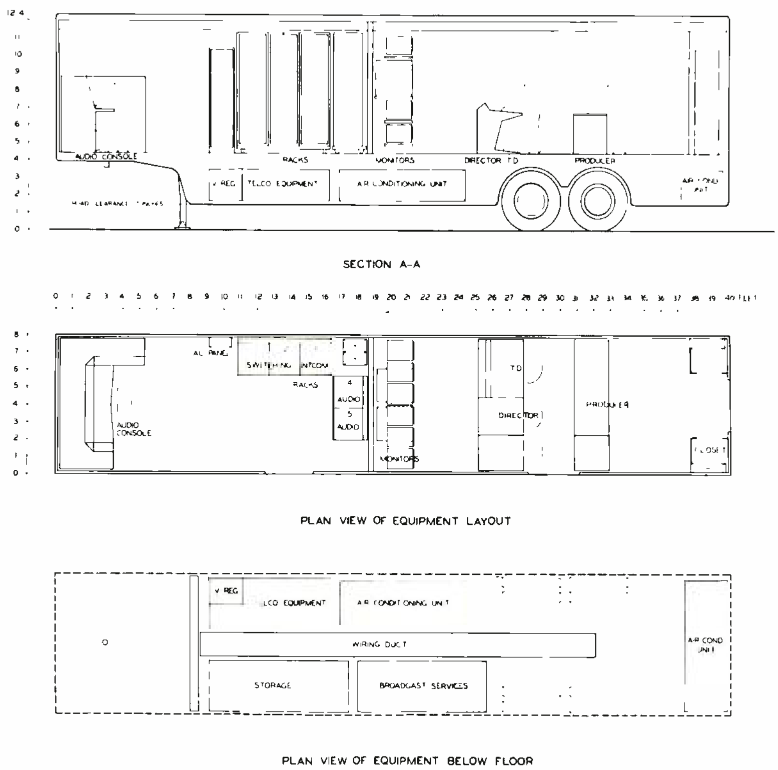


Fig. 5—Diagram of "B" unit.

production personnel. The Headset interphone system is shared jointly by engineering and production personnel for the relaying of instructions via conventional headset type equipment and may, if required, be connected to the Telco private line. The Engineering command is used by engineering personnel only for the relaying of technical information to a limited number of critical locations via loud speakers. The combination of these three systems may on the surface appear to be superfluous. However, experience has taught that thorough understanding of all instructions is the key to good production and technical operations. This is particularly true in the field where operating locations are more widely dispersed than in the studio. The design of the communication system was made so that all three phases may be expanded as operating conditions require.

VIDEO TAPE

The video tape section is equipped with two TR-22 color-TV tape recorders with associated monitoring and switching facilities. These recorders may be used for on the spot prerecording, such as interviews, instant replay or any other type of recording requested by the program director.

CONTROL OR PRODUCTION "B" UNIT

The control or production vehicle (Fig. 5) incorporates all the mechanical features of the *A* unit. However, because of its function, there is an entirely different interior layout. It is divided by a centrally located partition into two separate compartments each of which is provided with 2-tons of air conditioning. Starting at the front there is the audio control room with console, associated equipment racks, video switching racks, power distribution panel, plus adequate space for tape recorders, turntables, technical and production personnel. The second compartment contains all production monitors, director's console, TD switching console, comfortable seating for six program and technical personnel, and two convenient coat closets at the rear. It is in this area that the greatest departure from conventional mobile unit design has been made. The two units, *A* and *B*, although designed primarily to operate as a pair, may be operated individually or with other units as required.

AUDIO

The audio system, comprised of a console, Fig. 6, with self-contained jackfield and two equipment racks, was constructed to a design employing RCA BN-16C transistorized field amplifiers. Auxiliary services such as monitoring feeds, loud speaker drivers and facilities to feed split outputs employ the conventional line of RCA audio amplifiers of the BA-31-34 series. To enumerate all facilities within this system and describe the intergration would warrant a separate paper on audio alone. However, the following is a listing of some of the more important audio features:

1) 32 active microphone inputs;
2) 4-position submixer;
3) 30 switchable nemo job inputs with preview and level setting facilities;
4) regular and emergency program amplifiers;

Fig. 6—Photo audio console.

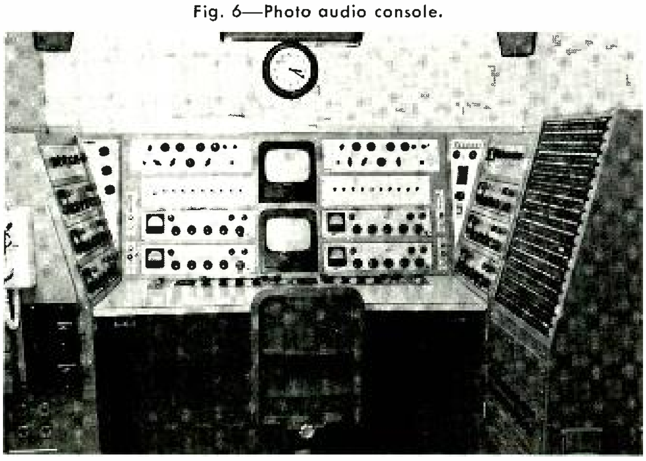
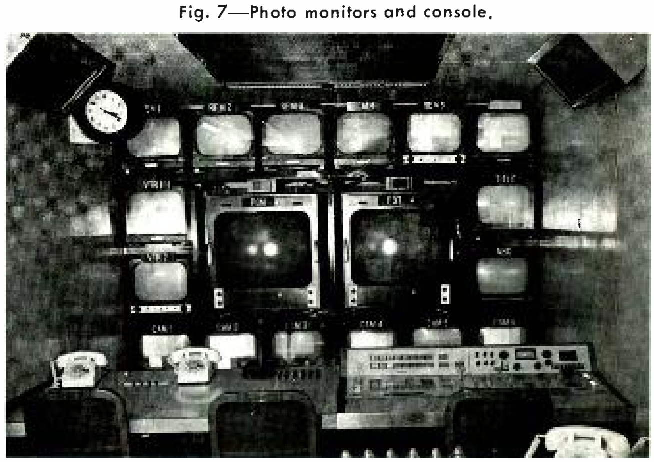


Fig. 7—Photo monitors and console.



5) program and preview video monitoring;
6) audio-video tracking switching on 20 inputs;
7) 4 patchable no-loss audio filters;
8) 2 patchable audio compressors;
9) 2 Pultec variable effects filters;
10) 8 utility patchable faders;
11) ample spare coils, keys and line isolation pads.

Test results of the system show the overall frequency response to be $\pm$ 1 dB from 50 to 15,000 Hz, noise level 56 dB below + 8 vu output, and overall distortion at + 16 vu, 0.7% or less. The facilities as noted may appear to be more than necessary for the average program. However, this mobile complex was designed to service not only the average, but the spectacular as well. In this connection, at the Sugar Bowl game in New Orleans this past January 2 a total of 36 microphones were used.

MONITORING & SWITCHING SYSTEM

Production monitors, director and TD consoles are shown on Fig. 7. The basic concept in the design of this portion of the complex was to provide a field equivalent of that employed in any modern day studio. Therefore, a 14-inch monochrome monitor is provided for each source input and two 21-inch color monitors for program and preset. It is of interest to note that to satisfy some producers it was necessary to install a monitor position and tally switching system whereby the assignment of monitors within the bank can be changed without physically being removed to other than normal positions.

The switching system is comprised of a TD console (Fig. 8) and two equipment racks. It is fundamentally an RCA TS-40 solid-state vertical-interval switcher, assembled to handle 19 composite inputs to each of 9 primary buses. Five of the 9 buses, by means of the secondary logic system, are channelled into either of two lap dissolve amplifiers and the special effects system. The 4 remaining buses are used for video previews, video tape, and transmission.

The first five buses designated *program*, *preset*, *A*, *B*, and *C* constitute the program assembly portion. The mechanics of a vertical interval type switcher is well known, making further explanation unnecessary, except to state that logic from a DC source directs the trigger pulse, generated from vertical synch, to the proper cross-point where the actual video switch is made in 1 to 2 microseconds during the vertical blanking interval. Through the use of two lap dissolves and special effects equipment a wide variety of novel program effects, including title inserts, can be achieved.

CARRYALL

The carryall as shown on Fig. 9 is the third vehicle in the complex, designed basically to conform with the old proverb of "A place for everything and everything in place." This vehicle is a standard commercial type trailer equipped with a side located battery operated lift to assist in loading and unloading. Cameras and other pieces of delicate equipment. mounted on special cushioned dollies, cable reels, tripods, and all other miscellaneous items are transported in the carryall. Considerable effort was devoted to developing improved methods of handling, and transporting television equipment. It has paid off, because, with the first complex delivered in 1965, after approximately 40,000 miles of road travel and more than 18 months of continuous service from coast to coast, not one instance of equipment damage attributable to faulty transport has been reported.

ACKNOWLEDGEMENTS

The author expresses appreciation to the several members of the NBC Engineering Department who participated in the design and construction of the new mobile Television equipment.

Fig. 8—Photo TD switching console.

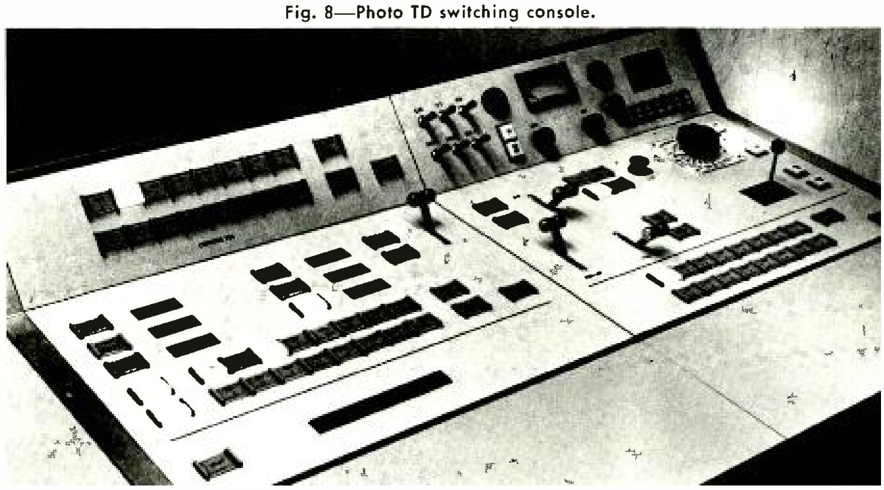
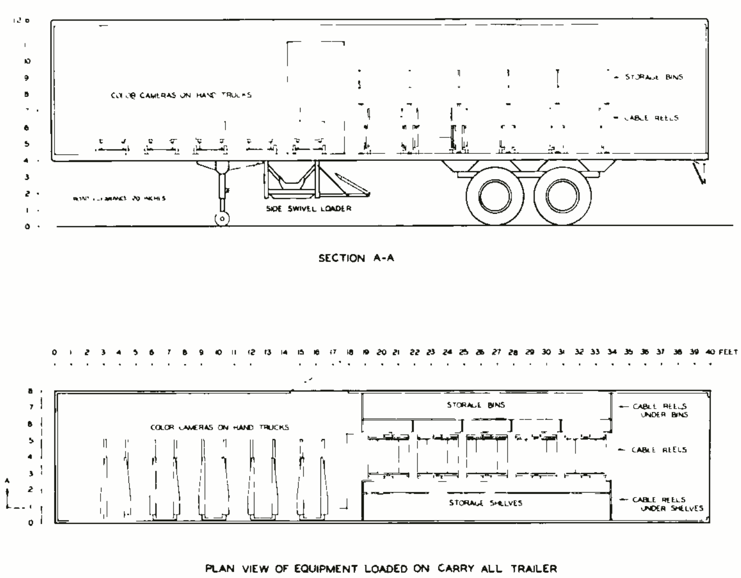
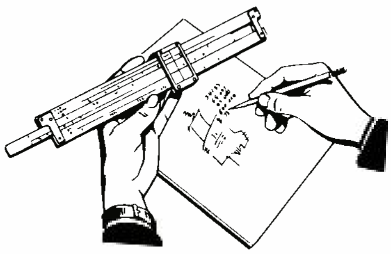


Fig. 9—Diagram of carryall.



Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST



Chopper-less Amplitude Modulator

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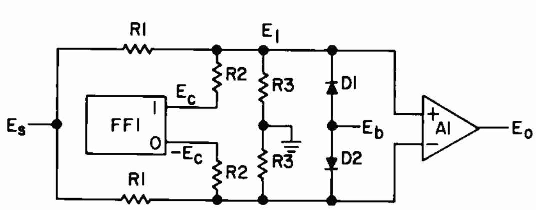
The novel circuit arrangement shown in Fig. 1 simulates the function of a full-wave chopper modulator by using the inverting and non-inverting characteristics of a differential amplifier. The amplifier performs a dual function by providing the amplitude modulated output and also providing use of its gain to increase the signal level. The maximum modulating frequency of operation is set by the gain-bandwidth characteristic of the differential amplifier and the diode impedances.

The waveforms shown in Fig. 2 occur at designated points within the circuit. Flip-flop FF1 provides the carrier frequency voltage E_c; both outputs (E_c and $-E_c$) from FF1 are utilized. The signal voltage, E_s, is resistively summed with the carrier voltage and its inverted complement. Linear superposition of the signal onto the carrier by the summing network causes little distortion of the signal waveform. Diode clippers D1 and D2 allow only positive polarity voltage to pass to the inputs of differential amplifier, A1. (Positive or negative clipping of the signal produces the same result.) Forward biasing of the diodes by a voltage E_b provides an effective means for adjusting the relative amplitudes of signal and carrier voltages. This means full advantage can be taken of the amplifier's dynamic range for increasing the signal level. Differentially, this voltage offset will cancel at the amplifier output with minor adjustments.

Because of the inversion of one of the input voltages through the differential amplifier, the resulting output, E_o, will have the waveform of a full-wave chopper modulator, as shown in the waveform diagram.

Final manuscript received March 22, 1967.

Fig. 1—Full-wave chopper modulator using a differential amplifier.



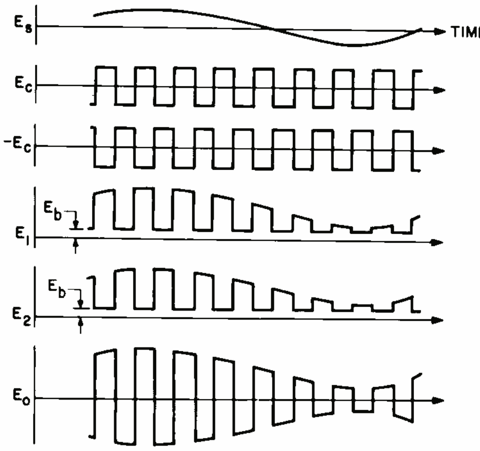
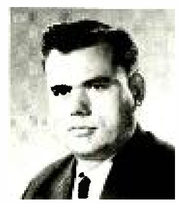


Fig. 2—Circuit waveforms.

A Monostable Multivibrator using an IC Operational Amplifier



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The monostahle multivibrator shown in Fig. 1 is unique in that the same configuration serves as a one-shot multivibrator, a fixed-delay circuit, or a count-down circuit. The addition of a potentiometer allows one to vary the amount of delay or the countdown ratio.

The high impedance characteristic of the integrated circuit operational amplifier is the key to the design. This allows a more convenient selection of the individual values of resistance and capacitance with the resistance much larger than in conventional designs.

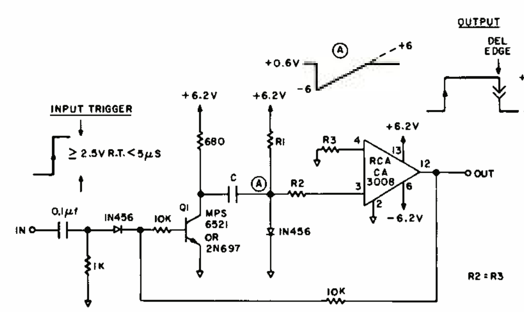
The basic operation of the circuit is based on a high-gain amplifier with positive feedback with a time constant in the feedback path. The actual bias levels are enough to saturate the amplifier into the two basic states, *on* and *off*.

The circuit was tested as a variable-delay circuit and fixed-delay circuit. During the first test, R1 was replaced by a 500 kilohm potentiometer and a fixed 47 kilohm, 5% carbon resistor. As a fixed-delay circuit, R1 was made a 1% fixed-film resistor, R2 and R3 were selected for the best temperature stability, and C was a standard mylar capacitor (CTM).

Special Advantages of the Circuit:

1) When used as a fixed-delay circuit, the duty cycle can be from 10% to 90%.
2) When used as a variable delay circuit, the delay can be varied ten-to-one with R1 at 500 kilohm.
3) A relatively small timing capacitor (10 μF) will give delays of seconds.

Fig. 1—Monostable multivibrator.



4) Very stable delays (better than ±0.2% timing stability) are possible if resistor R1 has a 1% tolerance and capacitor C is selected for temperature stability (good paper or mylar).

5) The output will drive a kilohm load, so the circuit needs no additional output driver or emitter-follower circuit.

Performance Data:

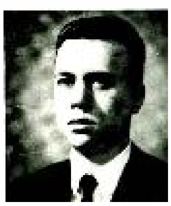
Input Trigger Pulse:	Amplitude	≥ 2.5 Vpp
	Rise Time	< 5 μs
	Width	> 10 μs

		Hi Z Load	*1K Load*
Output Pulse:			
(F.T. edge = delay edge)			
	Amplitude	−3V to +5V	0V to +5V
	Rise Time	≈0.3 μs	≈0.4 μs
	Fall Time	≈0.5 μs	≈0.4 μs

	Delay	*C(μF)*	*R1*	*R2 & R3*
As a variable delay:				
	7 ms to 80 ms	0.22	47-547K	10K
	0.4 sec. to 4 sec.	10	47-547K	10K
As a fixed delay:				
	*17.5 ms	0.22	121K 1%	10K
	*640 μs	0.01	100K 1%	5.6K

* Timing stability ±0.2% for temperature variations from 0°C to +50°C.

Gain Saturation in Crystal Mixers



P. Torrione

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In his analysis, Pantell[1] derives a general power relationship for a nonlinear resistance device with two sinusoidal voltages applied. His analysis is limited to the case of a large local-oscillator voltage and a small signal voltage. The following analysis includes the effect of a large signal voltage applied to the mixer.

The mixer conductance variation with time is now expressed as

$$\frac{\partial i}{\partial v} = g(t) = \sum_{r=-\infty}^{\infty} \sum_{u=-\infty}^{\infty} G_{ru} \exp[j(rx + uy)]. \qquad (1)$$

Using Equation (1) above, Pantell's Equation (26) thus becomes:

$$h_n = \frac{1}{4\pi^2} \int_0^{2\pi}\int_0^{2\pi} \sum_{r,u=-\infty}^{\infty} G_{ru} \sum_{m,n,p,q=-\infty} (-nq) V_{mn} V_{pq} \exp\{j[(m+p+r)x + (n+p+u)y]\}\, dxdy, \qquad (2)$$

where r and u refer to the conductance-variation harmonics of the local-oscillator and signal frequencies, m and p are harmonics of the local-oscillator frequency, and n and q are the signal-frequency harmonics. The x and y terms in the exponent are equal to $\omega_p t$ and $\omega_s t$, respectively, where ω_p and ω_s are the local-oscillator and signal frequencies, respectively. The variables associated with the summations are taken from $-\infty$ to $+\infty$ independently. Using the orthogonality principle to integrate the exponents, the following result is obtained:

$$\sum_{n=0}^{\infty} \sum_{m=-\infty}^{\infty} n^2 W_{mn} = \sum_{r,u,m,n=-\infty}^{\infty} n(n+u) V_{mn} \overset{*}{V}_{(r+m)\,(n+u)} G_{ru}, \qquad (3)$$

where the right hand side is from Pantell's Equation (19), and the term W_{mn} is the power at frequency: $m\omega_p + n\omega_s$.

If we confine our interest to the power at only the signal, IF, and local-oscillator frequencies, and make the power at all other frequencies zero by filtering, Equation (3) becomes:

$$W_{01} = 2\overset{*}{V}_{01}[V_{01}G_{00} + V_{11}G_{10}],$$
$$W_{11} = 2\overset{*}{V}_{11}[V_{01}G_{10} + V_{11}G_{00}], \qquad (4)$$

where equation (4) neglects conductance variations at second and higher harmonics.

From the power relations in Equation (4), the circuit of Fig. 1 is derived. An exponential diode is used and the conductance components are[2]

$$G_{mn} = \alpha I_{sat} I_m(\alpha V_{10}) I_n(\alpha V_{01}), \qquad (5)$$

where α is the diode exponent, I_{sat} is the diode saturation current, and $I_m(\alpha V_{10})$ and $I_n(\alpha V_{01})$ are the mth- and nth-order Bessel functions (of the first kind) with imaginary arguments.

For simplicity in the analysis, the pump voltage across the diode (V_{10}) can be assumed constant, and independent of signal power. The magnitude of this voltage can also be determined as a function of local-oscillator power.[2] Also, since the mixer is generally operated under a small-signal match condition, the values of G_s and G_{IF} can be calculated using V_{01} equal to zero in Equation (5).

Since the conductances are indeterminate functions of signal voltage (V_{s1}), it is necessary to assume a value of V_{01}, calculate the conductances (G_{mn}), and then calculate voltage V_{s1}. From this, the available signal power ($\frac{1}{4} V_{s1}^2 G_s$) can be calculated. The IF voltage (V_{11}) can be calculated from the knowledge of G_{mn} and G_{IF}. The mixer loss,

$$\text{Loss (dB)} = 10 \log \left[\frac{2V_{11}^2 G_{IF}}{V_{s1}^2 G_s}\right] \qquad (6)$$

can then be calculated as a function of available signal power.

A comparison of calculated and experimental data is shown in Fig. 2.[3] It is seen that the theoretical curve agrees, to within 1 dB, with the measured result. The curves were made for 0.5 mW of local-oscillator power.

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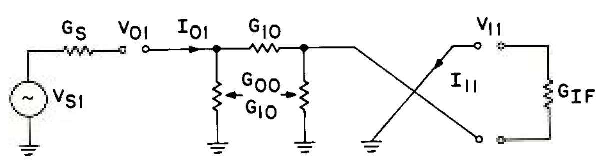
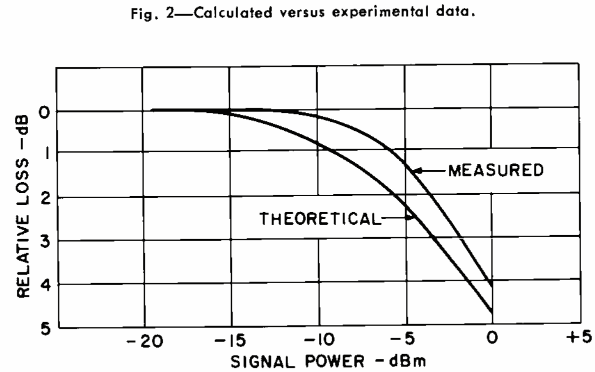
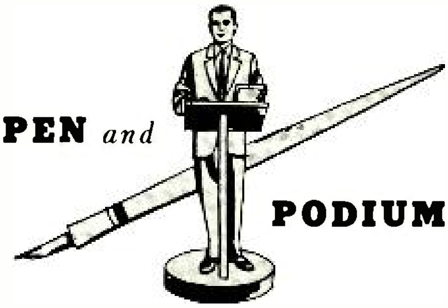


Fig. 1—Derived circuit.

Fig. 2—Calculated versus experimental data.





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RCA LABORATORIES

Multiple Superconductive Element Parametric Amplifiers and Switches—J. Pearl (Labs, Pr) U.S. Pat. 3,324,403, June 6, 1967

Electro-Optical Elements Utilizing An Organic Nematic Compound—R. Williams (Labs, Pr) U.S. Pat. 3,322,485, May 30, 1967

Electrophotographic Reproduction Process Including Removal of Electroscopic Particles from Developed Electrostatic Image—E. C. Giaimo, Jr. (Labs, Pr) U.S. Pat. 3,322,537, May 30, 1967

Electrophotographic Developing Method Utilizing A Thermoplastic Photoconductive Layer Having Entrapped Solvent Therein—E. C. Giaimo, Jr. (Labs, Pr) U.S. Pat. 3,322,540, May 30, 1967

Method of Making A Two Sided Storage Electrode—C. H. F. Morris (Labs, Pr) U.S. Pat. 3,322,653, May 30, 1967

Method of Forming A Pattern—R. L. Noack, C. Wentworth (Labs, Pr) U.S. Pat. 3,322,871, May 30, 1967

Electrical Circuit—J. J. Amodei (Labs, Pr) U.S. Pat. 3,321,640, May 23, 1967

Electron Multiplier Having Resistive Secondary Emissive Surface Which is Adapted to Sustain a Potential Gradient, Whereby Successive Multiplication is Possible—E. G. Ramberg (Labs, Pr) U.S. Pat. 3,321,660, May 23, 1967

Interconnection of Multi-layer Circuits and Method—H. R. Beelitz (Labs, Pr) U.S. Pat. 3,318,993, May 9, 1967

Tuning Indicator System for Multiplex Radio Receivers—J. Avins (Labs, Pr) U.S. Pat. 3,319,004, May 9, 1967

Electro-Optical Digital System—R. H. Cornely, J. R. Burns (Labs, Pr) U.S. Pat. 3,319,080, May 9, 1967

Testing Apparatus Including A Parametric Amplifier—H. W. Lorber (Labs, Pr) U.S. Pat. 3,311,822, March 28, 1967 (assigned to U.S. Gov't)

Electrostatic Printing Apparatus—K. J. Magnusson (Labs, Pr) U.S. Pat. 3,319,546, May 16, 1967

Selectively Controllable Light Guide Apparatus—H. Johnson (Labs, Pr) U.S. Pat. 3,320,013, May 16, 1967

Method of Making Connection to Stacked Printed Circuit Boards—J. Guarracini (Labs, Pr) U.S. Pat. 3,316,618, May 2, 1967

Method of Making Connections to Stacked Printed Circuit Boards—H. R. Beelitz (Labs, Pr) U.S. Pat. 3,316,619, May 2, 1967

Electrostatic Printing Method and Element—F. H. Nicoll, H. F. Ogawa (Labs, Pr) U.S. Pat. 3,317,315, May 2, 1967

High Power Laser Incorporating Plural Tunable Amplifier Stages—H. R. Lewis (Labs, Pr) U.S. Pat. 3,312,905, April 4, 1967

Electrical Circuits Using Negative Resistance Diode-Transistor Combination—J. J. Amodei (Labs, Pr) U.S. Pat. 3,315,100, April 18, 1967

Transistorized Power Supply for a Storage Capacitor with a Regulating Feedback Control—R. W. Ahrons (Labs, Pr) U.S. Pat. 3,316,445, April 25, 1967

Electrophotographic Member and Process Utilizing Polyarylmethane Dye Intermediates—H. G. Greig (Labs, Pr) U.S. Pat. 3,310,401, March 21, 1967

Photoconductive Device Incorporating Stabilizing Layers on the Face of the Selenium Layer—J. Dresner, H. P. D. Lanyon (Labs, Pr) U.S. Pat. 3,310,700, March 21, 1967

Semiconductor Rectifying Device with a Plurality of Junctions—J. T. Wallmark (Labs, Pr) U.S. Pat. 3,312,838, April 4, 1967

Coincident Current Magnetic Plate Memory—J. A. Rajchman (Labs, Pr) U.S. Pat. 3,312,961, April 4, 1967

RECORD DIVISION

Endless Tape Cartridge—H. E. Roys (Rec, Indpls) U.S. Pat. 3,322,360, May 30, 1967

APPLIED RESEARCH DIVISION

Threshold Gate—T. R. Mayhew (AppRes, Cam) U.S. Pat. 3,317,753, May 2, 1967

Information Processing Apparatus—T. C. Hilinski (AppRes, Cam) U.S. Pat. 3,310,784, March 21, 1967

Arc Lamp Intensity Control System—C. Lauxen (AppRes, Cam) U.S. Pat. 3,297,904, January 10, 1967 (assigned to U.S. Gov't)

COMMUNICATIONS SYSTEMS DIVISION

Neuron Information Processing Apparatus—F. L. Putzrath (CSD, Cam) U.S. Pat. 3,310,783, March 21, 1967

AEROSPACE SYSTEMS DIVISION

Flip Flip Circuits Utilizing Set-Reset Dominate Techniques—L. F. Valentine (ASD, Burl) U.S. Pat. 3,310,686, March 21, 1967

DEFENSE ELECTRONIC PRODUCTS DIVISION

Bistable Flip-Flop Employing Insulated Gate Field Effect Transistors—E. Ker-Chuang Yu, A. K. Rapp (DEP, Cam) U.S. Pat. 3,309,534, March 14, 1967 (assigned to U.S. Gov't)

Voltage Reference Circuit—A. Ostroff, M. D'Agostino (DEP, Cam) U.S. Pat. 3,310,731, March 21, 1967

Signal Distortion Correction Circuit Employing Means for Storing Signal Samples and Initiating Correction When the Pattern of Stored Samples Indicates the Presence of Distortion—C. R. Atzenbeck (DEP, N.Y.) U.S. Pat. 3,310,751, March 21, 1967

RCA VICTOR

Pulse Echo Recognition Systems—D. S. Bond (RCAV, Cam) U.S. Pat. 3,312,970, April 4, 1967

SPECIAL CONTRACT INVENTOR

Printer With Rolling Anvil Member—C. J. Young, U.S. Pat. 3,317,017, May 2, 1967

Calls for Papers

SEPT. 11-14, 1967: **22nd Annual ISA Conference & Exhibit**, McCormick Place, Chicago, Illinois. **Prog. Info.:** Conference Program Coordinator c/o ISA Headquarters, 530 William Penn Place, Pittsburgh, Pa.

OCT. 16-18, 1967: **Fall URSI-IEEE Meeting**, URSI-IEEE, Rackham Bldg., Univ. of Michigan, Ann Arbor, Mich. **Deadline Info.**, (Abst.) **8/1/67**, TO: T.B.A. Senior, Radiation Lab., 201 Catherine St., Ann Arbor, Mich.

OCT. 17-19, 1967: **Int'l Symposium on Antennas & Propagation**, G-AP, Rackham Bldg., Univ. of Michigan, Ann Arbor, Mich. **Deadline Info.:** (Sum.) 7/1/67 TO: T.B.A. Senior, Radiation Lab., 201 Catherine St., Ann Arbor, Mich.

OCT. 22-26, 1967: **American Documentation Institute**, Hilton Hotel, New York. **Deadline Info.: Aug. 1** TO: Paul Fasana, Program Chairman, ADI 1967 Annual Convention, Columbia University, The Libraries, New York, N.Y.

NOV., 1967: **20th Annual Conference on Engineering in Medicine and Biology**, with Exhibit, ISA, IEEE, Boston, Mass. **Deadline Info.:** B. S. Hines, Meetings Assistant, ISA Headquarters, 530 William Penn Place, Pittsburgh, Pa.

NOV. 13-16, 1967: **Conference on Engineering in Medicine and Biology**, G-EMB, JCEMB, Statler Hilton Hotel, Boston, Mass. **Deadline Info.: 8/1/67**, TO: Bill Maloney, Prof. Relations & Res. Inst. Inc., 6 Beacon St., Boston, Mass.

JAN. 28-FEB. 2, 1968: **Winter Power Meeting**, G-P, Statler Hilton Hotel, New York, N.Y. **Deadline Info.: 10/30/67** (Papers) IEEE Hdqs., Technical Conference Services, 345 E. 47th St., New York, N.Y.

SPRING, 1968: **14th National ISA Analysis Instrumentation Symposium**, Philadelphia, Pa. **Deadline Info.:** (abstract) 4 months prior to meeting TO: Dr. Lewis Fowler, Division Director, Monsanto Company, 1700 South Second Street St. Louis, Missouri.

Meetings

JULY 18-20, 1967: **Electromagnetic Compatibility Symposium**, Shoreham Hotel, Washington, D.C. **Prog. Info.:** F. T. Mitchell, Atlantic Res. Corp., Shirley Hwy. & Edsall Rd., Alexandria, Va.

JULY 31-AUG. 2, 1967: **Effective Supervision of the Engineering Project**, American Management Association Headquarters, 135 W. 50th St., New York.

AUG. 13-17, 1967: **Intersociety Energy Conversion Engineering Conference**, IEEE, ASME, AIChE, ANS, SAE, AIAA, Fontainebleu Hotel, Miami Beach, Florida. **Prog. Info.:** A. Merrick Taylor, Douglas Aircraft Co., Inc., Santa Monica, Calif.

AUG. 16-18, 1967: **Computer Programming—Advanced Management of Computer Programming.** AMA Headquarters, 135 W. 50th St., New York.

PROFESSIONAL MEETINGS

DATES AND DEADLINES

Be sure deadlines are met—consult your Technical Publications Administrator or your Editorial Representative for the lead time necessary to obtain RCA approvals (and government approvals, if applicable). Remember, abstracts and manuscripts must be so approved BEFORE sending them to the meeting committee.

AUG. 22-25, 1967: **Western Electronic Show & Convention (WESCON)**, Region 6, Groups, WEMA, Cow Palace & Fairmont Hotel, San Francisco, Calif. **Prog. Info.:** WESCON, 3600 Wilshire Blvd., Los Angeles, Calif.

AUG. 29-31, 1967: **Cornell Conference on High Frequency Generation and Amplification**, Cornell University, Ithaca, New York. **Prog. Info:** Conference Committee, school of Electrical Engineering, Phillips Hall, Cornell University, Ithaca, New York.

AUG. 29-31, 1967: **ACM National Conference**, Twentieth Anniversary, The Association for Computing Machinery, Washington Hilton Hotel, Washington, D.C. **Prog. Info.:** Thomas Willette, P.O. Box 21115, Kalorama Station, Washington, D.C.

SEPT. 5-8, 1967: **Solid State Devices Conference**, U.K. & Rep. of Ireland Section, Inst. of Physics & Physical Soc., IEE, IERE, Univ. of Manchester Institute of Science and Technology, Manchester, England. **Prog. Info.:** L. Lawrence, Inst. of Physics and Physical Soc., 47 Belgrave Sq., London, S.W. 1, England.

SEPT. 6-8, 1967: **Computer Conference**, G-C, Edgewater Beach Hotel, Chicago, Illinois. **Prog. Info.:** S. S. Yau, N.W. Univ., Dept. of E.E., Evanston, Ill.

SEPT. 11-13, 1967: **Production Engineering—The Job of the Industrial Engineering Manager**, American Management Association Headquarters, 135 W. 50th St., New York.

SEPT. 11-15, 1967: **Int'l Symposium on Information Theory**, G-IT, Kings Palace Hotel, Athens, Greece.

SEPT. 17-20, 1967: **Fall Meeting, The American Ceramic Society, Electronics Division**, Concord Hotel, Kiamesha Lake, New York. **Prog. Info.:** The American Ceramic Society, 4055 North High Street, Columbus, Ohio.

SEPT. 18-20, 1967: **Evaluation & Measurement of the Research & Development Program**, American Management Association Headquarters, 135 W. 50th St., New York.

SEPT. 19-22, 1967: **Fall Meeting, The American Ceramic Society, Nuclear Division**, University of Illinois, Urbana, Illinois. **Prog. Info.:** The American Ceramic Society, 4055 North High Street, Columbus, Ohio.

SEPT. 20-22, 1967: **Organizing, Planning and Controlling the Value Engineering** Program, American Management Association Headquarters, 135 W. 50th St., New York.

SEPT. 24-28, 1967: **Joint Power Generation Conference**, G-P, ASME et al, Statler Hilton Hotel, Detroit, Michigan. **Prog. Info.:** Henry Wallace, Jr., 110 S. Orange, Livingston, N.J.

Sept. 25-27, 1967: **Int'l Elec. Conference & Exposition of the Canadian Region**, Toronto Section, Automotive Bldg., in Exhibition Park, Toronto, Ontario, Canada. **Prog. Info.:** R. G. deBuda, 1819 Yonge St., Toronto, Ontario, Canada.

SEPT. 25-27, 1967: **Research Project Management**, American Management Association Headquarters, 135 W. 50th St., New York.

SEPT. 26-28, 1967: **Conference on Magnetic Materials and Their Applications**, U. K. & Rep. of Ireland Section, Inst. of Physics & Physical Soc., IEE, London, England. **Prog. Info.:** R. G. Cox. IEE, 2 Savoy Pl., London, W.C. 2, England.

SEPT. 27-29, 1967: **Management Information Systems Design**, LaSalle Hotel, AMA Headquarters in Chicago.

OCT. 2-4, 1967: **How Research & Development Can Utilize Computers Effectively**—New Opportunities, New Applications, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 2-4, 1967: **Managing Engineering Services**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 4-6, 1967: **Allerton Conference on Circuit & System Theory**, G-CT, Univ. of Illinois, Allerton House, Monticello, Illinois.

OCT. 4-6, 1967: **Ultrasonics Symposium**, G-SU Bayshore Inn, Vancouver, B.C. (Canada). **Prog. Info.:** Burt Auld, Hanson Labs., Stanford Univ., Stanford, Calif.

OCT. 9-10, 1967: **Joint Engineering Management Conference**, IEEE and seven other societies, Jack Tar Hotel, San Francisco, Calif. **Prog. Info.:** B. B. Winer, Westinghouse Elec. Corp., E. Pittsburgh, Pa.

OCT. 11-13, 1967: **System Science & Cybernetics Conference**, G-SSC, Statler Hilton Hotel, Boston, Mass. **Prog. Info.:** David, Smith, Moore School of Electrical Engrg., Univ. of Penna., Phila., Pa.

OCT. 11-13, 1967: **Effective Technical Service—Improving Coordination and Communication Between the Technical Service and Marketing Efforts**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 11-13, 1967: **Improving R & D Communications**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 15-19, 1967: **Electrical Insulation Conference**, G-EI, NEMA, Palmer House, Chicago, Illinois. **Prog. Info.:** John Lenkey, Anaconda, 605 3rd Ave., N.Y.

OCT. 15-20, 1967: **Fall Meeting, Electrochemical Society, Inc.**, Sheraton-Chicago Hotel, Chicago, Illinois. **Prog. Info.:** The Electrochemical Society, 30 East 42nd Street, New York, N.Y.

OCT. 16-18, 1967: **Aerospace & Electronic Systems Convention**, G-AES, Sheraton Park Hotel, Washington, D.C. **Prog. Info.:** Donald Hagner, Bellcomm, Inc., 1100 17th St., N.W. Washington, D.C.

OCT. 16-18, 1967: **Joint Material Handling Conference**, G-IGA, Milwaukee Section, ASME, Pfister Hotel, Milwaukee, Wisc. **Prog. Info.:** Pfister Hotel, Milwaukee, Wisc.

OCT. 16-18, 1967: **Information Retrieval—Indexing and Search Techniques** American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 18-20, 1967: **Configuration Management—Administering an Effective Configuration Management Program**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 18-20, 1967: **Designing Scientific and Engineering Information Retrieval Systems**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 18-20, 1967: **Organizing and Managing the Technical Publications Operation**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 18-20, 1967: **Int'l Electron Devices Meeting**, G-ED, Sheraton Park Hotel, Washington, D.C. **Prog. Info.:** V. H. Grinich, Fairchild Inst., 844 Charleston Rd., Palo Alto, Calif.

OCT. 23-25, 1967: **Symposium on Adaptive Processes**, G-AC, G-IT, G-SSC, Int'l Amphitheater, Chicago, Illinois. **Prog. Info.:** L. M. Benningfield, Univ. of Missouri, Columbia, Mo.

OCT. 23-25, 1967: **Nat'l Electronics Conf.**, Region 4, Groups, et al, Int'l Amphitheater, Chicago, Illinois, **Prog. Info.:** P. E. Mayes, Univ. of Illinois, Urbana, Illinois.

OCT. 25-27, 1967: **Production Engineering—The Job of the Manufacturing Engineer**, American Management Association Headquarters, 135 W. 50th St., New York.

OCT. 30-NOV. 2, 1967: **Nuclear Science Symposium**, G-NS, Statler Hilton Hotel, Los Angeles, Calif. **Prog. Info.:** R. C. Maninger, Lawrence Radiation Lab., P.O. Box 808, Livermore, Calif.

Engineering NEWS *and* HIGHLIGHTS

NEW FORMAT FOR 1968 IEEE CONVENTION

The Technical Program for the 1968 convention in New York City, March 18-21, will differ from those in recent years: under a new policy, the emphasis will be on new scientific and engineering topics not yet under the active sponsorship of IEEE Group, and on interdisciplinary topics involving interests that do not lie completely inside those of any one Group, but frequently involving two or more Groups. Tutorial and state-of-the-art surveys will also be included, with particular attention to recent advances.

It is planned to use invited sessions, rather than to issue a general call for voluntarily contributed papers. However, all Groups or IEEE members who know of interesting developments meeting the above criteria are urged to send their information to the 1968 Technical Program Committee.

Members of the 1968 IEEE Convention Technical Program Committee are **E. W. Herold,** Chairman; **W. R. Beam,** Vice-Chairman; **L. A. DeRosa,** Vice-Chairman; **H. Trotter, Jr.,** Vice-Chairman; and **R. M. Emberson,** Secretary. The other members are **A. B. Giordano, A. Dorne, P. K. McElroy, H. A. Manoogian, P. L. Schwartz,** and **J. W. Wentworth.**

FIRST 14-INCH COLOR PORTABLE INTRODUCED BY RCA VICTOR

The industry's first portable color TV set with a 14-inch diagonal size picture tube has been introduced by RCA. The new portable color TV receiver (102 square inches overall viewing area) is priced optionally at $329.95, lower than any color model ever shown by the RCA Victor Home Instruments Division.

MANNED SPACE STATION FOR ATMOSPHERIC OBSERVATIONS

A manned meteorological space station has been recommended by RCA scientists for NASA's Apollo Applications Program. The proposed Atmospheric Sciences Laboratory (ASL) would enable man to gain maximum knowledge of atmospheric phenomena by observing, from space, dynamic Sun-Earth interactions before, during, and after solar flares.

The Apollo Applications Program for which the ASL was proposed is a NASA program to utilize equipment and techniques developed primarily for the Apollo manned lunar landing for wide range of scientific investigations in space.

The concept of ASL was developed by **Dr. Ernst de Haas** and **Miss Sima Miluschewa** of the Astro-Electronics Division, Princeton, N.J. RCA plans to submit a detailed proposal to NASA at a future date.

NEW LOCATION FOR VEHICULAR TRAFFIC SYSTEMS

Vehicular Traffic Systems, a new function of RCA's new Business Programs, Industrial and Automation Products, moved into new headquarters at 36 W. State Street, Trenton, N.J., in May. The Engineering and Marketing headquarters will be located there.

—*H. Lawrence*

TV CAMERA IN $3800 PRICE RANGE

A new high-performance television camera in the $3800 price range has been introduced by the Broadcast and Communications Products Division. The PK-315 camera, with 5-inch viewfinder and solid-state circuitry, was a feature of the B&CP Instructional Electronics Department's exhibit at the American Association of School Administrators annual convention.

The new PK-315 will accept one of three motor-driven zoom lenses, available as options, and makes use of RCA's unique pan and tilt system which keeps the viewfinder constantly at eye level when the camera head is moved up or down.

ARGON-GAS LASER FOR USE IN HOLOGRAPHY, SURGERY AND RESEARCH APPLICATIONS.

A new argon gas laser with more than three times the life-span of previous units has been developed by RCA for possible use in such areas at data processing, space communications, satellite tracking, earthquake detection and "bloodless surgery."

The new long-life laser now is being offered to research laboratories, government agencies and universities for evaluation and product development.

The new laser, which is far more reliable than previous DC excited argon-gas lasers, is a high intensity, highly directive light source housed in a cylinder approximately 10 inches in diameter.

CONTENTS OF THE JUNE 1967 RCA REVIEW

The RCA REVIEW is published quarterly. Copies are available in all RCA libraries. Subscription rates are as follows (rates are discounted 20% for RCA employees):

	DOMESTIC	FOREIGN
1-year	$2.00	$2.40
2-year	3.50	4.30
3-year	4.50	5.70

HERTZ BECOMES SUBSIDIARY OF RCA

The Hertz Corporation has become a wholly-owned subsidiary of the Radio Corporation of America. The announcement was made on May 11, 1967, by **Robert W. Sarnoff,** RCA President. The move had been approved by the Boards of Directors of the two companies last December 8, and by the shareholders of both companies at their respective annual meetings on May 2. Mr. Sarnoff said that Hertz will continue to function as a separate entity with its own Board of Directors and its present personnel and management. **Leon C. Greenebaum,** Chairman of the Board of Directors of Hertz, is expected to be elected to the RCA Board of Directors.

ENGINEERING UTILIZATION GROUP FORMED

A new organizational function, Engineering Utilization, has been formed within the RCA Missile Test Project's Engineering Support section. According to Engineering Support Manager, **P. G. Leger,** the new group will be responsible for ensuring the most effective use of Engineering Support manpower. It will function specifically in the areas of planning, scheduling, and coordination of Engineering requirements. **C. L. Sharp,** formerly Manager of Maintenance Engineering, has been named Manager of the new group. **James Brady,** formerly with the RCA BMEWS Project in Alaska, has been appointed MTP Maintenance Engineering Manager.—*W. R. Mack*

LOY E. BARTON HONORED

Loy E. Barton, former Research Engineer at the RCA Laboratories, was honored this month when he was admitted to the College of Engineering Hall of Fame at Arkansas University. "Two or three distinguished Arkansas engineers are admitted to the Hall of Fame each year in recognition of their contribution to the field of engineering and in recognition of the credit they have reflected on the University of Arkansas," Dean, George F. Branigan said.

Mr. Barton, a native of Fayetteville, earned his BSEE in 1925. During his career, most of it devoted to research for RCA, he obtained nearly 100 patents. He considers his work on the class "B" amplifier his most important contribution to the radio industry. He was instrumental in the development of the amplifier, applied to high level modulation for broadcast stations.

Barton joined RCA in 1929 after teaching and doing research at the UA. Until he retired as Senior Engineer at RCA Laboratories in 1962, he worked on such electronic developments as sonar, transistors, and color television. He holds the Distinguished Alumnus Citation from the University of Arkansas.

PROFESSIONAL ACTIVITIES

Astro-Electronics Division, Princeton, N. J.: **W. Wilson,** Mgr., Design Services, has been appointed to represent the EIA on the board of the United States of America Standards Institute in connection with the decimal inch. **H. Gurin,** Staff Engineer, has been renewed as Associate Editor of the AIAA *Journal of Spacecraft and Rockets.—S. Weisberger*

J. Hillier, Vice President, RCA Laboratories was recently elected to the National Academy of Engineering. This in recognition of his work in the development of electron microscopy.

Central Engineering, DEP, Camden, N.J.: On April 24, 1967, **A. Siegel,** Electromechanical Parts Activity, served on the five-man awards Committee of the National Association of Relay Manufacturers at Oklahoma State University. **J. Jakabcin,** Materials Laboratory completed his twenty-first year as part-time Adjunct Professor in Chemistry at Drexel Institute of Technology.

M. Gokhale, Electro-Mechanical Parts Activity and a Fellow of the Standards Engineers Society (SES), was reappointed a Member of the following three SES Committees (at the National level) for 1967: International Membership, Research and Education, and SES-ASTM Awards Committee. Mr. Gokhale was also appointed (1) Chairman of the Research and Educational Committee and (2) Member of the Nominating Committee of the Philadelphia Section of the same society. **B. Tiger,** Product Assurance Techniques Activity, was elected Chairman, Group on Reliability of the Philadelphia Section of the IEEE for the next year. Also, he was appointed Chairman of the Technical Session on "Reliability Predictions" for the Sixth Reliability and Maintainability Conference to be held July 17-19, 1967 at Cocoa Beach, Florida (sponsored by AIAA, SAE and other societies). **J. Kaufman,** Materials Laboratory, was re-elected Treasurer of the Philadelphia Section of the American Society for Metals for a two-year term. **S. Canale,** Product Assurance Techniques Activity, was elected to the Board of Directors of the Aerospace Systems Safety Society for 1967. He had been Vice-President of the same society in 1966. **R. Green,** Manager of the Materials Laboratory, has been elected a Fellow of the British Institution of Metallurgists.—*J. R. Hendrickson*

Advanced Technology, Camden, N.J.: **L. Morris,** Manager, Applied Physics, contributed to a presentation at Ft. Monmouth regarding communications techniques for a communications network which the Army plans to build in the late 1970's. **H. Zieper, W. Clapp,** and **A. Cornish,** Machine Organization group, presented a training session on the use of LOGSIM to approximately 15 Burlington engineers. Further training sessions are scheduled at DME, CSD, and M&SR.—*M. G. Pietz* and *J. E. Friedman*

Aerospace Systems Division, Burlington, Mass.: **E. Richter** was Chairman of the Local Arrangements Committee for the 1967 International Microwave Symposium held in Boston, May 7-11, 1967. **L. Drew** has been appointed Chairman of the Goals and Policy Committee of IEEE-CADAR (Computer Aided Design, Analysis, and Reliability). **A. DiMarzio** has been appointed Chairman of the Boston chapter of the IEEE group on Electromagnetic Compatibility. **A. Spear** is completing a term on the Educational Film Committee of the Society of Women Engineers. The Boston Section of the Precision Measurements Association held its May meeting at Aerospace Systems Division. The speaker from Hewlett-Packard reviewed the recent test equipment symposium. Forty-five engineering attended; **J. Engley** was host.—*D. B. Dobson*

M. Bachynski, Director of Research, RCA Victor Company, Ltd., Montreal, was recently elected a Fellow of the Royal Society of Canada. This is the Canarian counterpart of the Royal Society of Great Britain. *—H. J. Russell*

On May 10, 1967, **R. D. Sidnam** addressed the student branch of the IEEE at the University of Illinois. The subject of his talk was "Computer System Design for LSI" (Large Scale Integration).—*G. D. Smoliar*

A. L. Conrad, President of the RCA Service Company, addressed the Fourth Annual Space Congress, April 4, at Cocoa Beach. Of the 127 technical papers delivered, nine were prepared by RCA scientists and engineers.

W. Y. Pan of ACTL, CSD, New York was invited as a special guest to the Sino-American Technological Cooperation Conference jointly sponsored by the National Academy of Science and the *Academia Sinica* of the Republic of China. The Conference took place in the Academy, in Washington, D.C. on April 5th through 7th, 1967. In 1966, Dr. Pan, President of the Chinese Institute of Engineers, led a group of sixteen Chinese and American Scientists and Engineers to China for a three-week Seminar on Modern Engineering and Technology.

F. Huber (DME, Somerville), **W. Y. Pan** (ACTL, CSD, New York), and **W. Witt** (DME, Somerville) received the Conference paper Award from the Electronics Components Conference which took place in Washington, D.C. in May 1966. They jointly presented the paper on "Hafnium—Hafnium Dioxide Thin Film Capacitors."

LICENSED ENGINEERS

H. Bragdon, DEP-ASD, Burl., PE 35038, New York

W. E. Scull, Lincoln Labs., PE 15283, New Jersey

F. X. Beck, DEP-MSR, Mrstn., PE 15355, New Jersey

D. P. Schnorr, DEP-CE, PE 12703-E, Pennsylvania

DEGREES GRANTED

N. VanDelft, CSD .....MSEE, Polytechnic Inst. of Brooklyn

M. Feryszka, AED ..Ph.D., Electrical Eng., University of Penn.

R. H. Arlett, Pr. Labs. ...Ph.D., Ceramics, School of Ceramics, Rutgers Univ.

R. Eubanks, ECD ..BSEE, Newark College of Engineering

W. C. Johnson, ECD ....MS, Engineering, Newark College of Engineering

RAPPAPORT NAMED FELLOW OF APS

Paul Rappaport of the RCA Laboratories recently was named a Fellow of the American Physical Society in recognition of his contributions to the field of radiation effects in semiconductors and for his work which led to the development of a radiation resistant solar cell. Mr. Rappaport is currently the Associate Laboratory Director of the Materials Research Laboratory.

DR. LEWIN NAMED OUTSTANDING YOUNG ENGINEER

Dr. Morton H. Lewin of the Computer Research Laboratory, RCA Laboratories was cited as the Outstanding young Electrical Engineer for 1966 for "his notable contributions to computer research in areas of logic memories, and input-output devices, and his dedication to community activities." He received the award from **Dr. Clyde M. Hyde,** National President of Eta Kappa Nu.

M&SR AUTHOR'S RECEPTION (1967)

Authors of Missile and Surface Radar Division were hosted recently at the Moorestown plant. They were guests of Messrs. **D. M. Cottler,** Chief Engineer, M&SR, and **S. G. Miller,** Manager, SEER, at a reception honoring them for their writing accomplishments. Thirty-eight engineers from M&SR who had authored papers during 1966 and six from SEER were invited; *hors d'oeuvres* and refreshments were served. Other guests included **D. Shore,** Chief Defense Engineer; **W. Morrison,** Director, Product Engineering; **W. O. Hadlock,** Editor, RCA ENGINEER; and **G. W. Van Citters,** M&SR Marketing and Security Approval.—*T. Greene*

RCA VIDICON IN TV-GUIDED WEAPON

A small television camera tube is being made by the EC&D Industrial Tube Division for use as the sensitive electronic eye of the Nation's first TV-guided tactical weapon. The camera tube is employed in the Navy-developed air-to-surface WALLEYE weapon to be installed in Navy and Air Force tactical aircraft.

The EC&D plant at Lancaster, Pa., has already made and delivered a substantial number of vidicon camera tubes for the WALLEYE weapon. The Martin Marietta Corp. which fabricates WALLEYE, recently gave RCA a multimillion dollar production order for vidicon tubes. This order represents one of the largest single orders for vidicons ever received by RCA. The RCA vidicon is mounted in a compact television camera behind a glass window in the nose of the WALLEYE weapon. After a pilot finds his target, he locks the weapon on its objective. Once WALLEYE is released, the electronic sight of the RCA vidicon takes over and homes on the target.

STAFF ANNOUNCEMENTS

R. S. Holmes, Division Vice President, Medical Electronics, announced the organization of Medical Electronics as follows: **G. V. Bradshaw,** Manager, Design and Development Engineering; **L. E. Flory,** Chief Scientist and Acting Manager, Advanced Development Engineering; **F. J. Herrmann,** Administrator, Technical Liaison, Hoffmann-LaRoche; **W. E. Lloyd,** Manager, Financial Operations; and **W. J. Schoener,** Administrator, Personnel.

W. C. Morrison announced the following organization changes: **W. O. Hadlock,** Manager, Technical Publications, in addition to his current responsibility for the RCA ENGINEER, will assume responsibility for TREND magazine. **J. C. Phillips** is appointed Administrator, Technical Publications. Mr. Phillips will assist in the planning, editing, production and distribution of the RCA ENGINEER.

W. O. Hadlock, Manager, Technical Publications announces the appointment of **E. M. Geverd** to the position of Administrator, Technical Publications. Mr. Geverd's primary responsibility will be Editor of TREND, the monthly Research and Engineering News Digest. Mr. Geverd will also be responsible for the expanded use of RCA technical articles in outside publications.

G. A. Kiessling, Manager, Product Engineering Professional Development, announces the appointment of **E. R. Jennings** to the newly established position of Administrator, Technical Library System. In this capacity, Mr. Jennings will be responsible for the development and administration of a corporate-wide technical library system to facilitate the interchange of technical information and to increase technical information services throughout the corporation.

The appointment of **Gerald B. Herzog** as Director and **Nikolaus E. Wolff** as Associate Director of the Process Research and Development Laboratory has been announced by **Dr. James Hillier,** Vice President, RCA Laboratories, Princeton.

The organization of Manufacturing Services and Materials has been announced by **A. L. Malcarney,** Executive Vice President as follows: **G. A. Fadler,** Staff Vice President, Materials; **M. H. Glauberman,** Manager, Plans and Programs; **R. A. Schieber,** Staff Vice President, Manufacturing; and **F. Sleeter,** Vice President, Facilities.

The organization of Manufacturing has been announced by **R. A. Schieber,** Staff Vice President, as follows: **B. V. Dale,** Manager, Automatic Test and Measurement Systems; **R. V. Miraldi,** Director, Industrial Engineering; **E. H. Panczner,** Director, Production Engineering; and **J. A. Scarlett,** Director, Manufacturing Services—Special International Accounts.

B. G. Curry, Director, Management Information Systems Programs, appointed **E. R. Dickey, Jr.** to the newly established position of Manager, Corporate Information Systems Center. The organization of the Corporate Information Systems Center is announced as follows: **J. A. Branco,** Manager, Center Operations; **K. W. Moore,** Manager, Systems and Finance; **S. J. Levine,** Administrator, Systems and Programs; and **W. B. Noyovitz,** Administrator, Customer Relations.

E. S. Kauffman, Staff Vice President, Management Information Systems, appointed **B. W. Wheeler, Jr.,** Director, Systems Consulting Services. The staff organization of the Director, Systems Consulting Services, is announced as follows: **H. F. Boylan,** Systems Engineer; **M. S. Demurjian,** Administrator, Systems Projects; **T. F. Lalor,** Manager, Management Systems Studies; and **A. M. Trifiletti,** Systems Engineer.

The organization of the Industrial and Automation Products Department has been announced by **N. R. Amberg,** Manager, Industrial and Automation Products Department, as follows: **C. A. Della Bella,** Manager, RCA Automation Programs; **R. O. Graham,** Manager, Purchasing; **M. G. Kopasz,** Manager, Financial Operations; **H. C. Lawrence,** Manager, Vehicular Traffic Systems; **G. A. McAlpine,** Manager, Industrial Automation Equipment Marketing; **M. A. Scherrens,** Plant Manager, Plymouth Plant; **Harriett C. Wacker,** Administrator, Personnel and **R. G. Walz,** Manager, Automatic Equipment Engineering.

J. Hillier, Vice President, RCA Laboratories has appointed **L. R. Day,** Director, Special Development Projects. In this capacity, Mr. Day will be responsible for directing the business development of new systems which have originated in RCA Laboratories, and which now require substantial participation of several divisions and subsidiaries.

C. H. Colledge, Division Vice President and General Manager, Broadcast and Communications Products Division has appointed **E. J. Dudley,** Administrator, News and Information.

A. D. Beard, Chief Engineer, Electronic Data Processing announced the Engineering organization as follows: **H. Kleinberg,** Manager, Engineering, Palm Beach; and **B. W. Pollard,** Manager, Engineering, Camden.

B. W. Pollard, Manager, Engineering (Camden) Electronic Data Processing announced the organization of Engineering (Camden) as follows: **C. M. Breder,** Manager, Administration and Control; **L. Iby,** Manager, Design Integration; **J. L. Maddox,** Manager, Systems Engineering; **J. N. Marshall,** Manager, Computer and Communications Product Engineering; **H. J. Martell,** Manager, Peripheral Equipment Programs; and **G. D. Smoliar,** Staff Engineer.

The organization of the Conversion Tube Operations Department, Industrial Tube Division, RCA Electronic Components and Devices, has been announced by **D. W. Epstein,** Manager, as follows: **R. W. Engstrom,** Manager, Advanced Development Engineering; **W. G. Fahnestock,** Manager, Operations Planning and Controls; **L. W. Grove,** Manager, Development Services and Display Tube Operation; **J. K. Johnson,** Manager, Vidicon Operation; **J. A. Molzahn,** Manager, Quality and Reliability Assurance; **G. A. Morton,** Director, Conversion Devices Laboratory—Princeton; **M. Petrisek,** Manager, Image Orthicon Operation; and **R. C. Pontz,** Manager, Photo and Image Tube Operation.

The organization of Management Information Systems and Services, RCA Electronic Components and Devices, has been announced by **W. K. Halstead,** Manager as follows: **M. A. Cofone,** Manager, Management Information Systems Development; **R. E. Timm,** Manager, Distribution Systems Development; **A. J. Sullivan,** Manager, Management Information Systems Development; **W. E. Bahls,** Manager, Computer-Control Systems; **R. K. Koch,** Manager, Management Information Systems; and **J. F. Lynch,** Manager, Data Processing Operations.

J. B. Farese, Vice President, RCA Electronic Components and Devices, has announced that the functions of the Special Electronic Components Department and the Direct Energy Conversion Marketing activity in the Solid State and Receiving Tube Division are transferred to the following Industrial Tube Division activities: **G. Y. Eastman,** Manager, Thermionic Converter Engineering, will report to **M. B. Shrader,** Manager, Power Devices Operations Department; **L. J. Caprarola,** Manager, Thermoelectric Products Engineering, and **N. S. Freedman,** Manager, Superconductive Products Operations, will report to **W. G. Hartzell,** Manager, Microwave Devices Operations Department; and **P. P. Roudakoff,** Manager, Direct Energy Conversion Marketing, will report to **V. C. Houk,** Manager, Marketing Department.

D. L. Mills, Executive Vice President, Consumer Products appointed **P. B. Garver** Division Vice President and General Manager, RCA Parts and Accessories.

C. E. Burnett, Division Vice President and General Manager, Solid State and Receiving Tube Division, RCA Electronic Components and Devices, has announced the following organization of the Solid State and Receiving Tube Division: **C. E. Burnett,** Acting Manager, Special Electronic Components Department; **H. A. DeMooy,** Manager, Receiving Tube Operations Department; **D. J. Donahue,** Manager, Solid State Operations Department; **N. H. Green,** Manager, Solid State and Receiving Tube Planning; **J. W. Karoly,** Administrator, Financial Controls; **C. H. Lane,** Manager, Marketing Department; and **W. H. Warren,** Administrator, Quality and Reliability Assurance.

The organization of the Solid State Signal Device Manufacturing activity, Solid State and Receiving Tube Division, RCA Electronic Components and Devices, has been announced by **R. J. Hall,** Manager, as follows: **G. J. Feder,** Manager, Discrete Device Manufacturing, Somerville; **G. A. Hiatt,** Plant Manager, Lewiston Plant; **E. M. Klein,** Manager, Manufacturing Standards, Somerville, and **E. M. Troy,** Manager, Integrated Circuit Manufacturing, Somerville.

Staff Announcements (cont'd)

The organization of the Special Electronic Components Department, Solid State and Receiving Tube Division, RCA Electronic Components and Devices, has been announced by **C. E. Burnett,** Acting Manager as follows: **L. J. Caprarola,** Manager, Thermoelectric Products Engineering; **G. Y. Eastman,** Manager, Thermionic Converter Engineering; and **N. S. Freedman,** Manager, Superconductive Products Operations. The above-named individuals will report to the Acting Manager, Special Electronic Components Department.

The organization of the Receiving Tube Operations Department, Solid State and Receiving Tube Division, RCA Electronic Components and Devices, has been announced by **H. A. DeMooy,** Manager, as follows: **H. S. Basche,** Administrator, Space and Facilities Planning; **M. Bondy,** Manager, Receiving Tube Engineering; **W. B. Brown,** Administrator, Manufacturing Planning and Cost Reduction; **G. W. Farmer,** Plant Manager, Harrison Plant; **F. J. Lautenschlaeger,** Plant Manager, Woodbridge Plant; **W. E. Lynar,** Manager, Quality and Reliability Assurance; **J. W. MacDougall,** Administrator, Controls and Standards; **E. Rudolph,** Manager, Equipment Design and Development; and **N. A. Stegens,** Plant Manager, Cincinnati Plant. The above-named individuals will report to the Manager, Receiving Tube Operations Department.

The organization of the Solid State Operations Department, Solid State and Receiving Tube Division, RCA Electronic Components and Devices, has been announced by **D. J. Donahue,** Manager as follows: **R. M. Cohen,** Manager, Solid State Signal Device Engineering; **R. J. Hall,** Manager, Solid State Signal Device Manufacturing; **R. W. Hummel,** Manager, Financial Controls; **R. L. Klem,** Manager, Operations Planning and Services; **R. H. Pollack,** Manager, Solid State Power Device Engineering; **H. A. Uhl,** Plant Manager, Findlay Plant; and **P. T. Valentine,** Plant Manager, Mountaintop Plant.

... PROMOTIONS ...

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parentheses.

RCA Service Company

- **M. J. Harry:** from Field Support Engr. to *Ldr., Field Support Engr.* (J. L. Sharp, Cocoa, Florida)
- **E. W. Hithersay:** from Systems Service Eng. to *Ldr., Systems Service Engr.* (W. J. Siddall, Bermuda)
- **A. E. Glei:** from Engr. to *Mgr., Operations Planning* (J. W. Falkenstein, Andros Island, Bahamas)
- **M. J. Pedelty:** from Engr. to *Mgr., Data Processing* (J. W. Falkenstein, Andros Island)

Electronic Data Processing

- **D. Jones:** from Mbr. D&D Engr, Staff to *Ldr. Tech. Staff* (H. N. Morris, Palm Beach)
- **L. J. Busch:** from Eng. to *Ldr., Des. & Dev. Eng.* (R. H. Yen, Camden)
- **R. G. Wolcott:** from Eng. to *Ldr., Des. & Dev.* (R. D. Sidnam, Camden)

Electronic Components and Devices

- **L. P. Garvey:** from Engr. Ldr., Product Development to *Program Manager, Thermoelectric* (L. J. Caprarola, Harrison)
- **A. A. Kulakowich:** from Engr. Manufacturing to *Engr. Ldr., Product Development* (M. Nowogrodzki, Harrison)
- **T. J. Morris:** from Engr. Manufacturing to *Mgr., Production Engineering* (A. M. Trax, Marion)
- **W. S. Chaves:** from Engr. Manufacturing to *Admin., Materials Handling and Package Design* (J. A. Collins, Marion)
- **F. G. Hammersand:** from Ldr. to *Mgr., Super Power Tube, Design & Development* (T. E. Yingst, Lancaster)
- **J. DeMott:** from Eng., Product Development to *Mgr., Quality Control* (W. E. Bradley, Lancaster)
- **H. Becker:** from Eng. Equipment Devel. to *Ldr. Equipment Devel.* (M. M. Bell, Harrison)
- **A. A. Stanley:** from Ldr., Product Devel. to *Mgr., Product Engr.* (W. E. Breen, Harrison)
- **D. D. Mawhinney:** from Ldr., Product Devel. to *Mgr. Product Engr.* (H. K. Jenny, Harrison)
- **W. E. Bradley:** from Engr. Manufacturing to *Mgr. Quality & Reliability Assurance Power Devices* (M. B. Shrader, Lancaster)
- **J. J. Free:** from Engr., Product Devel. to *Eng. Ldr., Product Devel.* (M. B. Shrader, Lancaster)
- **H. E. Medsger:** from Engr. Product Devel. to *Mgr., Super Power Device, Production Engr.* (R. T. Rihn, Lancaster)

Broadcast and Communications Division

- **S. C. Starr:** from Engr. to *Ldr., Des. & Devel.* (R. J. Smith, Camden)

Advanced Technology

- **H. R. Teel, Jr.:** from Comp. Operator "A" to *Engr. Design Automation Coord.* (D. J. Parker, Camden)
- **L. C. Morris:** from Ldr., Design and Development Eng. to *Mgr. Applied Physics* (J. Vollmer, Camden)
- **L. J. Krolak:** from Ldr., D & D Engr. to *Staff Engr., Applied Research* (J. Vollmer, Camden)
- **J. Vollmer:** from Mgr. Applied Physics to *Manager Applied Research* (D. J. Parker, Camden)
- **D. J. Parker:** from Manager Applied Research to *Mgr. Advanced Tech.* (D. Shore, Camden)
- **D. J. Miller:** from Engr. Design & Devel. to *Ldr., Design & Devel.* (D. J. Parker, Camden)

Aerospace Systems Division

- **Amy Spear:** from Sr. Proj. Mbr. to *Proj. Engr.* (A. L. Warren, Burl)
- **K. J. Klarman:** from Engr. Scientist to *Ldr., T.S.* (S. Piccirillo, Burl)
- **F. L. Pratt:** from Sr. Proj. Mbr. to *Ldr., T.S* (S. Piccirillo, Burl)
- **H. Logemann:** from Sr. Proj. Engr. to *Mgr., T.V. Projects* (S. Kolodkin, Burl)
- **H. W. Pownell:** from Ldr. to *Project Engr.* (A. Warren, Burl)
- **D. M. Larson:** from Ldr., T.S. to *Mgr. Reliability & Standards* (J. Furnstahl, Burl)
- **W. A. Castner:** from Adm., Logistics & Support to *Mgr., Logistics & Support Eng.* (J. Furnstahl, Burl)

West Coast Division

- **J. M. Chambers:** from Sr. Mbr. D&D Engr. Staff to *Ldr., D&D Eng. Staff* (F. Worth, Van Nuys)
- **M. H. Blasjo:** from Prin. Mem. D&D Eng. Staff to *Ldr., D&D Eng. Staff* (J. C. Groce, Van Nuys)
- **J. C. Wight:** Ldr. D&D Engrg. Staff to *Mgr., Electronic D&D Engr.* (J. C. Groce, Van Nuys)
- **E. A. Cornwall:** Ldr., D&D Engr. Staff to *Mgr., Electronic D&D Engr.* (J. C. Groce, Van Nuys)
- **A. L. Kelsey:** from Mgr., Lab. Services to *Ldr., D&D Engr. Staff* (G. F. Fairhurst, Van Nuys, Calif)
- **R. M. Signer:** from Sr. Mbr., D&D Engr. to *Ldr., D&D Engr. Staff* (C. Johnson, Van Nuys, Calif)

Communications Systems Division

- **R. L. Davis:** from Engr. "A" to *Ldr. Systems Projects* (J. M. Osborne, Camden)
- **D. Hampel:** from Sr. Proj. Mbr. Tech. Staff to *Ldr., Tech. Staff* (R. Guenther, New York)
- **R. J. Singer:** from Mgr. New Techniques to *Ldr., Engrg. Systems Projs.* (C. K. Law, Camden)
- **E. T. Wojciechowski:** from "A" Engr. to *Ldr., Engrg. Projects* (R. M. Asler, Camden)
- **F. J. McFarland:** from "A" Engr. to *Ldr., Design & Devel.* (G. H. Lines, Camden)
- **E. J. Wojciechowski:** from "A" Engr. to *Ldr., Engr. Projs.* (M. Amsler, Camden)
- **A. Paris:** from Mgr. Air Surface Sys. to *Mgr. Space Engr. Proj.* (C. K. Law, Camden)

Astro-Electronics Division

- **S. Goldfarb:** from Sr. Engr. to *Ldr. Engr.* (F. A. Beisel, Astro)
- **G. Bandstra:** from Associate Engr. to *Engr.* (F. Yannotti, Princeton)
- **J. Horowitz:** from Associate Engr. to *Engr.* (M. Shepetin, Princeton)
- **R. J. Williams:** from Associate Engr. to *Engr.* (R. Packer, Princeton)
- **H. W. Bilsky:** from Engr. to *Sr. Engr.* (S. Winkler, Princeton)
- **J. R. Engel:** from Engr. to *Ldr. Engr.* (G. Hieber, Princeton)
- **L. S. Herczeg:** from Engr. to *Sr. Engr.* (G. A. Beck, Princeton)
- **G. M. Hieber:** from Sr. Mbr. Tech. Staff to *Mgr. Engr.* (F. Yannotti, Princeton)
- **J. McClanahan:** from Engr. to *Ldr., Engr.* (F. Yannotti, Princeton)
- **D. B. Pollock:** from Engr. to *Ldr., Engr.* (M. Shepetin, Princeton)
- **J. R. Siegel:** from Engr. to *Ldr., Engr.* (M. Shepetin, Princeton)
- **G. L. Raffaelli:** from Sr. Engr. to *Ldr. Engr.* (F. J. Yannotti, Princeton)

Princeton Laboratories

- **W. G. McGuffin:** from Ldr. Engr. to *Mgr. Sanquine Operations* (E. Minzenberger, Pr. Labs.)

E. M. GEVERD IS "TREND" EDITOR

E. M. Geverd has been named Administrator, Technical Publications, reporting to W. O. Hadlock, Mgr. Technical Publications. In this new position, Mr. Geverd's major responsibility is Editor of TREND, **T**he **R**esearch and **E**ngineering **N**ews **D**igest. He is also responsible for expanding the use of RCA technical articles in external publications.

TREND is published to provide RCA scientists and engineers with a better understanding of the Corporation's activities including current and future technical projects and engineering management objectives. TREND covers professional activities, scientific and engineering advances, policies and new markets.

E. M. (Mike) Geverd received the BS degree in Electrical Engineering from Drexel Institute of Technology in June 1966. His early experience included 3 years in the U. S. Army as an Electronics Instructor on the NIKE Surface-to-Air Missile System, prior to joining the RCA Service Co. as a technical writer in 1958. Mr. Geverd was employed by Renner Inc. as an engineering writer in 1960 and then joined AED in 1962. From 1962 until early 1967 he was the Documentation Coordinator for the TIROS/TOS program. While serving in that capacity, he was responsible for the preparation and publication of all reports and manuals generated by AED on the TIROS/TOS program. Prior to becoming TREND Editor, he was employed as a Project Engineer in the TIROS/TOS Program management office at AED.

AL PINSKY MOVES TO LABS "PR" POST

Al Pinsky has been named Administrator, Scientific Information Services, RCA Laboratories, Princeton, N. J. In this capacity, Mr. Pinsky reports to A. N. Curtiss, Director Administration, RCA Laboratories.

Since 1962, Al Pinsky has been Administrator, Professional Development Communications, Product Engineering. In this activity Mr. Pinsky served as Editor of TREND, RCA's research and engineering news digest published and distributed monthly.

Mr. Pinsky formerly worked in DEP-ACCD's Reports and Proposals group in Camden. Before that he was a senior technical writer at the Burroughs Corporation Research Center in Paoli, Pa. He received a BS in 1943 from the University of Connecticut. As a Marine Lieutenant during World War II, he completed special courses in electronics at the Harvard University Graduate School of Engineering and M. I. T. After that, he became a newspaperman and was city editor of the *Elkhart Truth* in Elkhart, Ind., and the *Evening Press* in Levittown, Pa.

J. C. PHILLIPS ON RCA ENGINEER STAFF

John C. Phillips comes from Astro Electronics Division to assume the position of Administrator, Technical Publications. In this capacity, Mr. Phillips' primary responsibility will be Assistant Editor, RCA ENGINEER; he reports to W. O. Hadlock, Manager, Technical Publications.

John will maintain close contact with the RCA ENGINEER Editorial Representatives in all divisions to assure that future issues will continue to contain timely papers of corporate-wide interest.

Mr. Phillips, who has been an Editorial Representative of the RCA ENGINEER since 1964, joined the Astro-Electronics Division in 1962; he has been closely associated with publications for most of the major AED space programs. From 1960 to 1962, he was a technical writer at the Bendix Corporation, where he advanced to the position of group leader. He has been studying at Rutgers University Evening School for the past five years towards his degree in mathematics. He previously completed two years of evening school at Newark College of Engineering. John was on active duty with the U. S. Navy from 1956 to 1960, and during this time took advanced courses in radar, sonar, and communications. He was assigned the responsibility for maintenance of all types of submarine electronic equipment, including a complete prototype missile guidance system for the REGULUS missile. In addition he taught courses in basic electronics and electronics equipment. John recently coordinated many of the papers appearing in Volume 12, No. 6 RCA ENGINEER.

ED JENNINGS TO HEAD WORK ON RCA TECHNICAL LIBRARY SYSTEM

E. R. Jennings has been appointed to the newly established position of Administrator, Technical Library System. Prior to this, Mr. Jennings served on the staff of the RCA ENGINEER; he introduced "Pen-and-Podium" categorized indexes and annual RCA papers indexes. The staff and the Editorial Representatives acknowledge Ed's many achievements.

In his new post, Mr. Jennings will be responsible for the development and administration of a corporate-wide technical library system to facilitate the interchange of technical information and to increase technical information services throughout the corporation. Mr. Jennings will report to G. A. Kiessling, Manager, Product Engineering Professional Development.

Mr. Jennings received his BSME from Illinois Institute of Technology in 1950, and has pursued graduate studies in Information Science at Drexel Institute of Technology. During 1950-1954, he worked first as a technical journal editor, and then as a structural design engineer. His military service in 1954-55 was spent at White Sands Proving Ground, N. M., on missile test projects. After discharge, he joined the nuclear-weapon test organization at Sandia Base, Albuquerque, N. M., where he was Assistant Chief, Reports Branch, from 1956 to 1959. He joined Astro-Electronics Division in 1959 as an engineering editor, and later in 1959 moved to staff Product Engineering as Assistant Editor, RCA ENGINEER. In 1965, he was named Associate Editor and Administrator, RCA Staff Technical Publications. During 1966, he was responsible for a staff study of RCA Technical Libraries and information retrieval methodology. Mr. Jennings is a member of the IEEE and of the American Documentation Institute.

GSD NAMES J. L. GOLD AS TECHNICAL PUBLICATIONS ADMINISTRATOR

J. L. Gold has been named to serve as Technical Publications Administrator for RCA Graphic Systems Division (GSD), Princeton, New Jersey. He will be responsible for the review and approval of all technical papers and presentations originating in his division and will also serve as the RCA ENGINEER Editorial Representative for GSD.

Mr. Gold received a bachelors degree in science and a masters degree in education from Temple University. He has taught in the public schools and held positions in the field of adult education in private and military organizations. Since joining RCA in 1951, Mr. Gold has served in engineering positions for approximately five years and in writing, editing, and management positions in the field of technical publications for approximately ten years. He has participated in major RCA projects, such as Talos, C-Stellarator, BMEWS, and SAM-D. He is currently responsible for all technical publications and reports in the Engineering Department of the Graphic Systems Division.

Al Pinsky

Ed Jennings

J. L. Gold

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

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