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OUR COVER

As has been our custom over the past 11 years in every June-July issue, our cover for this eleventh-anniversary issue repeats the basic cover design of the first issue of the RCA ENGINEER (June-July 1955, Vol. I, No. 1). Cover art direction, J. Parvin.

Eleventh Anniversary

In the 11 years of publication marked by this anniversary issue, the RCA Engineer has reflected the widening involvement of electronics in man's most diverse and vital interests, ranging from color television and computers to the exploration of space.

Electronics has become so closely engaged in human affairs because of its unique ability to extend our powers of perceiving, learning, communicating, and creating. It is the only vehicle of information sufficiently swift and flexible to meet the multiplying informational needs of contemporary life.

Our dependence on electronics is certain to increase. In business, in government, in education, in the physical and social sciences, and, in fact, wherever there are problems to be solved, a wide range of information—quickly available—is a crucial need. As the frontiers of knowledge are pushed back and as society grows more complex, further progress will require an even greater flow of new information.

For these reasons, the information industry is the fastest growing sector of the economy. As part of that industry, RCA must be alert to all research and engineering developments that may have an effect upon the techniques of handling information. Since we are engaged in an extremely broad range of activities in this field, the problem of keeping ourselves informed of the technical advances within the many divisions of RCA is in itself a considerable challenge.

The RCA Engineer has risen to that challenge. Its reports have provided an essential dialogue among RCA engineers from which all of us can gain a better understanding of the company's varied activities. To the staff and contributors of the RCA Engineer, I offer congratulations on the achievements of the past 11 years and every good wish for future success.

Robert W. Sarn
Preside
Radio Corporation of Amer

RCA ENGINEER

VOL. 12, NO. 1
JUNE-JULY, 1966

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PAPERS

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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."

INITIALLY, the assigned topic was "Transfer of Technology from the Research Laboratory to the Product Division's Applied Research." To get a first-hand feel for that which was expected to be transferred, I asked about 40 RCA technical people, "What is technology?" The 40 different answers were straddled in the following three responses:

"Art of performing scientific feats."

"Alchemy supported by theory."

"Practical witchcraft that makes science work."

TECHNOLOGY INCLUDES SCIENCE AND ART

It is small wonder that there are different personal definitions of technology, because the combining form techno- comes from the Greek *techne*, meaning *art*, while technology comes from the Greek *technologia*, meaning *systematic treatment.* Dictionary definitions of technology are: 1) Industrial science; systematic knowledge of the industrial arts, 2) Terminology used in arts, sciences, or the like, and 3) Applied science. The 19-volume *Encyclopedia of Science and Technology*, McGraw-Hill (1960) evades the definition issue by saying it is "A work of, not about, science and technology." My definition of technology appears later. For the present, let us assume that technology includes both *science and art.* The science part can be communicated (transferred) in impersonal written form, but the art part usually requires person-to-person communication.

The Engineer and the Corporation

TECHNOLOGY AND YOU

H. W. LEVERENZ
Associate Director
RCA Laboratories

TECHNOLOGY: A VALUABLE ECONOMIC RESOURCE

At the topmost levels of our Federal Government there is concern about technology. In a report of the President to the Congress in 1964, it is stated, "the Federal Government should join with private business and our universities in speeding the development and spread of new technology."[1] As one result of this high-level concern, the Advanced Research Projects Agency of the Department of Defense started three industry-university teams on a $5.5 million program to couple science and technology of structural materials. An ARPA official said, "The basic idea of the program is to couple the research and science not only from the universities covered in the contracts, but from anywhere in the world, with the applied technology of the industrial laboratories."[2]

On a national scale, technology is an economically valuable subset of culture (which is the set of beneficial qualities that people do not inherit, but can learn).[3] More specifically, *technology comprises those parts of art and science that can be applied to provide goods and services.* Where technology is vigorously learned, generated, and used, as in many industries in the USA, it is appreciated as a valuable resource. Where the fruits of technology are scant, as in underdeveloped nations, it is not because technology will not work there, but because the people there do not work to learn and use suitable technology.

Final manuscript received March 1, 1966.

RCA — A TECHNOLOGICAL INNOVATOR

Coming closer to home, we in RCA are fortunate to be in a company and industry with a tradition of growth by technological innovation. Over 98% of RCA's present business is founded on technological developments made after RCA's birth in 1919. Since then, ingenious combinations of useful new concepts, materials, phenomena, devices, and techniques made possible AM and FM radio, modern audio records and players, radar, monochrome and color television, electronic computers, and a host of other apparatus and components.

Coming still closer to home, namely you, a working definition of technology is *"those parts of art and science that are applicable in RCA's businesses."* We are expected to generate, learn, communicate, and apply technology that promotes the health and growth of RCA. We function most efficiently when we are responsive to RCA's best business opportunities.

CRITICAL EVALUATION IS ESSENTIAL

This leads to the vital role of *attitude* toward technology. When people are apathetic toward available technology they are not responsive to the latent opportunity to produce valuable goods and services. On the other hand, when people are overenthusiastic or oversold about technological outcome from any and all research and development, then some inordinately large efforts can lead to negligible improvement in the quality and quantity of goods and services.

Since each of us has moments of apathy and of overenthusiasm, we can benefit greatly from the steadying influence of our associates' candid questions and comments about our technological objectives and approaches. We owe it to ourselves and our associates to initiate and participate in such candid discussions, including critical evaluations of RCA's business opportunities that require new technology. Business, like art, requires considerable person-to-person communication.

TRANSFER AND INTERCHANGE OF TECHNICAL INFORMATION

In RCA, we have many means for technical communication. From the Laboratories, for example, numerous internal reports and memoranda, covering all our research and engineering activities, are issued. Also, appropriate technical papers are published in internal and external professional journals. In addition, there are many oral section meetings, group meetings, project meetings, computer seminars, solid-state seminars, and colloquia, and special reviews are presented for people from various parts of the company.

More specific technological communication is provided by person-to-person discussions. Regular provision is made for such discussions in the Laboratories Applied Research Projects. These projects are conducted in the product divisions with the financial support and technical guidance of the Laboratories. Over 150 technological discussions are held each year when about 50 different groups of Laboratories and product division personnel meet for quarterly reviews of the approximately 50 Applied Research Projects. The meetings are held alternately at the Laboratories and product division locations. Applied Research Projects have been used for nearly 20 years as one of our working means to transfer technology, usually in the form of useful new techniques, materials, devices, and apparatus, from RCA Laboratories to the product divisions. Some of the Applied Research Projects are set up with two or more product divisions to take advantage of their joint deliberation and cooperative action.

Over the years we have found that the most effective means for *transferring* technology, especially when considerable art is involved, is to have the transferors and transferees literally *work together*. The questions of "who and where" usually are different for each case, and there is considerable variety in the answers.

TYPICAL TRANSFERS OF TECHNOLOGY

Here are some specific transfer cases that involved new materials and techniques:

1) Not long ago, researchers in RCA Laboratories evolved a) the germanium-silicon alloys and junction elements for generating power thermoelectrically, and b) a vapor-phase process for coating niobium stannide on wires and ribbons to make very-high-field superconducting solenoid magnets. Both of these developments involved considerable preparative art, and both were untried in our product divisions. In these instances, the technology transfers were made by a) having two engineers from Harrison work for several months with personnel and facilities in Princeton, and then return to design equipment and initiate the project that led to the multimillion-dollar development and production program of thermoelectric modules for nuclear-powered spacecraft, and b) by having another group transfer from Harrison to Princeton, as an Affiliated Laboratory for two years, and then return with the new technology to embark on the production and sale of superconductor solenoids and wire as a new business venture.

2) More recently, as a "fallout" from research on lasers, researchers in RCA Laboratories devised a kinescope phosphor containing a rare earth ion that emits intensely in a very narrow spectral band. This work, again, involved considerable preparative art, but—unlike the two previous examples—it was in a field where there was already technical competence and related manufacturing activity in the product division. In this instance, the technology transfer was made by having Princeton personnel travel often to Lancaster in order to work out quickly with Lancaster people a practical composition and technique for making and putting into production a new, red-emitting, rare-earth, color-kinescope phosphor. Such a joint effort is conducted at the product division site to shorten the time required to go from research to development and production, and to intensify the practical, business-oriented considerations that are essential in achieving timely technological objectives in an existing competitive business.

3) Magnetic tape technology was transferred from Princeton to Indianapolis by sending to Indianapolis the massive tape coater that was first designed, built, and operated in RCA Laboratories (after Record Division personnel had operated it there). The process and machine were used to produce tapes for audio recording. Since then, tape station machines for testing computer tapes have been sent from Electronic Data Processing to Indianapolis and to Princeton; other materials, processes, techniques, and coating machines have been developed; and personnel of the Laboratories and product divisions have often worked temporarily at other than their normal locations to expedite the technological expansion from audio to computer, instrumentation, and video tape.

EACH CASE IS SPECIAL

These examples by no means exhaust the possibilities of creating suitable conditions for people to transfer and advance technology. At the outset of a transfer, it is wise to assume that the best division of responsibility and effort between transferors and transferees is 70:30, *both* ways. There is not enough overlap of concern in a 50:50 division. Each case has to be considered and decided on its own merits, and the business opportunity deserves as persistent attention as the technical excellence and reproducibility of the new technology. The examples given, however, illustrate some of the flexibility of attitude, approach, and organizational arrangement that is possible in RCA. That flexibility can be one of RCA's greatest strengths in meeting technological challenges of the future.

CONCLUSION

In general, our means for technical communication are excellent, but the use that we make of them could be improved. Much of what you, as an individual, receive from within and without RCA is general art and science, rather than technology pertinent to your particular needs. That occurs partly because RCA has so many different business and technology needs at its various locations, and partly because your specific needs are not known by others who are working on new technology. As a first step in alleviating that situation, we urge you to identify and make known your most important technological needs, particularly the persistent basic needs, preferably on a person-to-person basis. When you do not know the most appropriate research person, please address your specific technological need to Technical Administration, RCA Laboratories, Princeton, N.J.

Selectivity is essential in this era of burgeoning art and science, and you can help yourself and your associates greatly by candid discussions with them at Applied-Research-Project meetings and other meetings aimed at identifying and working toward the specific technologies that are essential to success in RCA's best business opportunities.

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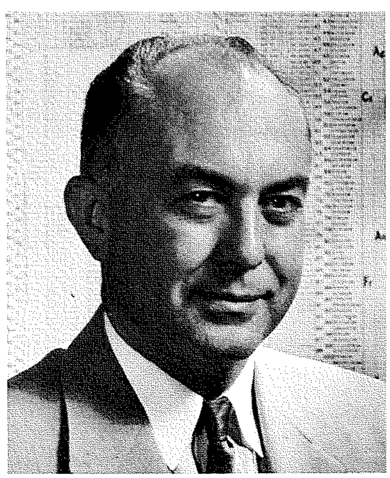
2. *Chemical and Engineering News,* p. 31, April 12, 1965.
3. H. W. Leverenz, "The Design of Instructional Equipment," Occasional Paper No. 8, The Department of Audiovisual Instruction, National Educational Association, Washington 6, D.C., 1963.

HUMBOLDT W. LEVERENZ received his BA degree in Chemistry from Stanford University in 1930 and later studied physics and chemistry as an Exchange Fellow at the Institute of International Education, University of Munster, Germany. After joining RCA as a chemico-physicist in 1931, he pioneered in devising superior phosphors and in evolving methods for effectively synthesizing, applying, and testing them. He devised the economical acid process for preparing superior ultrapure zinc sulfide and cadmium sulfide and designed the Lancaster phosphor plant. In 1942 he assumed supervision of research on electronically active solids at RCA Laboratories, Princeton. He was named Director of the Physical and Chemical Research Laboratory in 1954, Assistant Director of Research in 1957, and Director of Research in 1959. He assumed his present position as Associate Director, RCA Laboratories in 1961. He also is a member of the Board of Directors of Laboratories RCA, Ltd., Zurich, Switzerland and a member and past chairman of the Operating Committee of Industrial Reactor Laboratories, Inc., Plainsboro, N.J. Over 60 patents have been issued on Mr. Leverenz' inventions. He is a Fellow of the American Physical Society, and the Optical Society of America. He is a member of the American Chemical Society, IEEE, Swiss Physical Society, AAAS, and Sigma Xi. In 1964 he was named to the Materials Advisory Board (National Academy of Sciences/National Research Council). He is the author of numerous scientific and technical papers and books.



FOOD ELECTRONICS

RF-Accelerated Freeze-Drying of Foods

H. F. KAZANOWSKI, Mgr.,
Industrial Market Development

W. N. PARKER, Staff Engineer,
Super-Power Tube Operations

Industrial Tube and Semiconductor Div., ECD, Lancaster, Pa.

Freeze-dried food products, such as those pictured above, may be RF-dried in the future.

An accelerated freeze-drying technique using RF energy for the processing of foods has been developed by RCA. The RF technique takes less time and uses lower temperatures, and the food thus processed retains more flavor, than is possible with conventional radiation drying. The RF freeze-drying system includes a vacuum chamber, a UHF oven, and a UHF generator. This paper reviews some of the technical considerations involved in the investigation of RF freeze-drying, and discusses the test results.

The application of RF energy to food, whether for microwave cooking or for commercial processing, offers expanding market opportunities for RCA. In the industrial area, however, the analysis of a new process system often requires a demonstration of feasibility and performance. This paper summarizes some of the early technical considerations associated with the investigation of such a program. The purpose of this effort was in the nature of "applied research" to determine: 1) whether RF power, uniformly applied, could accelerate the drying process sufficiently, and 2) whether the economics of RF could justify its use on a commercial scale. Initial results have been sufficiently encouraging to continue development of prototype continuous-flow systems.

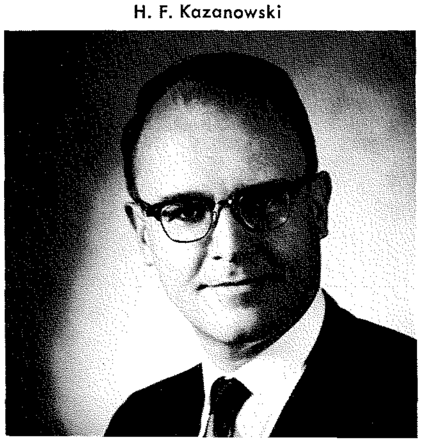
The importance of new processing methods for food products is brought into sharp focus by the realization that two-thirds of today's processed foods will be out of date in less than 20 years.

One of the newest food-preservation techniques is *freeze drying*. This procedure promises major advances in convenience foods, and has significant potential for the use of RF energy in food processing. Moreover, this process retains the fidelity and authenticity of the original flavors and preserves more of the heat-sensitive vitamins and protein value than any other current commercial drying method. Properly packaged freeze-dried foods have an almost indefinite shelf-life without refrigeration; also, complete water removal reduces weight more than any other preservation technique.

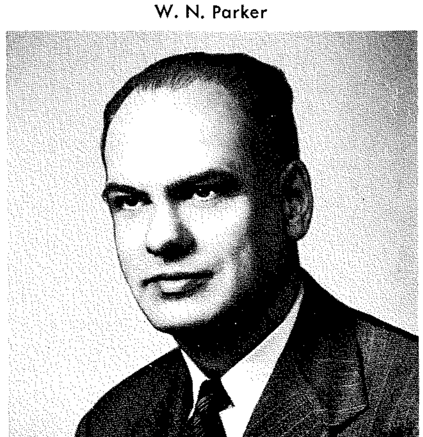
Final manuscript received April 27, 1966.

HENRY F. KAZANOWSKI received his BSEE degree from Northeastern University in 1948 and his MS in Physics from Franklin and Marshall College in 1954. He joined RCA in 1948 as a power-tube design engineer and subsequently developed the RCA type 6181, the first ceramic-metal power-tube, which found wide use in commercial UHF-TV transmitters, including the RCA TTU-1B. He transferred to the ECD Product Administration activity in 1952, where he coordinated government contract programs for several product lines and planned the introduction of new tube types, including the RCA Cermolox Line. Since 1957 he has worked in Divisional Financial Control and in Advance Market Planning, conducting special business analyses and plant expansion studies. Mr. Kazanowski currently heads the Industrial Market Development activity in IT&SD and is responsible for new industrial business planning for the power tube, microwave, conversion tube, and semiconductor product lines. He is a member of A.A.A.S. and the Institute of Food Technologists. In 1965 he was elected to the Board of Directors of Research and Development Associates Inc.

H. F. Kazanowski



W. N. Parker



WILLIAM N. PARKER received his BSEE from the University of Illinois in 1928. He was employed in 1929 by Western Television Corp. in the development of mechanical TV equipment. After serving as Chief Engineer of broadcast station XENT, he joined Philco in 1934, where he pioneered in TV transmitters. During World War II, he was with the U.S. Expediting Production Agency. Since joining RCA in 1943, he has been engaged in the development of super-power and high-power UHF tubes at Lancaster. He was Manager, Large Power Tube Development from 1953 to 1955, when he was appointed Staff Engineer. Other assignments involved design of the C-Stellarator vacuum system, integrated-circuit super-power coaxitrons, and RF processing of food. He holds 15 patents. Mr. Parker is a registered Professional Engineer, and is a member of Sigma Tau, Eta Kappa Nu, Sigma Xi, Pi Mu Epsilon, Institute of Food Technologists, and IEEE.

Freeze-drying is a sublimation process that removes moisture from frozen products without changing their shapes, colors, or flavors. In processing, the frozen raw or precooked products are placed on trays in a vacuum chamber where a controlled amount of heat (heat of sublimation) is applied through liquid-heated trays or platens. The ice in the food evaporates and the dry foods emerge in a solid, sponge-like condition. After hermetic packaging in either film-pouches or cans, the products can be shipped or stored without refrigeration. Prior to eating, cooking, or otherwise handling as fresh food, the products require only rehydration.

RCA's interest in freeze-drying is long-standing,[1] particularly as a large market potential for the application of RF power. Recent projections[2,3] indicate that, if RF-accelerated freeze-drying is successful, more megawatts of RF energy will be required than are used currently in the combined AM, FM, and TV installations in the United States. Although there are reports[4,5,6] of successful accelerated freeze-drying experiments by means of UHF or microwaves, engineering details are meager.

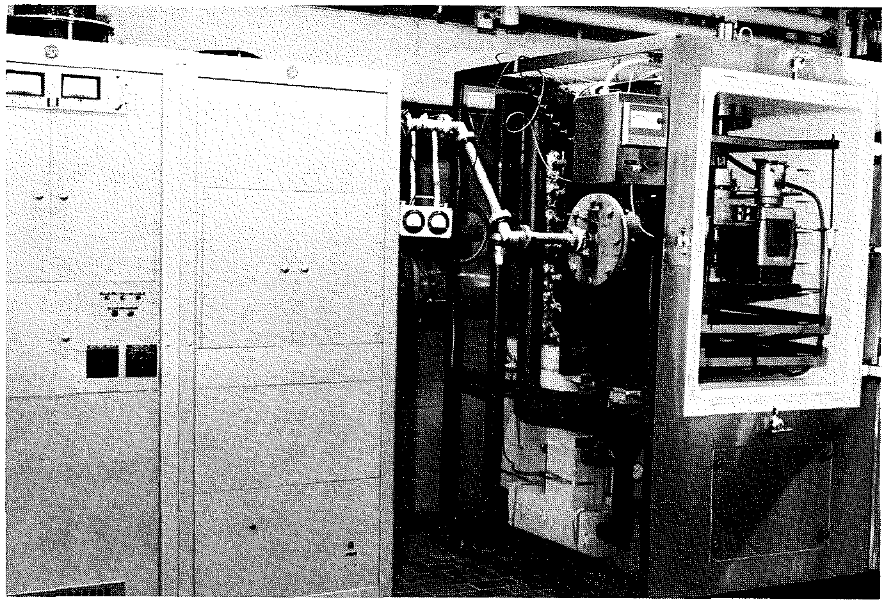


Fig. 2—Front view of freeze-drying unit. The UHF generator is at the left. The UHF transmission line and tuning controls enter the left side of the sublimation chamber.

PRELIMINARY EVALUATION

In 1963, as a result of an engineering analysis of the freeze-drying principles, an electrical analog was prepared to investigate the effects of UHF energy on a typical frozen food in vacuum. Parameters were established to check power absorption, drying time, temperature rises in the dried and frozen material, surface temperature, and ionization breakdown. Then, several computer runs were made to verify the effect of UHF heating.

During conventional freeze-drying with heated platens, the already-dried layer of food surrounding the undried frozen portion acts as a heat-flow barrier and retards the transfer of heat from the hot platens to the interior of the product. Drying times of 8 to 24 hours are often required to sublime the ice completely. The engineering study indicated that RF heating, which is volumetric, should speed up the drying rate significantly, increase the product output, and thus reduce the price of freeze-dried foods.

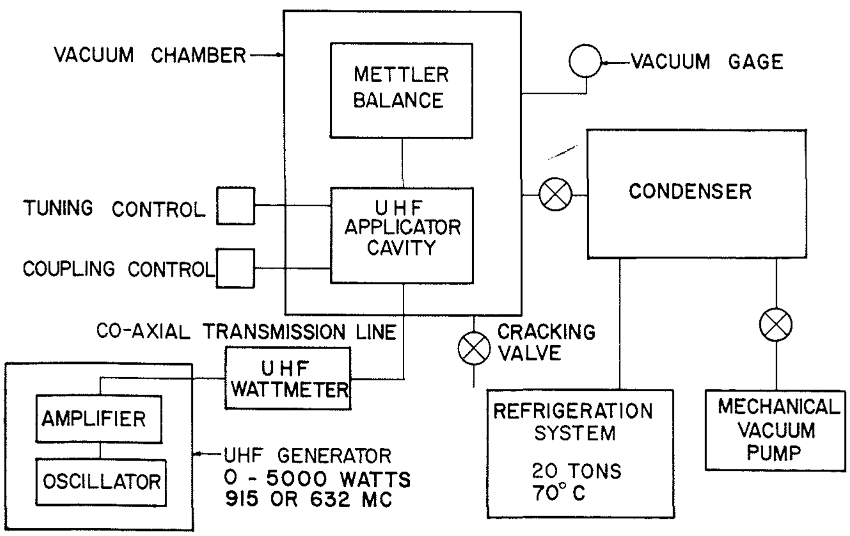
An equipment and test program, based on the theoretical and mathematical analyses, was undertaken by RCA in cooperation with the Department of Food Science of North Carolina State University. The principal objectives of this investigation were to demonstrate the technical and economic feasibilities of using RF energy during the freeze-drying process, and to obtain basic engineering information that would be useful to food processors and food equipment manufacturers.[7]

The freeze-drying system used in the RCA-North Carolina University tests is diagrammed in Fig. 1. It consists of a vacuum chamber, housing four 2- x 2-foot platens, and a UHF oven (or resonant cavity) electrically connected to a UHF generator for food processing. For comparison with conventional radiant heating, the UHF-platen temperatures can be controlled from −30° to +130°C, while the refrigerated condenser used for water removal is maintained at −55°C. An ultimate chamber pressure of 20 to 30 microns is normally obtained.

During RF-accelerated freeze-drying, the product is heated in the UHF oven, which has slits cut in the walls to allow free passage for the vapor from the product to the refrigerated condenser. The oven (cavity) is made resonant for various food loads by means of tuning and coupling controls which extend through the vacuum-chamber walls. Maximum net power into the loads is obtained under resonant conditions.

The UHF generator, which consists of a master oscillator and power amplifier, was designed to operate at 915, 632, and 350 MHz to check for frequency-selective effects. Continuously variable power output from 0 to 5000 watts can be obtained by control of the grid-No. 2 (screen-grid) voltage for the RCA-8501 UHF power tube used in the amplifier. A coaxial transmission line fitted with forward- and reverse-reading UHF wattmeters carries power from the generator to the cavity.

Fig. 1—Diagram of system used for UHF freeze-drying experiments.



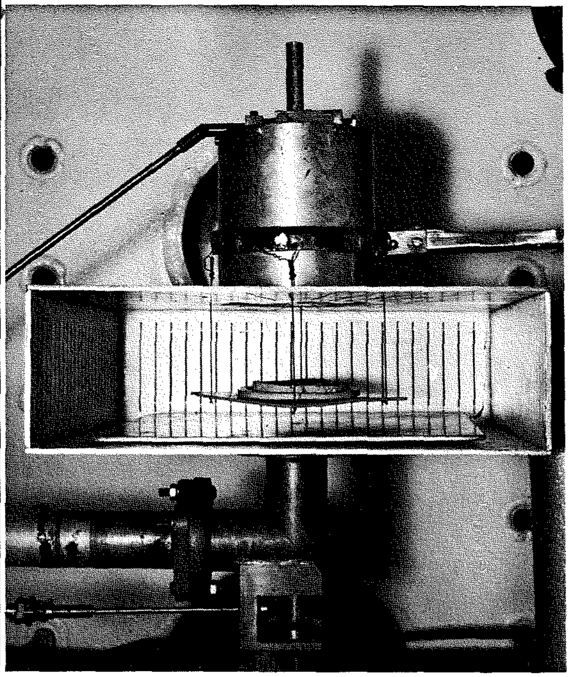


Fig. 3—UHF cavity inside sublimation chamber. Teflon weighing platform, containing beef patty, is suspended by nylon cords from weighing arm on balance.

The complete electronic system for the North Carolina State University test program was designed and built by RCA-Lancaster.

A general view of the freeze-drying equipment, the UHF generator, and the UHF transmission line is shown in Fig. 2. The instantaneous weight of the product is measured by a Mettler balance adjacent to the cavity and is observed through a porthole in the chamber door. Some of the foods investigated included ground beef, shrimp, and peas, which were formed into 3-inch-diameter samples having thicknesses from 0.25 inch to 2.5 inches. Beef samples were sized by machine to ensure product uniformity.

A close-up view of the UHF cavity with the door removed is shown in Fig. 3. For several UHF drying tests, a frozen sample was placed on the Teflon* weighing platform which was suspended inside the UHF cavity from an auxiliary beam on the weighing platform of the Mettler balance. Pumpdown of the chamber to a working pressure of 60 microns required about 10 minutes, after which time the UHF energy was applied, the cavity tuning was checked, and the RF power level was set. At 5-minute intervals, readings were taken of the sample weight, chamber pressure, net UHF power, and the power required for ionization of the residual gas (glow-power). For glow-power readings, the input power was momentarily increased, and the value noted at which a visible electrical discharge took place in the free space within the cavity. The power input must be kept below the glow-point for successful freeze-drying. The onset of glowing was also indicated by a sudden rise in the UHF wattmeter measurement of the reverse power in the coaxial transmission line.

** Registered trademark of E. I. duPont.*

TEST RESULTS AND DISCUSSION

Since early 1964, more than 100 freeze-drying tests have been made at two UHF frequencies: 915 MHz and 630 MHz. (No advantage was found at the lower frequencies used in the preliminary work.) A partial listing of foods tested includes potato patties, chopped beef patties, shrimp, lobster, peas, yeast, ice cream, orange juice concentrate, berries, and coffee extract. Product thickness ranged from 0.25 inch to 2.5 inches. Various initial moisture levels were also investigated.

Freeze-drying curves for 1-inch-thick meat patties, shown in Fig. 4 for radiant and UHF (915 MHz) heating, disclose that UHF heating accelerates freeze-drying very considerably. For constant dry weight, the drying times are 22 and 2.5 hours, respectively, or at the ratio of 9 to 1. For 5% moisture content, the drying times are approximately 15.5 and 2.25 hours, respectively, or at the ratio of 7 to 1. The most striking time reduction achieved by the use of UHF power is in the area of lower moisture content. For example, radiant-drying reduction of the moisture content of a sample from 10% to 5% required 2 hours, but UHF achieved the same results in only 8 minutes; thus the time ratio is 15 to 1.

Table I lists typical drying times for several food products to 2% final moisture by UHF and radiant freeze-drying. The drying times at 915 MHz were approximately constant for the various thicknesses of beef patties; at 632 MHz, slightly increased drying times were required. Conventional radiant drying times, in general, are markedly affected by thickness, e.g., a 1-inch meat patty requires more than twice the drying time of a 0.5-inch patty to reach the 2% level (with food-surface temperature maintained below 50°C to prevent scorching).[8]

Comparison of radiant drying times with those of UHF indicates that UHF heating achieves an average drying rate

Fig. 4—Comparison of UHF and radiant freeze-drying of 1-inch-thick chopped-beef patties from initial moisture of about 60% to approximately zero moisture.

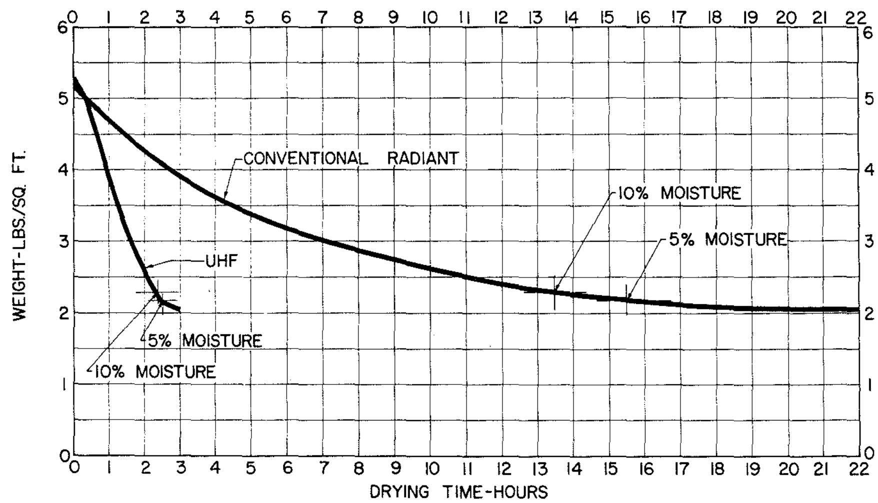


TABLE I. Summary of Typical Engineering Data Derived from Experimental Freeze-Drying Results

Food	*Depth (inches)*	*Drying Time to 2% Moisture (minutes)*			*Maximum Sublimation Rates (lb water/ lb dry solids/hr.)*			*Source Power (UHF kW/lb frozen food)*		*Process Rate (lb dried product/ UHF kWh)*	
		632 MHz	*915 MHz*	*Radiant*	*632 MHz*	*915 MHz*	*Radiant*	*632 MHz*	*915 MHz*	*632 MHz*	*915 MHz*
Chopped beef	0.25	145	142		0.687	0.749		0.104	0.104	1.51	1.80
	0.50	145	130	455	0.985	0.875	0.478	0.156	0.117	1.33	1.49
	0.75	160	138		0.728	1.030		0.113	0.106	1.36	1.66
	1.00	170	145	1090	0.738	0.735	0.261	0.113	0.115	1.45	1.62
	1.50	139			0.778			0.123		1.49	
Whole cooked shrimp	0.5	153	155	420	1.48	1.41	0.562	0.150	0.143	0.921	0.874
Loose peas	0.75		155	480		1.70			0.132		0.611
	1.25		145			1.75			0.128		0.628
	2.50		145								
Mashed potato	0.5		253	630		1.38	0.695				

more than three times faster for a 0.5-inch patty, and more than seven times faster for a 1-inch patty.

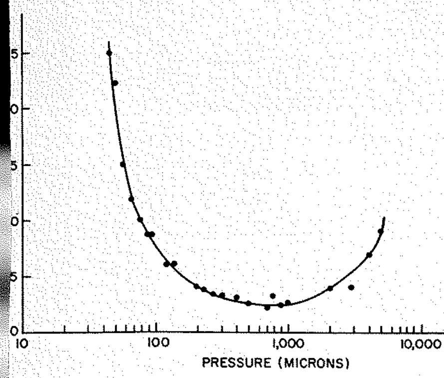
For loose peas with seed coats perforated to permit venting of the moisture, the UHF drying times (Table I) were independent of layer thicknesses up to 2.5 inches. The upper limit of layer thickness was set by the physical dimensions of the cavity and by the weighing mechanism. In radiant freeze-drying, about 8 hours is usually required for a layer of peas 0.75 inch deep. The combination of shorter drying time and greater layer depth results in an improved average drying rate of about 13 times for UHF freeze-drying.

Preliminary UHF freeze-drying tests of coffee extract were particularly encouraging. A drying time of 2 to 3 hours was obtained for coffee extract frozen into small pellets.

When UHF energy was used, mashed-potato patties required 4 hours to reach 2% moisture. Although this drying time is satisfactory, a dried patty could not be obtained without some internal darkening as a result of overheating. Local discoloration occurred even though a frozen, undried layer of pulp was present in the center of the potato patty. The already-dried material seemed to accept power readily, so that overheating and charring occurred even at relatively low input-power levels. By comparison, meat, shrimp, peas, and coffee extract exhibited ideal UHF drying characteristics.

In some preliminary tests, UHF- and radiant-freeze-dried meat patties, 0.50-inch thick, were rehydrated and then grilled. Both patties were found to be of acceptable quality by the taste panel of the North Carolina State University Food Science Department.

Fig. 5—This RF glow power vs. pressure curve shows the maximum UHF power that can be used without glowing for freeze-drying of a 0.5-inch-thick beef patty having 60% moisture content.



Glow-power as a function of pressure for a 0.5-inch patty is shown in Fig. 5. The ordinate of the curve represents the power necessary to cause a glow-discharge in the cavity, which contained a fresh-frozen patty on a Teflon platform, and gives a measure of the maximum usable power at any pressure. For example, a power input of 15 watts requires a pressure of 60 microns or less for useful freeze-drying. (A power of 15 watts for a single patty is equivalent to about 120 kilowatts for a 1000-pound load.)

The power level at which glowing occurs in the cavity during the heating of the meat patty indicates the ease with which the meat absorbs power. The ability to absorb power tends to decrease as full dryness is approached. The glow-power also indicates the maximum power that can be employed for freeze-drying. However, the use of power in excess of 15 watts on a single 0.5-inch meat patty can result in: 1) overheating of the patty and 2) *meltback*, a condition in which portions of the frozen product melt and overheat locally.

The designer of a freeze-drying system with adequate vapor-handling capacity can determine the drying rate at a given time from the slope of the weight-vs-time curve (drying curve). Table I lists some typical maximum sublimation rates for various products and thicknesses. Of particular interest is the case of the 1-inch beef patties, for which the 915-MHz drying rate of 0.735 pound of water/hour/pound of dry solids is 2.8 times faster than the radiant drying rate. As a result, the refrigerated condenser or other vapor-handling device must be slightly larger; however, the cost of the larger equipment is more than offset by the much shorter UHF drying time which, in this example, is only one-seventh that for radiant drying. Thus, UHF permits a much greater food-handling capability for a given plant investment, a key to lower food costs through lower production costs.

In the design of a UHF freeze-dryer, an engineer must know the UHF power required. Table I expresses typical power requirements in kilowatts of UHF power per pound of frozen food, e.g., a 750-pound load of fresh-frozen green peas requires a rated output from the UHF source of 750 x 0.132, or approximately 100 kilowatts.

Table I also contains some typical *process rates* expressed in pounds of finished dried product per UHF kilowatt-hour. Alternate ways of expressing process rates would be in pounds of frozen food or in pounds of dry solids. A yield of 150 pounds of 2% moisture peas would require 150 ÷ 0.611 or 245 kilowatt-hours of power delivered from the UHF source to the applicator cavity. A yield of 150 pounds of dried peas corresponds approximately to the fresh-frozen weight of 750 pounds used in the previous example.

All data in Table I were averaged from numerous experimental freeze-drying tests which used single-patty food samples dried with an arbitrary programming of heat input. In extrapolating these data, designers should allow for variations in food properties and electrical efficiencies. The data include the effect of the electrical efficiency of the UHF applicator cavity used in the experiments described.

The efficiency of a given UHF applicator cavity is determined as follows: the weight-loss rate is divided by the UHF input in watts, and the ratio is compared to the theoretical heat of sublimation for water (1210 Btu/lb). Only 10 to 15% of the UHF power input is wasted in heating the UHF cavity walls as a result of wall currents and electrical resistance. However, as the food product becomes dry, its ability to absorb UHF power decreases markedly and the cavity losses become more significant. Nevertheless, the actual amount of power "wasted" in this way is small because the total UHF power is programmed to lower levels toward the end of the drying cycle. Some products, such as potato patties and strawberries, do not show this sharp drop in efficiency for low moisture content. In fact, warm, dry strawberries seem to absorb UHF power more readily than cold, fresh-frozen ones. This fact may explain the difficulties experienced in accelerating the freeze-drying of strawberries by UHF energy.

DESIGN OF PRODUCTION EQUIPMENT

Applicator cavities capable of processing production quantities of food must, of course, be considerably larger than the single-sample test ovens used to obtain the foregoing engineering data. When large cavities are operated at UHF, however, patterns of alternate high and low electric fields are set up throughout the cavity interior. Because the high-field regions could be spaced approximately 6.45 inches apart at 915 MHz, careful food placement would be required to achieve uniform processing. Even then, a small change in the frequency of the UHF generator might change the field patterns adversely. Techniques have been proposed to achieve uniform processing at high frequencies.[9,10] One arrangement designed to freeze-dry up to twenty 0.5-inch patties at a time consists of a cavity which simultaneously sustains two field patterns that overlap each other spatially.[11] This form of cavity is called an

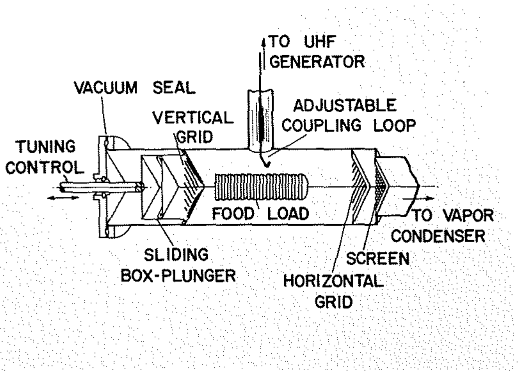


Fig. 6—Cutaway view of combined vacuum chamber and UHF orthogonal mode cavity. Food to be freeze-dried enters chamber at vacuum-seal end.

orthogonal mode cavity because of the perpendicular relation of the two field patterns.

A simplified cutaway drawing of the actual combined vacuum chamber and cavity using two overlapping field patterns is shown in Fig. 6. The position of the horizontal grid is fixed at a quarter-wavelength from the screened end. The vertical grid extends across a box plunger which is also a quarter-wavelength deep. The box-plunger assembly slides axially to permit simultaneous tuning of both modes. The food is loaded through the vacuum seal and is suspended in the center of the 10- x 10- x 54-inch chamber. A 10-inch pipe provides a minimum-restriction vacuum line to the refrigerated vapor condenser. The UHF power is coupled by an adjustable loop, and a load cell (not shown) permits continuous weighing of the food load. The Teflon load basket, containing 10 chopped beef patties, is shown in Fig. 7. Evaluation of this cavity with larger food loads has verified the results obtained with single food-patty samples.

SUMMARY AND OUTLOOK

The RF-accelerated freeze-drying technique developed by RCA has demonstrated its usefulness on a variety of food products. Meat, fish, poultry, fruits, vegetables, and certain beverages have been test-dried rapidly and successfully. However, strawberries and orange juice concentrate still require modified procedures and additional testing to obtain commercially acceptable drying characteristics. Definite quality improvements in RCA RF-dried products, resulting from the shorter time and the lower temperature required for processing, have been reported by food technologists. Moreover, the RF technique retains the volatile, organic, flavor constituents to a greater degree than the conventional process.

Experimental results indicate that freeze-drying is feasible for a variety of foods and that the use of thick bed-depths can increase food-handling capability by about an order of magnitude over that possible with conventional radiant freeze-drying techniques. Improved moisture uniformity in products of varied sizes is possible with UHF because the drying time is independent of thickness.

Current RCA RF-accelerated freeze-drying development 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 have been prepared by RCA on a cooperative basis with potential customers to demonstrate the advantages of RF processing. Work is proceeding toward prototype and pilot-plant operations. Cost studies have been made of freeze-drying plants capable of drying from 1 million to 30 million pounds of (wet) product annually. Analyses of capital investment requirements have been detailed, including vacuum-chamber conveyor, belt system, refrigeration, UHF generator (with applicator), and building costs. Operating costs, including equipment depreciation, labor, and utilities, have been calculated and reduced to *total cost per pound of wet product processed* or *total cost per pound of water removed*, which are the significant economic indexes.

The predicted total cost of RF freeze-dry processing is under three cents per pound of original product, which is significantly less than present process costs. The capital investment required to fully facilitate a production-sized plant for RF freeze-drying is approximately 30% less than for conventional (radiant) freeze-drying for an equivalent product output.

As freeze-dried food costs are reduced by the more efficient RF process, new foods will be developed for domestic use and for possible world markets in areas where nutritional deficiencies exist or where refrigeration and transportation are major problems.[12,13,14]

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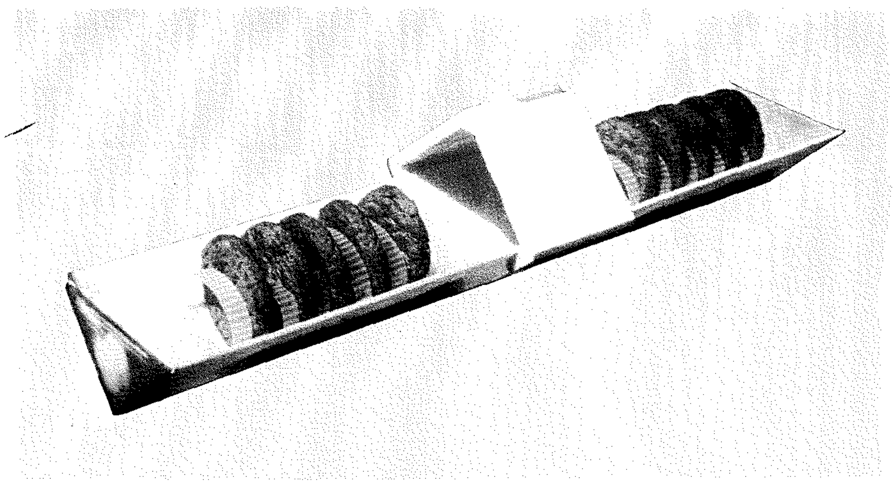
Fig. 7—Teflon basket containing ten chopped beef patties after freeze-drying in UHF orthogonal mode cavity.



INTEGRATED CIRCUITS

New Concepts in Circuit Design

The rapid progress achieved in integrated-circuit technology in the past two years has resulted in the penetration of the commercial electronics market. As integrated-circuit functions approach economic maturity, new design axioms have evolved. This paper reviews the new design approach and illustrates its basis and application.

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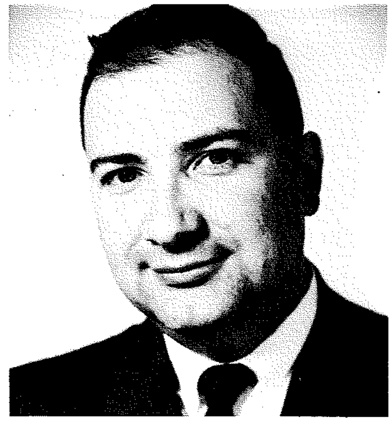


ISRAEL KALISH received his BSEE degree from the Cooper Union School of Engineering in 1953 and his MS degree in Electrical Engineering from Columbia University in 1956. He joined RCA in 1953 as a semiconductor-device engineer. He was promoted to Manager of Germanium Product Design in 1961, and assumed his present position as Manager of Integrated Circuit Device Technology in January 1963. Mr. Kalish is presently an Adjunct Professor in Physics and Electrical Engineering at the Cooper Union School of Engineering and Science.

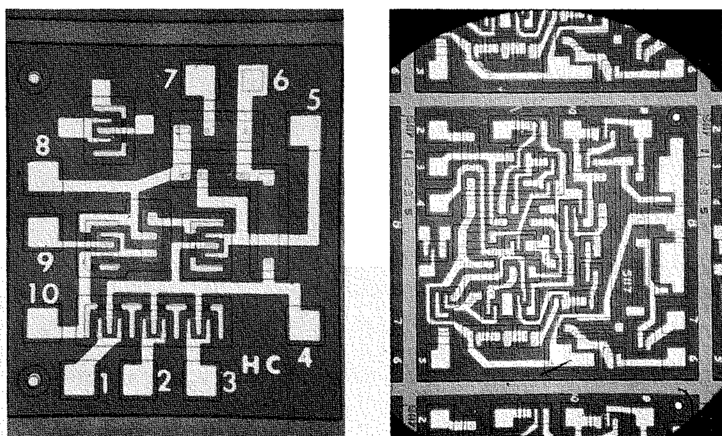
During the past two years, fabrication of integrated circuits at Somerville has made the transition from an exotic technology barely capable of meeting a sympathetic specification to a routine manufacturing process supplying competitive components to a cost- and performance-oriented commercial market. This progress is illustrated by the photographs of two integrated-circuit chips in Fig. 1. The chip at the left is a 12-component developmental digital gate previously described.[1] The chip at the right is a 39-component FM sound-IF circuit presently being supplied to the Home Instruments Division by the Somerville Integrated-Circuits Manufacturing Department.

Final manuscript received April 28, 1966.

Progress in integrated circuits has taken place on two major fronts. On the one hand, new technology has made available new devices, such as the complementary MOS structure shown in Fig. 2, and improved processes, such as the ceramic isolation technique shown in Fig. 3 (developed at the RCA Laboratories). On the other hand, as will be discussed in this paper, processing refinements and imaginative design approaches have reduced the cost of realizing specific circuit functions on silicon chips to the point where discrete components are becoming obsolete in many areas on the basis of cost and performance. This point has already been reached in the digital field, and is being approached in such standardized linear functions as operational amplifiers. This paper discusses the new design approach that has been evolved, and illustrates its basis and application.

NEW DESIGN AXIOMS

The rapid progress of integrated-circuit functions toward economic maturity has occurred despite the fact that the parameters of monolithic components often are not comparable to those of discrete components. Table I compares typical parameters of monolithic and discrete transistors, and also gives typical values for monolithic resistors and capacitors. Although progress has been made in closing the gap in transistor parameters, monolithic resistors are still of poor qual-



(a) Fig. 1—Photographs of integrated-circuit chips: a) early developmental 12-component digital gate; b) 39-component FM sound-IF strip. (b)

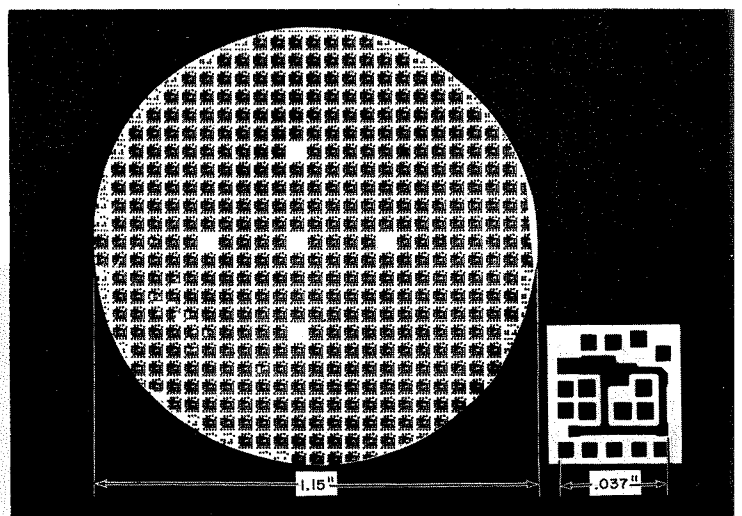


Fig. 3—RCA Laboratories ceramic isolation technique.

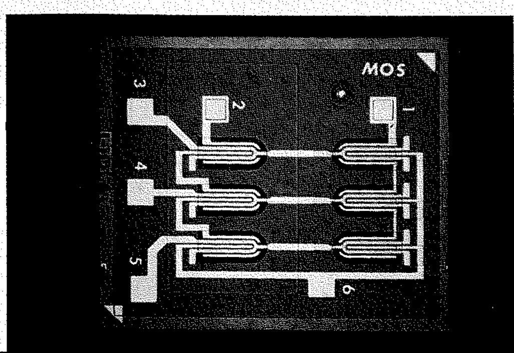
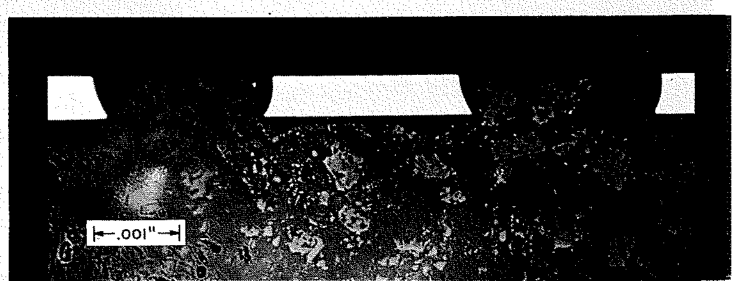


Fig. 2—Complementary MOS three-input gate.



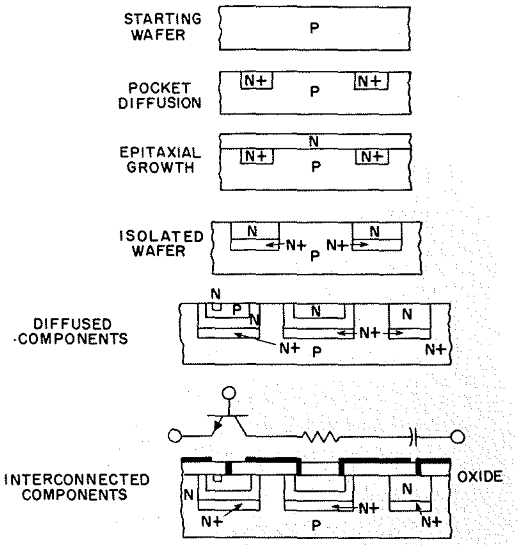
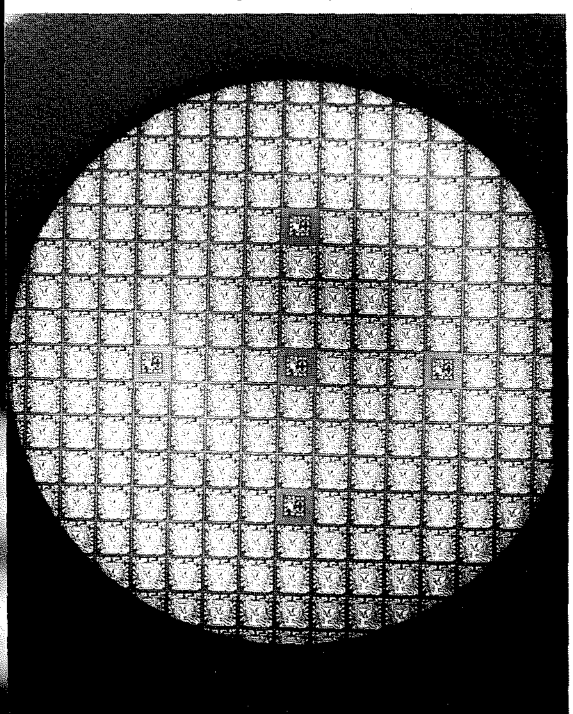


Fig. 4—Steps in monolithic component processing.

TABLE I—Typical Parameters of Monolithic and Discrete Components

Parameter	*Mono-lithic*	*Dis-crete*
TRANSISTORS		
Current Transfer Ratio	40-200	40-200
Breakdown Voltage (V)	50	100
Gain-Bandwidth Product (GHz)	1	2
Feedback Capacitance (pF)	1.5	0.3
Isolation Capacitance (pF)	1.5	—
Isolation Voltage (V)	75	—
RESISTORS (Monolithic)		
Range: 100-20,000 ohms ±20% routinely		
Ratios: ±3% routinely		
CAPACITORS (Monolithic)		
Range: up to 100 pF		

Fig. 5—Integrated-circuit wafer.



ity, and monolithic capacitors exist in only the smallest sizes. Nevertheless, circuit integration has progressed because the silicon planar technology used in the fabrication of monolithic circuits has revolutionized the economic rules for achieving a given electronic function.

Since the invention of the vacuum tube, circuit designers have worked with two axioms: 1) that active devices are more expensive than passive devices, and 2) that the cost of passive devices is a function only of tolerances and power ratings, and is independent of parameter values. (These rules are valid except in the case of large-value capacitors.) Two generations of circuit designers, therefore, have worked effectively to minimize the number of tubes and transistors in their equipments.

In the design of monolithic silicon circuits, however, the cost of passive devices is a direct function of parameter values, as well as of tolerances and power ratings. As a result, passive devices usually are more expensive than active devices, and often are prohibitively expensive in large values. Therefore, it is often economical to design circuits so that additional transistors can be used rather than capacitors or large resistors.

COST VS AREA

The cost of a monolithic component is determined primarily by the amount of chip area it uses. Fig. 4 shows the masking, diffusion, and metalization operations involved in the fabrication of a monolithic circuit; Fig. 5 shows a completed wafer containing hundreds of circuits. The processing operations are independent of the number of circuits on the wafer or the number of components in each circuit. The smaller the components, however, the more circuits can be obtained by the processing of a given wafer. In addition, if random defect patterns exist in the wafer, small circuit geometries have a greater probability of avoiding defects and thus exhibit a higher yield (number of good circuits per wafer).

The major factor in the economics of the integrated-circuit chip, therefore, is its area. Thus, the relative costs of components must be evaluated in terms of the amount of chip area that each occupies. Table II is a typical *price list* for monolithic components in terms of area. This table shows that a transistor *costs* no more than a 1000-ohm resistor or a 3-picofarad capacitor. As resistance and capacitance values increase, transistor *cost* becomes comparatively less. In integrated-circuit design, therefore, the passive components are minimized to take advantage of the *bargain* transistors.

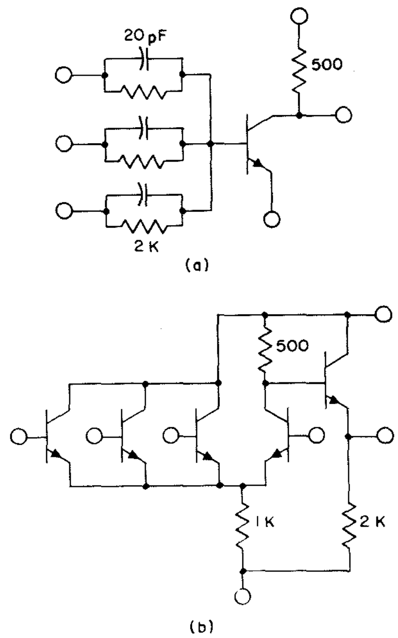


Fig. 6—Two types of three-input NOR gate: a) RCTL configuration; b) ECCSL configuration.

Fig. 6 demonstrates the impact of this new rule for integrated circuits on the design of a three-input *nor* gate. This function can be realized by use of only one transistor in the RCTL (resistance-capacitance-transistor logic) configuration, or by use of five transistors in the ECCSL (emitter-coupled current-steering logic) configuration. In discrete form, the RCTL gate would be the more economical choice, but in integrated form the reverse would be true. The reasons can be illustrated by the following computations.

TABLE II—Area "Price" List for Monolithic Components

Component	*Relative Area*
Transistor	10
Resistor (±20%)	5R/500 (R > 500 ohms) 5(500/R) (R < 500 ohms)
Capacitor	$3C \times 10^{12}$

Com-ponent	*Rela-tive Unit Cost*	*RCTL Gate No. Used*	*RCTL Gate Total Cost*	*ECCSL Gate No. Used*	*ECCSL Gate Total Cost*
Transistor	20	1	20	5	100
Resistor	2	4	8	3	6
Capacitor	5	3	15	—	—
Total Cost			43		106

In discrete form, therefore, the cost of an ECCSL gate is two and one-half times the cost of the logically equivalent RCTL gate. As a result, the ECCSL gate is rarely used in this form.

Table III shows the relative cost of components in their conventional discrete form. From this table the two gates shown in Fig. 6 can be evaluated as follows:

From the data given in Table II, a comparison of the two circuits can be made in terms of area values, as follows:

Component	Relative Unit Area	RCTL Gate No. Used	RCTL Gate Total Area	ECCSL Gate No. Used	ECCSL Gate Total Area
Transistor	10	1	10	5	50
Resistor	5	1	5	1	5
	10	—	—	1	10
	20	3	60	1	20
Capacitor	60	3	180	—	—
Total Cost			255		85

In monolithic form, therefore, the ECCSL gate has a three-to-one advantage over the RCTL configuration. Thus, in terms of area economics, the elimination of the need for capacitors makes the ECCSL circuit a wise choice.

COST VS TOLERANCE

Because of processing variations inherent in the monolithic silicon technology, circuit requirements for high-tolerance components minimize yields in integrated-circuit processing. Therefore, it is desirable to adopt design procedures wherein tight performance specifications can be met by use of components having wide parameter spreads. It is more economical, for example, to design a three-stage integrated-circuit amplifier that has fairly wide tolerances at each stage and to degenerate any excess gain than to insist on tight specifications for a single stage that can provide the desired gain.

The impact of component tolerances on cost can be demonstrated by consideration of the design of an integrated resistor. As shown in Fig. 7, the value of resistors in a semiconductor integrated circuit depends upon a diffusion parameter (the sheet resistance R_s) and the ratio of length to width in the resistor geometry. For simplicity, only the effect of variations in width need be considered. A variation of 0.05 mil in resistor width because of photochemistry limitations would imply an uncertainty of 5% in the specification of the resistance for a 1-mil-wide resistor. To reduce this uncertainty to 1% would require the use of a 5-mil-wide resistor. Thus, the price of obtaining an improvement of five times in resistor tolerance would be an increase in area of 25 times.

TABLE III—Relative Prices of Discrete Components

Component	Relative Price
Transistor	20
Resistor	2
Capacitor	5

To fully realize the potential of integration, therefore, systems must be analyzed in terms of the circuit functions to be achieved rather than in terms of duplication of discrete circuits in monolithic form.

ADVANTAGES OF MONOLITHIC DESIGN

The designer of monolithic circuits has advantages not available to the discrete-circuit designer. Because of the close proximity of integrated-circuit components, thermal tracking problems are minimized. Matched transistors are relatively easy to fabricate, and thus differential amplifiers become economical building blocks. In addition, the two-dimensional nature of the components minimizes capacitive and inductive coupling to the extent that high and stable gains can be achieved in configurations that would oscillate in discrete form.

BREADBOARDING

An additional factor in the progress of integrated circuits has been the development of circuit design and analysis techniques. One of the early fears about integrated-circuit design was that the long delay between circuit choice and chip realization (often a matter of weeks) would make it crucial for the circuit choice to be exactly correct. In practice, this requirement would be an untenable analytical burden. During the past few years, however, practices similar to discrete-component *breadboarding* have been evolved. One approach has been the use of special *parasitic* transistors having parameters similar to those in the final chip (Fig. 8). Because these transistors are in close proximity on the same chip of silicon, they exhibit the same thermal and parameter matching ability that will exist in transistors in the final circuit. In addition, because they are isolated from each other by means of *p-n* junctions on the same substrate, they permit the circuit designer to evaluate the effects of parasitic capacitances on circuit performance. The use of parasitic components has made experimental circuit evaluation valid to the extent that most circuits work the first time.

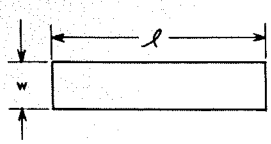
CONCLUSION

The penetration of integrated circuits into commercial electronics has begun. This year RCA scored an industry first with the introduction of the FM sound-IF circuit (Fig. 1) into several of its TV production lines. This penetration was achieved not on the basis of size, but on the basis of performance and price. If the circuit designer is to make effective use of monolithic circuits, he must understand the economic as well as the electronic implications of the technology.

REFERENCE

1. *RCA Integrated Circuits* (RCA Reprint PE-216), a collection of 15 technical papers by RCA scientists and engineers on monolithic-silicon, thin-film, and MOS integrated-circuit technology.

Fig. 7—Effect of tolerances in resistor design.



$$R = R_S \frac{\ell}{w}$$

Δw = PROCESSING UNCERTAINTY

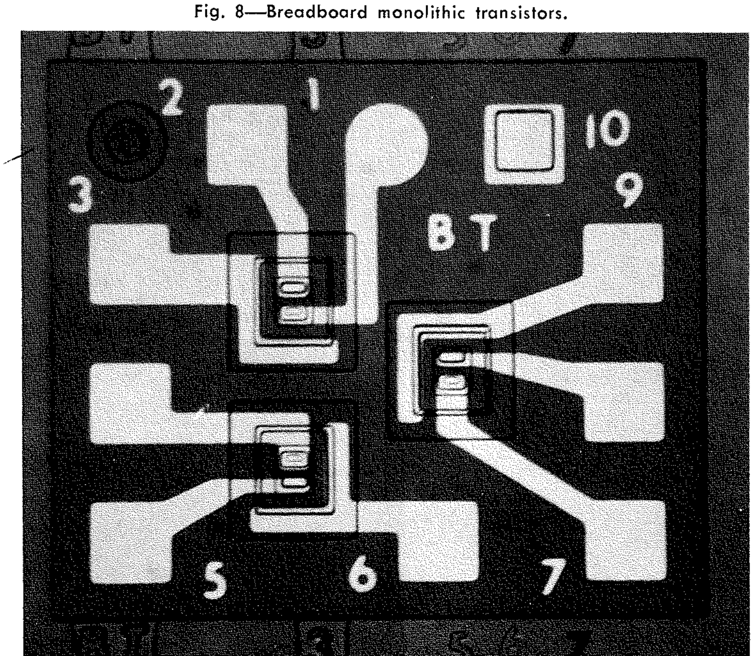
$$\frac{\Delta R}{R} = \frac{\Delta w}{w}$$

$$A = \text{AREA} = \ell \times w$$

$$\ell = \frac{R}{R_S} w$$

$$A = \frac{R}{R_S} w^2$$

Fig. 8—Breadboard monolithic transistors.



EXTENDING INTEGRATED CIRCUIT APPLICATIONS IN AEROSPACE SYSTEMS

Factors to be considered in extending the applications of integrated circuits in aerospace systems to achieve optimum designs are reviewed. Factors discussed include the potentially low cost of integrated circuits, the criteria for selection of new parts, the adaptation of digital circuits for analog functions, and the use of computer analyses for determining circuit parameters.

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The development and use of integrated circuits is experiencing one of the fastest growth patterns in the history of electronics. This fast growth has been spurred by military requirements for electronic systems that must be more complex and reliable but, on the other hand, must be smaller and less costly. It appears that integrated circuits may be the panacea for electronics because of the advantages of small size and weight, low power consumption, and, recently, low cost. As with any engineering decision, many factors must be considered, and in the case of integrated circuits many new problems arise that are subtle and new to the user. This paper reviews some of the factors involved in extending integrated-circuit applications in aerospace systems.

COST CONSIDERATIONS

The real impact of integrated circuits has been their low cost. The trend in miniaturization for low cost has been changed with the development of mass-produced monolithic circuits. The number of components on a chip has increased steadily from less than 10 to more than 50, with little price differential. The cost difference is a function largely of silicon wafer area and testing, the latter being a major difference between analog and digital circuits since analog circuit testing has not achieved the same degree of automation.

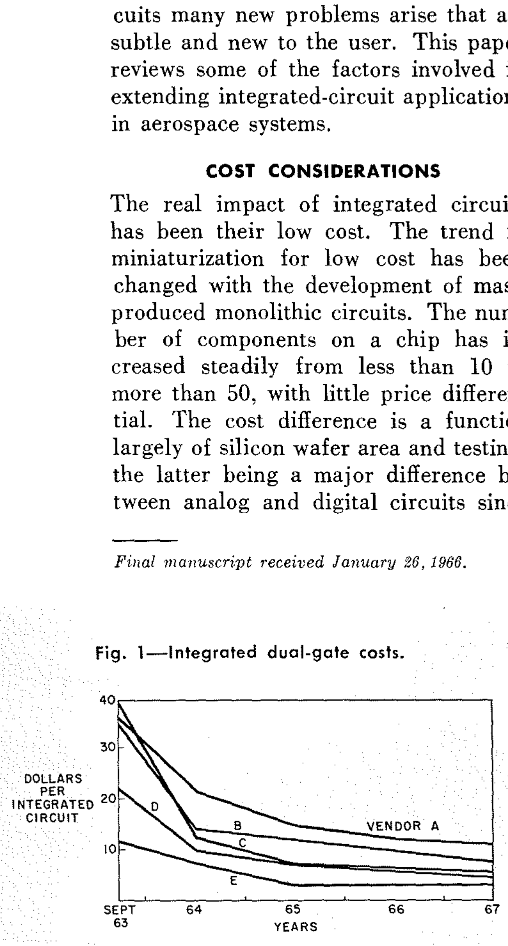
The cost trend is shown by the curves in Fig. 1. These curves were plotted from cost predictions of five major vendors in response to a quotation on a large military system studied by RCA. The trends have been verified with some interesting observations. Company A used an approach that did not utilize silicon area efficiently and its costs reflect this. Company E, emphasizing size and yield, maintained low-cost advantage over the entire time period. The prices of all companies are now quite competitive, particularly on circuits of a given type such as diode-transistor logic (DTL) or resistor-transistor logic (RTL).

The curves in Fig. 1 are for dual DTL gates in quantities of 1,500 to 3,000 and projected for a total quantity of 100,000. The accuracy of these curves today would depend on the special testing, screening, and burn-in costs which could be as high as the device cost itself. Typical costs on dual gates today for aerospace systems are following the curves, and ranging from 3 to 15 dollars as shown, depending on: quantity, temperature range, testing, and data required with each unit or lot.

Curves such as those in Fig. 1 show only that the cost trend is real, but other factors such as specifications and testing are most important in controlling costs. High reliability programs, such as LEM-Apollo, require as much effort in the technical specification and testing of circuits as is required in circuit design. The contractor's semiconductor knowledge is the greatest single factor in holding costs down, since realistic specifications are essential for low cost.

Final manuscript received January 26, 1966.

Fig. 1—Integrated dual-gate costs.



CRITERIA FOR SELECTION OF NEW PARTS

RCA has attempted to establish a realistic approach to the use of new parts. The first requirement is that the part have a significant advantage such as weight, power, reliability, or performance. Trade-offs must be made carefully because the new part invariably has certain unknown factors that may prove to be troublesome. The second requirement is that the required function must meet the demands of the system and its associated environment. Third, reliability data must be available in a form suitable for direct use or for extrapolation with reasonable confidence. Extrapolation can be made from data on similar parts, processes, and techniques. The judgment of experienced designers who are familiar with components as well as with circuit design is also very important.

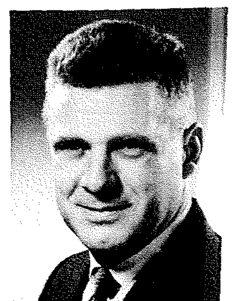
The data available on new integrated circuits usually is insufficient for decisive technical judgments. Parts on which there is a great amount of data are not necessarily better than those for which there is little or no data; however without data, statistical comparisons cannot be made with confidence on old parts vs new parts. For example, it cannot be assumed that any integrated circuit is more reliable than its discrete counterpart just because it is integrated.

LAURENCE C. DREW received his BSEE degree in 1960 from Tufts University. As a research assistant at Tufts, he designed and tested instrumentation for physiological studies of the brain. He joined RCA in 1962 as a member of the Technical Staff, working in the field of high-speed pulse circuitry and wideband video amplifiers. Since 1963, he has been a task engineer on company-sponsored IR&D programs. As project engineer, he was responsible for circuit design on the LEM attitude translation and control assembly (ATCA) and descent engine control assembly (DECA). Current responsibilities include circuit design of the frequency trackers and the carrier lock loop in the LEM rendezvous radar. Mr. Drew has disclosed two inventions in the field of high-speed pulse circuitry and one in integrated-circuit technology.

MARSHALL C. KIDD recieved his BChE degree in Chemical Engineering and his BEE from Ohio State University in 1944 and 1948, respectively. After graduation he joined the RCA Home Instruments Advanced Development Group, where he developed instrumentation techniques, video and pulse transistor circuits, digital systems of an automatic phase-control system, magnetic techniques, and avalanche transistor circuits. He also was responsible for development work on magnetic circuits, the RCA 110 Computer magnetic drum and A/D converter, a developmental colorimeter, and an instrumentation activity related to the Saturn checkout system. Since joining AED, he has had responsibility for operation and self-test of computer-controlled communication and checkout systems and for development of a magnetic multiplexer for low-level signals. He is currently Leader, Technical Staff, responsible for circuit design on LEM ATCA and DECA as well as being coordinator of integrated circuits for AED. Mr. Kidd holds 12 U.S. patents.

L. C. Drew

M. C. Kidd



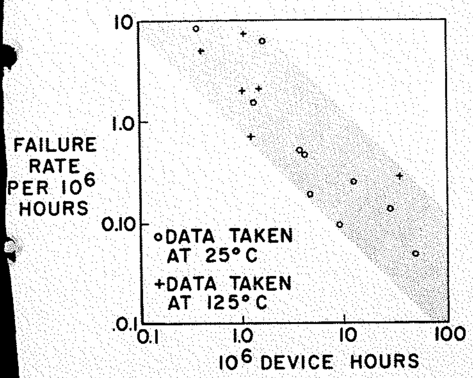


Fig. 2—Integrated-circuit failure rate.

Failure Modes

Physics-of-failure specialists have had a great impact on the reliability of integrated circuits. The modes of failure of these devices have been reasonably well defined as a result of the Apollo program and many of the recent military programs. The known failure modes listed below are described in detail by Partridge, Hanley, and Hall.[1]

1) Open bonds — purple plague; overbonding; underbonding.
2) Open aluminum interconnects — moisture-hydration; oxide under aluminum; scratches.
3) Metallic interfaces between aluminum and silicon
4) Bulk shorts—breakdown
5) Shorts due to scratches, pinholes, bonding, and broken leads
6) Foreign material in package
7) Surface effects—leakage

In nearly every case the failure modes listed can be controlled by careful quality-control inspection and process or technique correction from life tests and customer failure reports. This quality control is critical and cannot be "tested in," but it can be improved by screening and burn-in. Past performance is a major consideration for future performance and reliability. Proof can only be extrapolated from carefully controlled tests using statistically sampled quantities.

Reliability Data

Much has been said about integrated circuit reliability, and it is generally agreed that integrated circuits can be highly reliable as demonstrated by numerous tests. The reliability data by Farcus and Weir[2] summarized in Fig. 2 includes data from all major manufacturers and a number of large users. The integrated circuits were tested either at 125°C or 25°C, depending on the type of test. All circuits were digital but of widely different types. The following conclusions may be drawn from the chart:

1) The lowest rate of failure at 25°C for integrated circuit reliability is excellent (0.05 per 1 million hours).
2) The evidence of early failures, characteristic of semiconductors, indicates that tests should be of long duration for best results.
3) Some results based on short runs were two orders of magnitude poorer than the best results. It is realized, of course, that some of these early failures could be due to variations in vendors' products.
4) To obtain reliable data would require years of testing or a tremendous quantity of devices tested for a short time; the latter method might not produce the same results as the former.
5) Before reliability data is extrapolated it must be carefully investigated to see which data point in Fig. 2 is most appropriate, not which is most desirable.

The LEM-Apollo program at RCA uses 0.1 failure per 1 million hours for digital circuits and 0.3 failure per 1 million hours for analog circuits. These numbers are based on a high-reliability program of screening and burn-in, and on past experience with analog and digital transistor circuits. Experience on older programs has shown that analog circuits have higher failure rates than digital circuits, possibly due to higher stress levels in the circuit application or greater dependence on component stability, which could affect the DC operating point or frequency response.

Circuit Design Considerations

Standardization with integrated circuits has the same advantages as with any component, e.g., higher quantity with corresponding lower device cost, greater familiarity with the device characteristics due to wide usage, lower testing

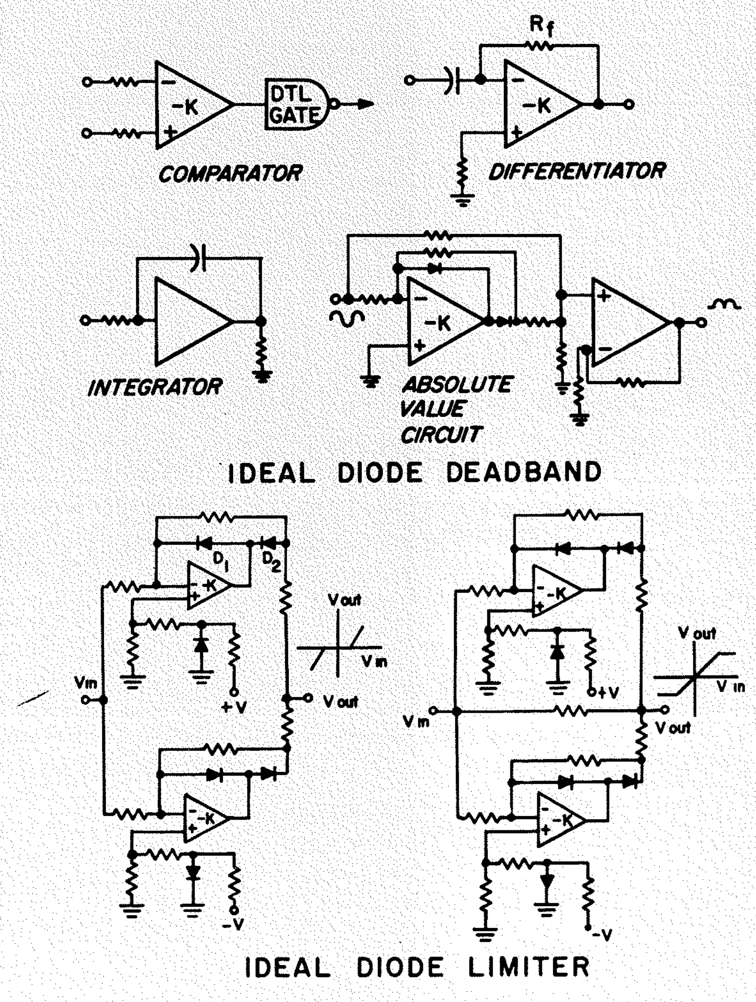


Fig. 3—Typical applications of operational amplifier.

cost, and opportunity to obtain more performance data on the device. Digital circuits tend to become standardized by the nature of their logic functions. Generally, a half-dozen types are quite adequate for computers or digital interfaces (excluding memory), and little is gained as the number of basic types is increased. The types meeting most requirements are dual and quad gates, triggerable flip-flop, dual buffer, expander, and one-shot multivibrator.

Analog circuits generally are not classified in such basic categories. However, the operational amplifier is probably the most basic analog circuit element. The advantages of the integrated circuit differential operational amplifier are basic and apply to the device, the circuit, and the system.

The device, with its inherent small size and weight, allows 20 to 50 components to be placed on a 50- by 50-mil chip, thus making high yields possible. The symmetry of the differential amplifier arrangement with associated resistor ratios provides maximum temperature stability and tracking. A small temperature differential of a fraction of a degree across the chip assures optimum temperature conditions.

The circuit advantages are largely due to the flexibility and versatility of the operational amplifier. Two inputs are available (inverting and non-inverting) which can be balanced, providing inherent low drift offset and good common mode rejection. The input circuit contributes largely to the high rejection of power-supply noise and voltage variation. The high-input and low-output impedances assure maximum flexibility of usage. The DC and differential features of the circuit eliminate coupling and bypass capacitors, thus yielding high gain with minimum size and weight. Feedback stabilization is improved by the feedback ratio that can be utilized for a given amplifier with a particular gain requirement; thus, maximum gain stability is achieved. Typical gains might be 20 dB with 40 dB feedback.

System advantages include the stability that can be achieved, and the large number of system applications possible with a single circuit element. Typical applications are illustrated in Fig. 3 for several aerospace control-system functions.

Integrated-circuit operational amplifiers that are presently available are somewhat limited compared to the best discrete amplifiers. These limitations consist largely of input impedance, output voltage, current capability, and gain. Although these parameters are continually being improved, present integrated-circuit devices are very useful and can be designed into systems where their size, weight, and performance advantages overcome their limitations.

A major aerospace system currently being designed uses 97 integrated operational amplifiers in three assemblies. Most of the functions shown in Fig. 3 have been designed with integrated circuits.

DIGITAL APPLICATIONS OF ANALOG FUNCTIONS

The size and weight constraints of aerospace systems and the wide temperature ranges to which such systems are subjected require that analog and digital techniques be carefully reviewed before a technique is chosen. A typical circuit where digital techniques offer advantage is a precision integrator. The two versions of this circuit are shown in Fig. 4. If the tolerances of the time constant are better than 5% in periods exceeding 1 second, digital techniques become very attractive since the capacitor required becomes very large. If the amplifiers are not integrated, the digital approach is even more attractive. This sweep function is basic in certain radar operations, and sweep accuracy can be improved with digital circuits. The resistors in the ladders, the voltage reference, and the quantization size are the main sources of major errors. These errors can be held under 5% in an aerospace environment. The counters can be either single or double flip-flops or a more complex array if desired. The greater the logic density on the chip, the more attractive the digital approach becomes. One of the remaining technical challenges is to reduce the ladder and switches to the size of the integrated circuits and maintain the required accuracy.

ANALYSIS OF INTEGRATED CIRCUITS

The analysis of analog integrated circuits poses a considerable number of computational problems. Contrary to the analysis of discrete circuits, in which simplifying approximations can be made realistically, the analysis of monolithic circuits does not permit similar approximations to be made for parasitic capacitances and leakage conductances. Yet it is these unwanted quantities that frequently establish the circuit performance limits.

Inclusion of the parasitic and leakage effects in any analysis virtually demands use of a general-purpose digital computer. A program for linear circuit analysis has been developed and successfully used to evaluate the performance of linear amplifiers composed of integrated circuits. This portion of the paper briefly describes the analytical techniques which have been programmed, and illustrates their application.

The computer analysis of the operational amplifier consists of two parts: 1) an equivalent circuit description of the hybrid-pi model of the transistors, and 2) the computer analysis.

Hybrid-Pi Model

Schematics of the operational amplifier and the transistor hybrid-pi model are shown in Figs. 5 and 6, respectively. Four versions of this model were used, differing only in collector currents.

The parameters are the following nominal values:

$$r_b' = 70\ \Omega$$

$$r_{b'e} = \frac{\beta}{g_m} = 5.8\ K\Omega$$

$$r_{b'c} = \text{negligible effect}$$

$$r_{ce} = \text{negligible effect}$$

$$C_{b'e} = 4.3\text{pF} = \frac{g_m}{\omega_a}$$

(includes Transition C)

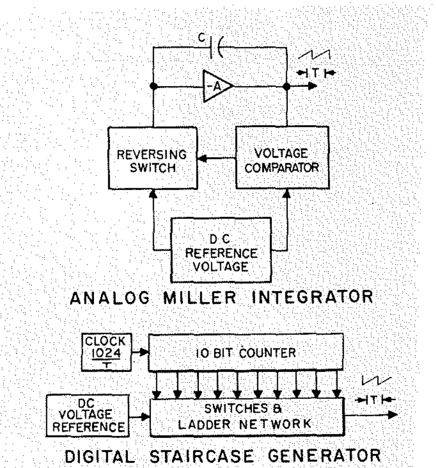
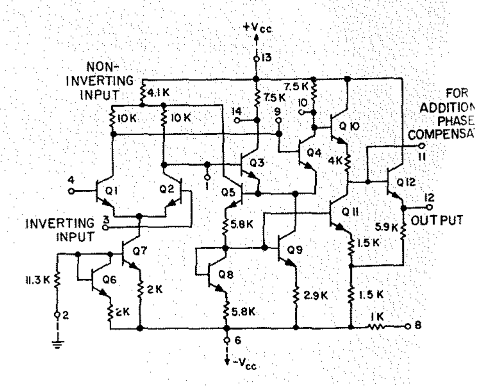


Fig. 4—Integrated-circuit analog functions (precision sweep circuits).

Fig. 5—Integrated operational model.



$$C_{b'c} \cong C_{ob} = 2\text{pF}$$

$$g_m = \frac{0.026}{I_e} = 40\, I_e = 0.008 \text{ to } 0.032 \text{ mho}$$

(depending on where transistor is used)

Computer Analysis

The computer analysis consists of 1) determining the Y parameters of the transistors from hybrid-pi models, and 2) introducing these quantities into nodal equations of the overall operational amplifier. There are 23 nodes in this amplifier (besides ground), resulting in a 23 by 23 complex coefficient matrix. Actually, neither the computer nor the engineer writes any equations. The computer is programmed with an algorithm in such a way as to automatically insert a given value into its proper place in the coefficient matrix. Inversion of this matrix to obtain the *solution* or *impedance* matrix then constitutes the heart of the computer analysis. A discussion of elements of the inverted matrix as related to the gain and the impedances follows.

The inverted Y matrix is a Z matrix and the nodal equations take the form:

$$\begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ e_n \end{bmatrix} = \begin{bmatrix} Z_{1,1}\, Z_{1,2} & & Z_{1,n} \\ Z_{2,1}\, Z_{2,2} & & Z_{2,n} \\ \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \\ Z_{n,1}\, Z_{n,2} & & Z_{n,n} \end{bmatrix} x \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ \cdot \\ I_n \end{bmatrix}$$

Since the impedance to ground at a given node in an electric circuit is defined by the ratio of voltage developed at that point to the external current introduced at that point, it becomes immediately evident that the main diagonal elements of the above Z matrix (e.g. $Z_{1,1}$) are in fact the respective nodal impedances to ground. Further, it should be clear that an element off the main diagonal (e.g. $Z_{i,j}$) represents the transimpedance from node j to node i since

$$Z_{i,j} = \frac{e_i}{I_j}$$

as defined by circuit theory; all external currents other than I_j are equal to zero.

Thus, with the input node labeled 1 (inverting input), and the output node designated 23, the result is:

$$Z_{in} = Z_{1,1}$$

$$Z_{out} = Z_{23,23}$$

$$\text{Gain} = \frac{e_{23}}{e_1} = \frac{e_{23}/I_1}{e_I/I_1} = \frac{Z_{23,1}}{Z_{1,1}}$$

where numerical values of all the $Z_{i,j}$'s are known from the computer-calculated matrix inversion.

Separate and distinct computer solutions (matrix inversions) are required at each frequency of interest. The computer is programmed to print out the magnitude and phase of the three functions: Z_{in}, Z_{out}, and gain.

The foregoing discussion relates to open-loop functions. For closed-loop calculations, the operational amplifier is treated as a *black box* with external feedback. The parameters to describe this *box* may be obtained directly from the solution matrix as described above for Z_{in}, Z_{out}, and gain.[3] The performance of the operational amplifier under worst-case conditions is shown in Fig. 7 for both open- and closed-loop functions.

To do a worst-case analysis, engineering assumptions may be used or the computer can run a sensitivity analysis in which essentially a partial derivative of gain is taken for each part and its tolerance to maximize gain. In this way the computer determines which parts are most sensitive and the degree of sensitivity. With respect to temperature changes, all parts are essentially one and can be assumed to be always at the same temperature. Therefore, this analysis considered all parts to change equally.

CONCLUSION

The impact of cost and reliability coupled with small size and weight has focused the attention of all circuit designers on the challenge of integrated circuits. Digital circuits, although somewhat more straightforward than analog circuits in their application, are changing in the complexity of logic function available on a single chip. Analog circuits, on the other hand, are presently undergoing some standardization, which the integrated operational amplifier and its inherent device, circuit, and system advantages have made possible. New tools in the form of computer programs help the engineer gain confidence in the design and operation of these circuits, since internal points are no longer available for experimental probing.

The trend of integrated circuits toward increased complexity can be illustrated along with the increasingly functional nature of the elements. Table I shows the evolutionary steps that have been made since 1960 from a single RTL gate using three transistors and four resistors to a digital differential analyzer now being built using 800 MOS transistors on a single chip. Since the trend in complexity is increasing so rapidly in both the analog and digital areas, the near future should be extremely interesting for the circuit designer who is trying to keep abreast of his art.

TABLE I—Evolution of Integrated Circuit Complexity 1960-1965

Circuits	*Components*
Single RTL Gate	7
DTL Gate	11
Dual Gate (DTL)	22
Quad Gate (DTL)	34
Operational Amplifier	20-30
Dual Comparator	37
AC Flip-Flop	42
Decade Counter	58
Dual Flip-Flop	65
Sense Amplifier	70
MOS 20-Bit Storage Register	120
MOS 100-Bit Storage Register	615
MOS Digital Differential Analyzer	800

ACKNOWLEDGEMENT

The authors wish to acknowledge the contributions of Alan G. Atwood in the development of a computerized tool for circuit analysis.

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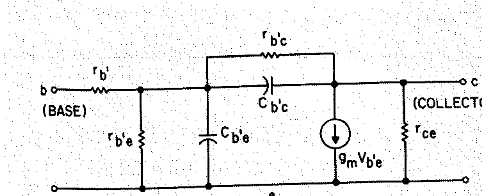
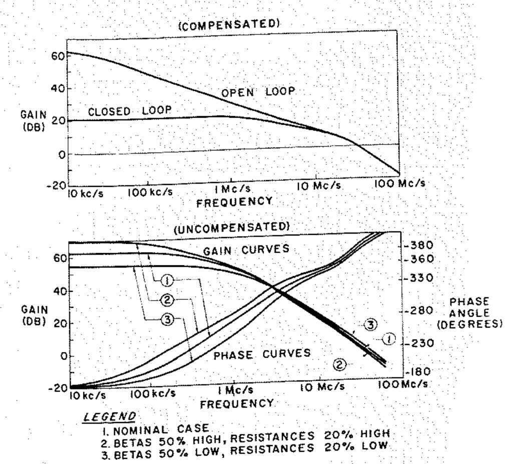


Fig. 6—Transistor hybrid-pi model.

Fig. 7—Frequency response of integrated operational amplifier.



PROCESS RESEARCH

An Increasing Need in the Electronics Industry

This paper examines the role of process research in the electronics industry and describes the work of RCA's Process Research and Development Laboratory. Various laboratory projects are discussed, including pattern-generation and optical processing, semiconductor processing, computer-aided design, numerically controlled machines, electrical discharge machining, and automatic testing.

C. PRICE SMITH, Director

Process Research and Development Laboratory

RCA Laboratories, Princeton, N.J.

If one considers for a moment the complex electronic systems needed for space exploration, the requirements for larger and faster computers to do massive data processing tasks, the demand for sophisticated electronic products being produced for the home (such as color television), and the trend toward automated factories with electronic process controls, the great need for new and improved manufacturing processes will be clearly recognized. Progress in electronics is being paced by materials research and processing technology. This fact is highlighted by the unfilled requirements of systems already conceived and proven feasible, but which cannot be produced economically at this time.

Final manuscript received March 30, 1966.

FACING UP TO THE PROBLEM

Processing technology in the electronics industry is expanding so rapidly that processes that were adequate a few years ago are now obsolete. Completely new products and services are demanding unusual equipment and process techniques. Some of these techniques are being borrowed from other areas and extended to meet the needs. An example of this is the use of photographic methods, such as photoengraving of copper-circuit interconnection boards and the photoreduction process used in making extremely small mask patterns for integrated circuits. In other areas where the known technology is inadequate, new methods must be discovered and applied, such as electrical discharge machining, ultrasonic bonding of materials, vapor-phase deposition of unusual materials, and many others. In recent years, RCA's manufacturing divisions have been spending an increasing portion of their engineering effort in designing and developing new processes and controls that will improve the performance of the products and reduce their cost. Although the product division engineers have been doing a remarkable job of meeting these demands, the pressure continues to mount for better methods, faster machines, higher yields, and improved uniformity of products.

When we anticipate the types of products and services that will be needed in the future, we know additional effort must be applied to the process technology field. Industry trends are already in evidence, such as computer-aided design, numerically-controlled machines, on-line computer control of processes, precision photographic processes, sophisticated diagnostic and monitoring techniques, and new methods of cutting, forming, and interconnecting materials. Recognizing these demands of the future, RCA management established a separate activity at the David Sarnoff Research Center in mid-1963, called the Process Research and Development Laboratory.

PROCESS RESEARCH AND DEVELOPMENT CHARTER

As stated in its organizing charter, the prime objective of this new laboratory is to execute the necessary research and development needed to demonstrate the

C. PRICE SMITH received his BSEE degree from the University of Missouri in 1942. He has taken graduate courses at Polytechnical Institute of Brooklyn, Temple University, and University of Pennsylvania. Following graduation in 1942 he joined RCA in Harrison, N.J. as a production engineer responsible for setting up process controls on new types of small power and gas tubes. In 1943 he transferred to the Lancaster, Pa. plant where he was engaged in design engineering of thyratrons. He became Group Supervisor in the Tube Development activity and, in 1948, Manager, Development Shop. In 1952 an RCA Victor Award of Merit cited Mr. Smith's contributions to the development of metal kinescopes. Starting in 1954 he served successively as Manager, Black-and-White Kinescope Engineering at the Marion, Ind. plant, Manager, Color Kinescope Engineering in Lancaster, and Manager, Engineering for all picture tubes. He was appointed to his present position as Director, Process Research and Development Laboratory in 1963. Mr. Smith holds several U.S. patents. He is a member of the AAAS and the IEEE.

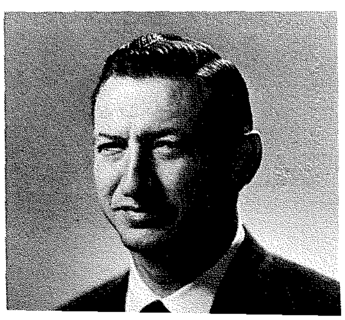
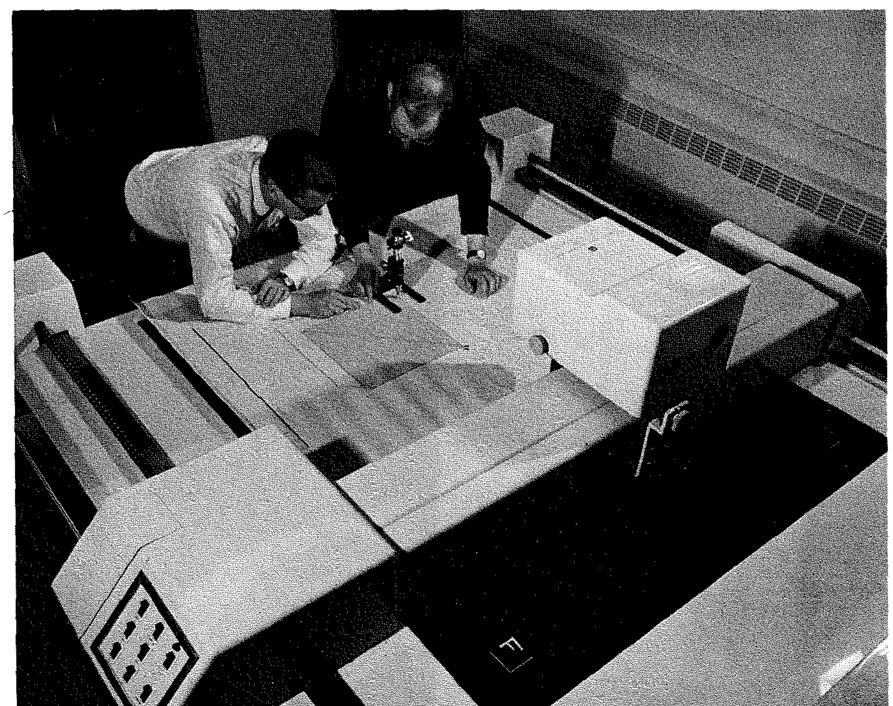


Fig. 1—The automatic coordinatograph is a precision drafting machine for making complex patterns, using a special photohead with 24 changeable apertures to expose photo-sensitive films or plates. The machine is controlled by instructions punched in paper tape. Instructions are generated by a computer which translates the simple programming language written especially for this machine.



feasibility of new processes that will have future significance for the manufacture of RCA products and to help transfer them to large-scale production. In general, the work will be directed to those processes relating to new families of products being developed in the RCA Laboratories, especially where there is high probability that the process will be used by two or more divisions of the company, or where the commercial value of the products and the need for process research is commanding. This laboratory is to be alert to the major trends in manufacturing processes for the electronics industry and establish competence in the fields necessary to support the affected RCA divisions. Obviously this laboratory must be aware of the findings of other laboratories at the David Sarnoff Research Center, and the needs of the product divisions if its efforts are to be effective. In doing this, an additional function of providing vital communications links between various individuals in the laboratories and the products divisions may be accomplished.

The new laboratory currently consists of a director and 15 members of the Technical Staff working on the wide range of processes narrated below. This year additional technical personnel will be added to adequately staff the current areas and to establish several areas of special interest to the company, including optical processing and an automation center. From time to time trips have been, and will be made, to outside companies to study unusual manufacturing methods, novel equipment, and special skills pertaining to such developments. Meetings are scheduled as needed with key groups in the product divisions to learn of special problems and needs and to report on process research results obtained.

Future devices and systems will require improved materials and processes. We intend to meet part of this need with process research.

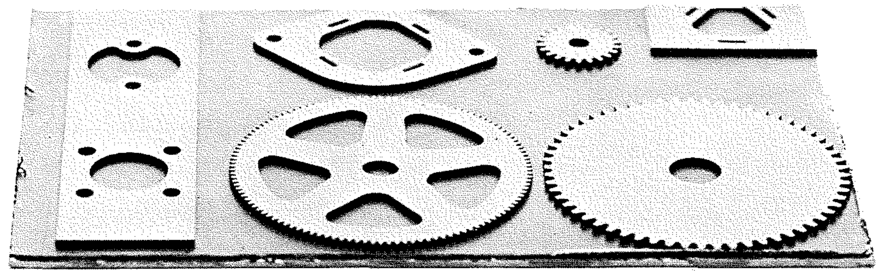


Fig. 4—These parts were formed in a photopolymer material by making a contact print using UV light and removing the unexposed material.

PROJECT SELECTION

The scope of work of the Process Research and Development Laboratory can be as broad as the product lines of the divisions. The projects selected will eventually be limited only by adequate economic justification of the work and the desirability of conducting the work in this location. With such a far-ranging charter, work should be selected on the basis of greatest potential commercial value to the company, since all possible projects cannot be studied. Many times, these areas of work will represent a common denominator of need by several divisions, as, for example, the ability to generate complex interconnection patterns quickly. Other guide lines used in selecting projects are concerned with trends in the industry indicating new processes that are becoming valuable. An example of this criterion is the use of numerically controlled machine tools and computer-aided design techniques that are being used by many industries other than the electronics industry. Also, it is important to evaluate processes by which competitors appear to be aiming for a major advance, such as hermetically sealed silicon circuits. In addition, decisions must be made as to whether the work can be done better by the product divisions' engineering departments or by one of the other research laboratories.

Fig. 2—This montage of patterns shows a few samples of the work performed on the automatic coordinatograph: a) computer circuit interconnections; b) connection board for memory; c) core loading fixture; d) conductor pattern for special memory.

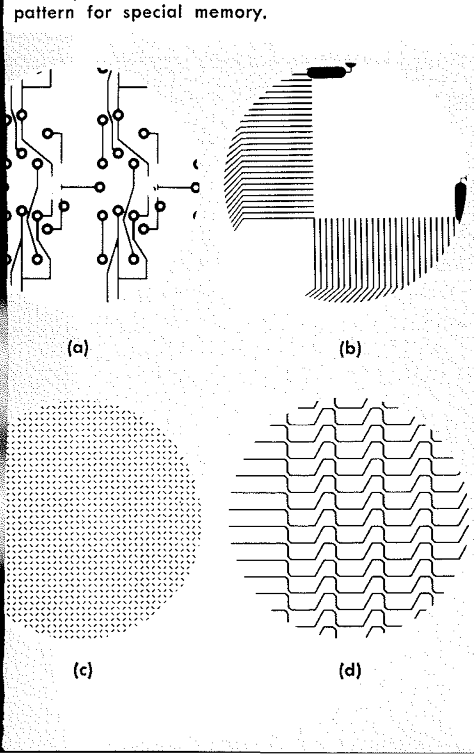


Fig. 3—This cross-section of a simulated multilayer interconnection board, magnified about 20X, illustrates the design freedom of providing interconnections between any two or more layers of circuitry only where needed, instead of having holes through all layers when two layers are to be connected. A method was found to improve the resolution of interconnection patterns to provide 0.004" conductor lines on 0.008" centers.

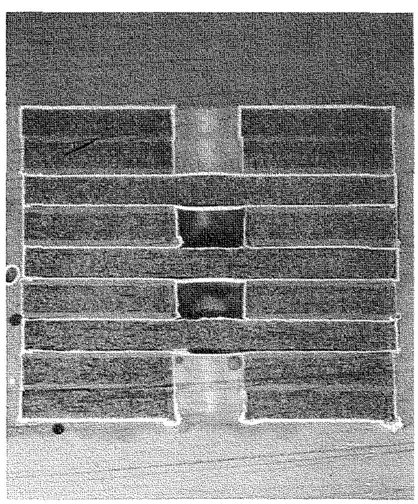
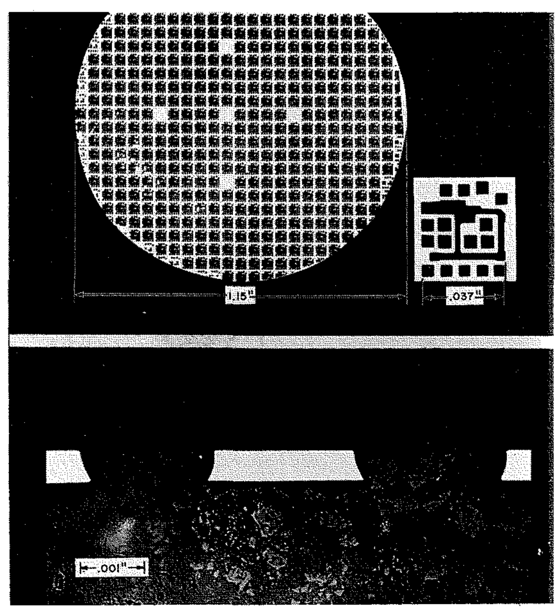


Fig. 5—Dielectrically isolated integrated-circuit wafer. Top photo shows silicon islands (black); detail of one circuit element on right. Bottom: cross-section through dielectric and silicon (white) of a single island.



PATTERN GENERATION AND OPTICAL PROCESSES

As mentioned previously, one of the obvious needs of the electronics manufacturer today is the capability to generate complex photographic patterns quickly, whether for intricate circuit boards, special diffusion masks for integrated circuits, multilayer board interconnections, aperture mask designs for color, or a multitude of other uses. Once the pattern is available, it is photographically reduced or enlarged in size as needed and then applied to the specific manufacturing process in a wide variety of ways. The ways in which these patterns are used usually involves the "fixing" of a photoresist material that masks the underlying material for subsequent operations, such as etching, diffusing, electroplating, etc.

Future requirements for electronic devices and systems will require the availability of rapid methods of generating high-resolution patterns in conductor, semiconductor, and insulating materials which are capable of interconnection by a one-step process. One approach to this problem was the acquisition of an automatic coordinatograph, a numerically controlled drafting machine with an accuracy of ± 0.001 inch any place on the 48-inch × 60-inch table, as shown in Fig. 1.

This machine employs a photohead with 24 aperture locations automatically selected by the program. Apertures can be used to flash-expose a pattern at a precise location, or the light can be left on while the machine travels with a circular or square aperture to generate a line. Obviously, the machine must operate in a dark room. We have written a programming language that greatly simplifies the programming. The RCA 601 computer, using an interpretive routine, translates the written instructions into machine language on a punched paper tape for the controller on the automatic coordinatograph. This machine is finding many uses in generating a variety of patterns for memories, integrated circuits, printing plates, and interconnection boards, as illustrated by the examples in Fig. 2.

Another application of photographic patterns involves a process for built-up multilayer circuit boards that are useful in computers and related logic equipment. The increased resolution and the design freedom of having wiring apertures, called "via holes," only where needed makes this process of interest to several divisions (Fig. 3).

An extension of the pattern-generation work is the fabrication of fixtures and parts from optically processed materials. For example, the parts shown in Fig. 4 were formed by the exposure of a photographic pattern onto a photopolymer material. A wide range of parts can be made in this manner, and facilities are being acquired to explore other applications, including offset printing plates, assembly fixtures, cams, and decorative bezels. The benefits of constructing three-dimensional items by optical means are the design flexibility of the photographic pattern and the speed of fabricating the complex shapes. We are anxious for the product divisions to utilize this technique.

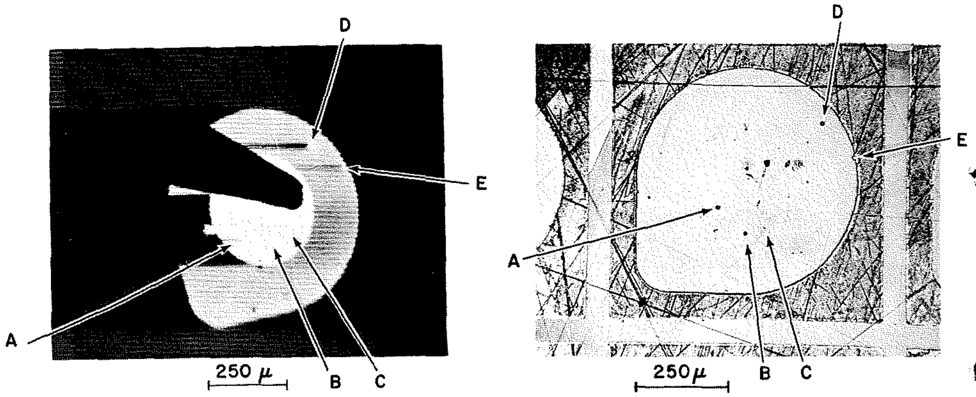
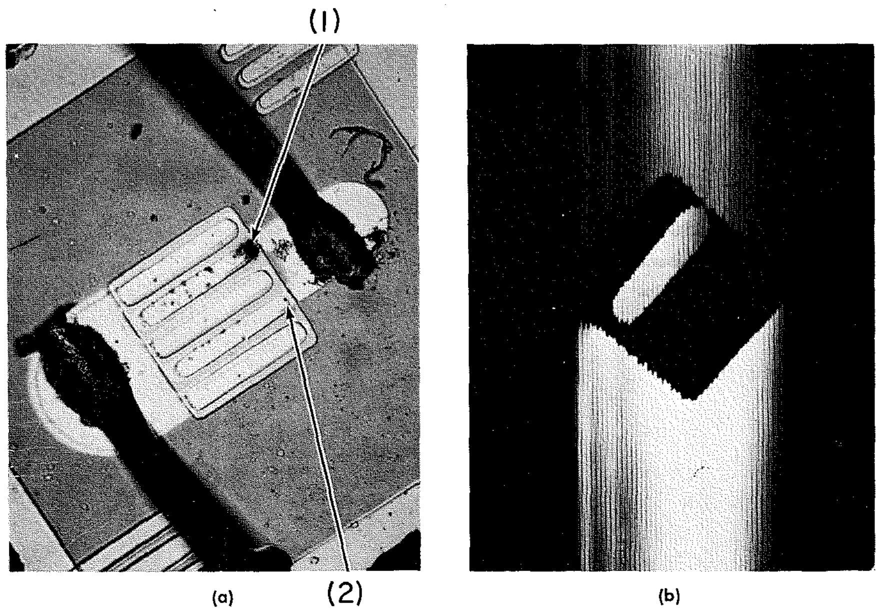


Fig. 6—(Left) Scanned electron beam micrograph of pnp silicon transistor showing avalanche sites (A,B,C,D,E). Analysis of this micrograph suggests that these avalanche sites are regions of high electric field caused by spikes of substrate material extending into the junction. (Right) Optical micrograph of junction after lapping and staining. The suggested model is verified showing substrate spikes as stained areas (A,B,C,D,E).

SEMICONDUCTOR PROCESSING

No one denies the major role that semiconductors now play, and will continue to play, in the future of any electronics company, or the importance of having high-speed, low-cost processing methods of making devices and circuits. Much effort in the Process Research and Development Laboratory is devoted to finding new and improved technologies that will advance the state of the art of planar silicon devices and integrated circuits. The work is aimed at finding new and improved isolation techniques, simplifying processes for making reliable complementary devices (*pnp* and *npn* transistors in the same wafer), and developing processes for metallizing and glassing devices in the wafer so that interconnected, hermetically sealed circuits will result. As an example, let us consider a new isolation process that resulted from a study on glasses and ceramics compatible with silicon. We found that certain dielectric compositions can be made to serve as a matrix to hold tiny islands of silicon in an

Fig. 7—Electron-beam image analysis of interconnection failure: a) optical micrograph of transistor indicates emitter metallization finger burned out at (1); b) electron-beam micrograph proves, contrary to optical conclusion, that emitter junction corresponding to finger (1) is operable and emitter finger (2) is open.



orderly array, as illustrated in Fig. 5. It was essential that the dielectric have a coefficient of expansion exactly matching that of silicon and, furthermore, be able to withstand the diffusion temperatures for subsequent device processing. As a result of this particular process study, a new substrate for integrated-circuit fabrication becomes available to the designer, allowing him to build circuits with higher frequency and voltage isolation capabilities.

PROCESS CONTROLS/ANALYTICAL METHODS

A knowledge of the effects of process variables on the resulting products can be very important; to obtain this information we must devise new and sensitive analytical methods. One tool that is proving especially useful in the study of semiconductor device processing is the scanning electron microscope. Fig. 6 shows the location of microplasma discharges under electron scanning conditions. These avalanche breakdown sites were limiting the performance of the device, and subsequent removal of the surface layer revealed the physical location of spikes in the underlying semiconductor material. There is evidence from these correlating data that the spikes project into the transistor junction, producing extremely high electric fields and causing avalanche breakdown. By determining the location and cause of the premature breakdown sites, we can begin to determine the processing variations and material defects that generate this type of failure. Fig. 7 shows the determination of a defective emitter connection using the electron beam. The optical microscope examination was misleading because the surface view indicated that one of the connections had been burned; the electron beam micrograph proved the other connection was faulty. The real defect was a small crack in the evaporated aluminum coating where it crossed the silicon dioxide mask leaving that connection open. Other phenomena are being studied with this instrument.

In addition, some work has been done to measure accurately the concentration level of dopants in the gas flow used for device processing. In the future, considerably more will be done to provide signals from sensitive monitoring devices for controlling processes, and eventually to feed these signals to an on-line computer for automatic control where the process requires and justifies this type of control.

PROCESS FOR PASSIVE COMPONENTS

The work in this area is aimed at providing a method for depositing high-

Fig. 8—Core loading fixture with ferrite cores in place (magnified 30X).

dielectric-constant materials ($K = 400 - 500$) onto the insulating surface of integrated circuits. A number of materials, as well as several methods of deposition, are being evaluated. Current emphasis is on RF-sputtering for deposition. Future work will include exploring ideas for producing larger inductances in small physical dimensions and electrically-variable values of inductance and capacitance for integrated circuits.

COMPUTER-AIDED DESIGN AND NUMERICAL CONTROL MACHINES

In order to study some of the problems associated with automated manufacture, we initiated several specific machining jobs using numerically controlled (N/C) milling machines. The time required for the design-evaluation cycle has been reduced by developing a specific part design from a general computer program and translating this information directly into N/C machine-tool language by means of an interface program. This method shortens the time cycle from concept to finished part.

Programming for several complex pieces has been difficult because of errors in the automatic-programmed-tool (APT) language; however, as the result of improvements in APT and our experience with it, considerable progress has been made. For the future, we expect to expand substantially our efforts on computer-aided-design methods, coupling these results directly to N/C machines. Eventually we should have sufficient data to design N/C controlled machines for any automatic process.

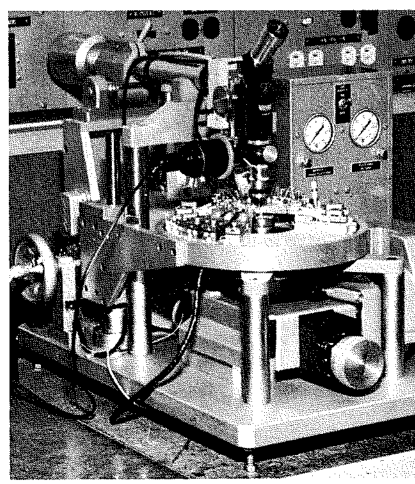
PRECISION FIXTURES

Electrical discharge machining (EDM) has been evaluated for precision forming of fixtures. The core-loading and wire-stringing fixture shown in Fig. 8 illustrates the degree of complexity achieved with an accuracy of 0.0003 inch in hardened tool steel. The deep cavities in the fixture are 0.0314 × 0.0107 × 0.0156 inch deep; the grooves between the cavities are 0.0043 inch wide at two different depths of 0.0043 and 0.0076 inch. On this core-loading fixture of 1.96 × 1.96 inches, there are 4096 such cavities and 128 grooves. There should be many applications for EDM in the precision machining of electrically conducting materials.

AUTOMATIC TESTING

The automatic testing of integrated circuits while they are still on the silicon wafer is a difficult problem. We decided to use this technique to gain experience with pre-programmed micropositioners. The intricate machine shown in Fig. 9 provides up to 24 minute probes that can be positioned on 0.004-inch-square pads around the perimeter of a 0.073-inch-square pellet. Of course, fewer probes can be applied to a smaller pellet. The machine is designed for minimum loss of production time because the probes and the wafer can be prealigned for a specific circuit design at a separate location and then placed on the probing machine in approximately 4 minutes. While the machine is testing one circuit, a separate platen with probes can be set up for the next circuit to be tested. The probe design is unique in providing a consistently small contact area of uniform low resistance. Defective units are marked automatically by a hypodermic-needle ink pen, and edge detection of a wafer under test is also accomplished automatically. Future work of this type will involve acquiring, orienting, and positioning extremely small devices and circuits to precise location for automatic assembly on small circuit boards.

Fig. 9—This machine can position up to 24 probes onto 0.004″ square pads located around the perimeter of 0.073″ square pellet containing an integrated circuit. It steps automatically from one circuit to the next, marking defective units and indicating when edge of wafer is reached.



USE OF INTEGRATED CIRCUITS IN COINCIDENT-CURRENT CORE MEMORY

This paper describes an investigation that demonstrated the feasibility of constructing a small, coincident-current, magnetic-core memory using integrated-circuit techniques. Conventional components were used only where power requirements exceeded integrated-circuit capabilities.

R. H. NORWALT

West Coast Div., DEP, Van Nuys, Calif.

One of the basic problems in developing a small, stable, video display system is the physical size of the memory required for the storage of display information. At present, the most space-consuming portion of a core memory is the electronics required to address, drive, and sense the memory stack.

To solve this space problem, an investigation was made to determine whether conventional circuit boards and their discrete components could be replaced by smaller circuit boards containing integrated circuits. Conventional components were used only where power requirements exceeded integrated-circuit techniques. Since the investigation was concerned primarily with proving the application of integrated-circuit techniques to memory construction, no attempt was made to minimize the physical size of the stack and circuit boards.

The design of the system under investigation was based upon an existing display having a minimum capacity of 2048 words containing 12 bits each, and the ability to read/regenerate or clear/write in 5.8 μs within a temperature range of 20° C to 40° C.

The logic interface between the memory and the display consisted of a reset line, a memory initiate line, a mode control line, 12 data input lines, and 12 data output lines. The reset and memory initiate lines were used to reset and increment the address counter in the memory. The mode control line was used to prevent the information stored in the memory from being presented at the 12 output lines during clear/write operation. The 12 input lines fed data to the memory to inhibit drivers during the clear/write cycle; the 12 output lines presented data to be read out of the memory to the display.

A read command pulse, occurring 0.5 μs after memory initiate, starts the read/regenerate cycle. Prior to the issuance of a memory initiate, a mode-control-level signal determines whether the cycle is to be read/regenerate or clear/write.

Final manuscript received April 4, 1966

BASIC CONSIDERATIONS

In designing the high-level line drive circuits and low-level sense line amplifiers required to interface with the stack, physically large components, such as transformers, capacitors, and high-power resistors, were avoided. The design approach for each circuit class was determined by the following considerations: power dissipation, voltage levels, frequency response, and required device balance.

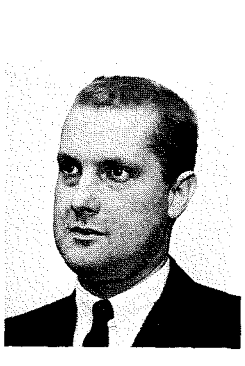
The first circuits investigated were the address and inhibit drivers. Since high currents and voltages were required to drive the core stack, standard diode-transistor-logic (DTL) elements were chosen for decoding logic. Emitter-coupled-logic (ECL) elements were considered but were not used because the small output swings would have required additional stages and components to obtain the desired driving power. A circuit configuration using ECL logic is shown in Fig. 1. Note that the power driver circuit requires four separate packs for the transformation from logic levels to stack driving levels. By using DTL logic (Fig. 2), the transformation can be achieved with one pack and one standard transistor.

Fig. 3 shows the basic driver/switch circuit used to select one unique core line in the X or Y axis of the core stack. To select this line, a pair of circuits (a driver and a switch) are selected and strobed, driving current through the core line in one direction. Selection of the other pair of driver/switch circuits drives current through the core line in the opposite direction.

The first *npn* stage of this combination is a low-level DTL element (monolithic chip). The *pnp* stage consists of a high-powered, high-voltage *pnp* silicon unit and a diode; the third stage (second *npn* stage) is an *npn* transistor in a T-05 header which allows temperature to rise at high current without affecting the operation of the logic stage.

In the units supplied for this memory, the first two stages were of hybrid design and were mounted in a single 10-pin T-05 case. The case was chosen because of the relatively high dissipation of the logic chip and the *pnp* device. However, because of this high dissipation, production circuits would probably be of flip-chip hybrid construction using a logic chip, transistor, and diode mounted upside down on a ceramic wafer upon which the interconnecting pattern had been previously evaporated.

The remaining special circuit considered was the sense amplifier. The design requirements for this circuit were a bandwidth of 2 MHz, a 40-dB voltage gain, and satisfactory operation with a 4-volt, peak-to-peak, common-mode signal. To keep the circuit count down, a quantizing stage was included in the same package with the linear amplifier. To achieve this packing density, the circuit had to be of monolithic construction. This requirement imposed the problem of large substrate capacity, with its as-



R. H. NORWALT received his BS degree in Physics from the University of Southern California in 1961. As an undergraduate he worked with Litton Industries and Magnavox Research Laboratories for more than two years on the design and development of magnetic-drum memory systems and associated solid-state control circuitry. Since joining RCA at Van Nuys in 1961, he has been responsible for the desgn and development of several drum and disc memories as well as a number of coincident-current core memory systems. He is presently engaged in the design and development of a highly reliable, solid-state core memory using microelectronic circuits.

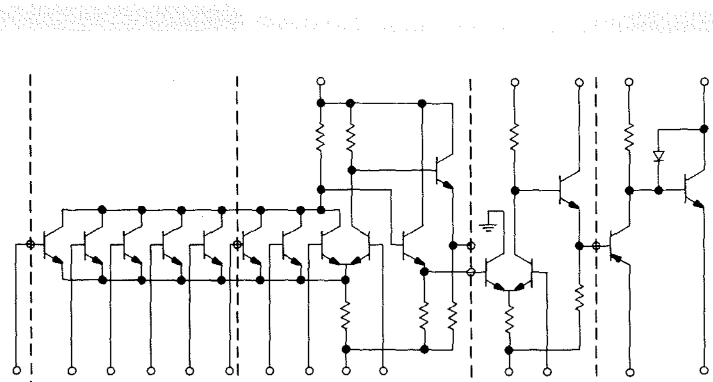


Fig. 1—ECL input driver-switch.

sociated reduction in bandwith and relatively low-voltage transistor breakdown.

During the early phase of the investigation, only one company offered a circuit that merited consideration as a sense amplifier. Although it provided a method for switching the output, this circuit tended to be linear with no single means of controlling the threshold of the amplified core output. Since the amplifier was constructed from a rather generalized chip, the vendor was willing to wire sufficient chips to fulfill the requirements of the experimental memory. The vendor also indicated that a mask could be cut to vacuum-deposit interconnections, which would substantially reduce costs and improve reliability under adverse stress conditions.

The schematic diagram for the sense amplifier and the associated threshold-adjusting circuit is shown in Fig. 4. In this configuration, variations in initial amplifier balance and variation of the threshold with temperature present a problem. Because of the small memory size and narrow temperature range involved in this investigation, these problems did not hinder the operation; in a more sophisticated memory, however, a different solution would be required.

STACK SELECTION

Since the primary goal of the investigation was to demonstrate a core memory using integrated-circuit techniques, miniaturization of the stack was not warranted at this time. It was felt that if the available sense amplifiers were capable of handling lower signals having sufficient threshold stability, then 30-mil cores could be used in place of 50-mil cores. The ensuing reduction in mat size, along with the replacement of standard matrix diodes with integrated diodes, would substantially reduce core stack size.

The relatively long cycle required to fabricate a core stack made it necessary to start procurement early in the investigation. Since the ability of integrated-circuit manufacturers to produce high-speed, high-power circuits was unknown at that time, it was decided to use cores with the lowest drive commensurate with reasonable output. These cores have poor output-vs.-temperature characteristics and, therefore, temperature compensation of the drive currents was required. As a result, a temperature-sensing element was included in the stack to permit testing with and without current compensation.

TEST RESULTS

At the completion of the investigation, the display console to be used with the memory was not available. Consequently, the memory was exercised as a separate unit with visual inspection of the output waveforms serving as the evaluation criteria. The output waveforms for the case of all *1's* and all *0's* shown in Fig. 5 appear to be more than adequate for reliable system operation.

A worst-case checkerboard was written into an individual plane by applying a 400-ma current to the sense line. This pattern was then read out at a reduced rate. The waveforms observed, due to the small stack size, were essentially the same as those for all *1's* and all *0's*.

CONCLUSIONS

The investigation has demonstrated that a small, coincident-current, magnetic-core memory may be successfully constructed using integrated circuit techniques in all the major areas. It was demonstrated that timing, address, sense, and inhibit functions could all be accomplished using a combination of standard and special integrated circuits. These circuits are commercially available at reasonable costs and with normal delivery cycles. It should be noted that appreciable cost savings could be effected by large-quantity orders of such circuits as matrix drivers, gates, flip-flops, and one shots. Finally, the physical size of the memory can be substantially reduced by the combined use of integrated circuits and relatively standard packaging and wiring. Further reduction is possible by the application of multilayer boards and special core stack techniques.

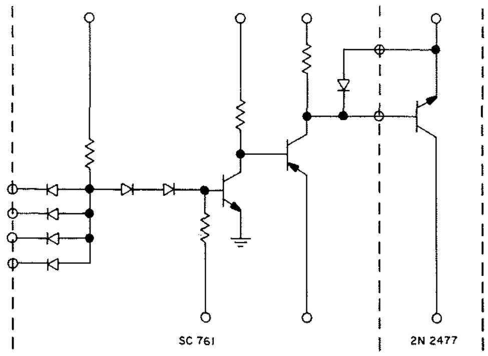


Fig. 2—Basic DTL input driver-switch.

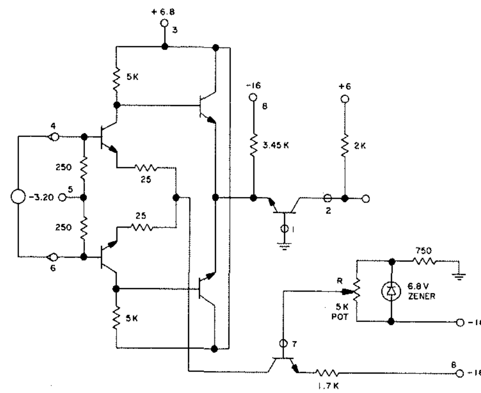
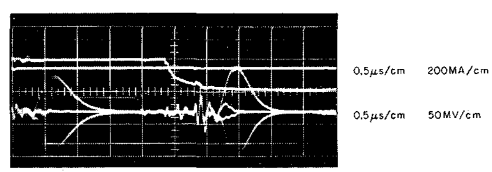
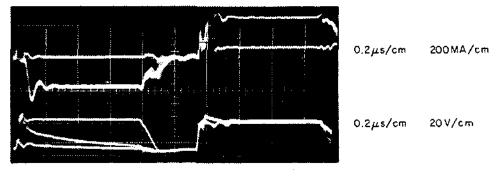


Fig. 4—Sense amplifier.



TRACE I DRIVE CURRENTS, READ, WRITE AND INHIBIT.

TRACE II SENSE LINE OUTPUT SHOWING ONE AND ZERO PATTERN SUPERIMPOSED.

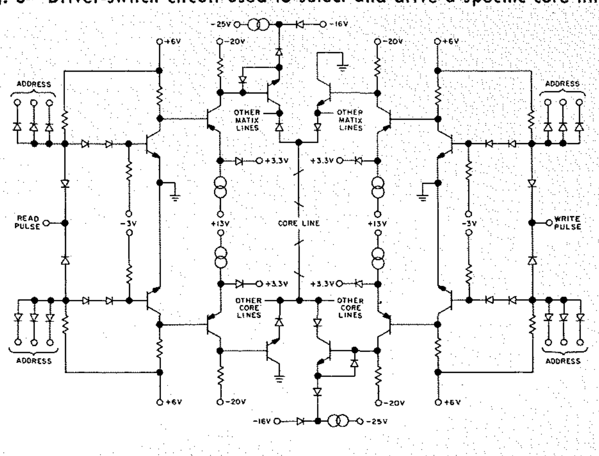


TRACE I DRIVE CURRENTS AT BOTTOM OF DIODE MATRIX.

TRACE II DRIVE VOLTAGES AT BOTTOM OF DIODE MATRIX.

Fig. 5—Test results: output waveforms for all 1's and all 0's.

Fig. 3—Driver-switch circuit used to select and drive a specific core line.



APPLICATION OF MICROELECTRONIC CIRCUITS IN VIDEO DISPLAY SYSTEMS

In today's complex display systems, the greatest portion of the volume usually is occupied by logic elements and associated power supplies. This paper describes how microelectronic circuitry was used in an RCA Model 6050 Video Data Terminal to reduce the overall volume without increasing the cost.

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West Coast Division, DEP, Van Nuys, California

THE RCA Model 6050 Video Data Terminal is a display system consisting of a disc memory, control unit, logic, and viewer. Using microelectronic circuits, engineers of DEP's West Coast Division substantially reduced the volume of the logic portion of the 6050 system without appreciably increasing the cost of the system (Fig. 1). To exercise the logic and evaluate the microelectronic circuits, it was necessary to use the disc, viewer, keyboard, and character generator of the standard 6050 system.

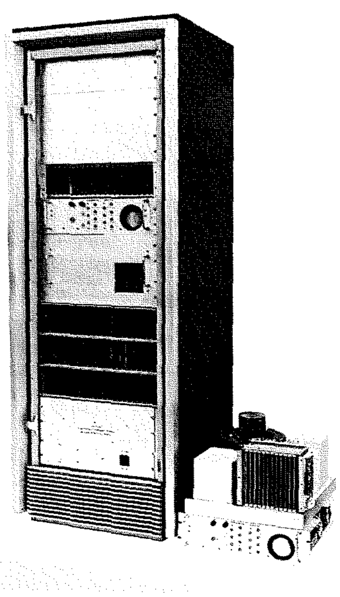
This paper discusses in detail the following major areas involved in the process of logic reduction:

1) Evaluation of available micrologic circuit configurations.
2) Design of special hybrid circuits requiring discrete components.
3) Investigation of soldering methods and jig fixtures for possible use in a production situation.

Other aspects of the size-reduction process included: reduction of existing logic for use with emitter-coupled logic; layout of multilayer boards to mount the microcircuits; and design and fabrication of a nest and drawer assembly.

Final manuscript received April 4, 1966.

Fig. 1—Comparison between standard logic cabinet (left) and microelectronic logic cabinet.



GENERAL SYSTEM CONSIDERATIONS

To understand the characteristics required of a logic circuit in a display system, one must first understand the basic operation of the logic areas in which this element will be used. The logic unit of the video display consists of plug-in modules to implement the logic, disc memory, character generator, and power supplies.

Disc Memory

The disc memory is a rotating magnetic disc storage unit capable of storing the 4160 bits (8 bit per character, 48 characters per line, four character times between lines, and 10 lines per page) required for one full-page message.

Basic Machine Logic

The master timing logic provides control signals for the Video Data Terminal (VDT) operating sequences. The following signals, permanently recorded on the disc memory, provide basic VDT timing:

1) 500 kHz (kc)
2) Character bit clock
3) End of line
4) End of page.

These pulses are processed to produce the following as required by the operating mode:

1) Basic clock pulses
2) Disc read strobe pulses
3) Beginning of line pulses
4) Beginning of page pulses
5) Character pulses
6) Character bit count pulses
7) Alternating phase 500 kHz (kc).

The read/write logic accepts data from the keyboard, controls reading and recording on the disc memory, provides parity check of information read from the disc memory, and, when in the transmit mode, provides storage for the next character word to be transmitted to the data-phone data set.

When operating in the write mode, the read/write logic is the transfer center of data entered from the keyboard, stored in the disc memory, transferred to the character generator for display, and again read from memory and sent to the character generator to refresh the displayed message. During receive or transmit modes the read/write register controls reading from and into the disc memory and controls the first or last of four characters to be received from or sent to the data-phone data set.

Input/Output Counter and Buffer

The input/output (I/O) counter controls the rate that received data is transferred to the read/write register and the rate that transmitted data is made available to the data-phone data set. The I/O counter also provides control signals for data format conversion in both receive and transmit modes. The data transfer rate is controlled by an oscillator which provides a time base for control signals. The oscillator frequency is determined by the maximum data rate of the data-phone data set.

The I/O buffer consists of three eight-bit serial shift registers (B1, B2, and B3), a register shift control (A1, A2, A3, and A4), and a slow-fast shift control. The shift registers provide temporary storage for character words during transmit and receive operations. The I/O buffer registers receive data during transmission from the disc memory.

Data read from the disc is shifted into the I/O buffer and read/write (R/W) register. When all registers are full, the data is shifted to the I/O register. At the appropriate time, determined by the I/O counter, the character word is shifted to the data-phone data set at the data-phone data set rate. Since the I/O buffer is now empty (contains no character bits) another character word is read from the disc memory and is shifted to I/O buffer register B1, shifting all the registers and filling the I/O register.

The register shift control logic determines the I/O buffer register to be shifted. The slow-fast shift control logic determines whether the I/O register will be shifted at the slow rate (data set input or output rate) or at the fast rate (VDT clock frequency).

The I/O register is the only register that is shifted at the slow or data set rate; the others, B1, B2, B3, and R/W, are shifted at the fast or VDT clock rate.

Index Mark Logic

The index mark logic controls the time the index mark is recorded on the disc memory, thus controlling character location. The index mark has a separate track on the disc memory which contains only one bit at any one time, although this bit may be recorded at any place on the index mark track. When the mark is to be positioned to the next character position, the mark is read from the disc memory, delayed five character times, and then recorded on the disc memory, which places the index mark one character position to the right. When the index mark is to be moved to the left one space for backspacing, it is read from the disc memory, delayed three character times, and recorded on the disc memory. When there are no commands, the index mark is read from the disc memory, delayed four character times, and recorded on the disc in the same position.

Character Generator

The character generator consists of a monoscope, a video preamplifier, two character selection amplifiers, an index mark and sweep generator, a 500-kHz and sync driver, a regulated low-voltage power supply, and a high-voltage power supply.

MICROCIRCUIT EVALUATION

The logical portions were implemented with RCA 301 hardware. To integrate this unit, circuits possessing the requirements listed below were needed:

1) Turn-on time $\leq$ 92 ns with 5 loads
2) Turn-off time $\leq$ 140 ns with 5 loads
3) Pair delay $\leq$ 200 ns
4) Fan in $\geq$ 10
5) Fan out $\geq$ 5 unit loads

At the time the project was initiated, the available microcircuit logic configurations were RTL (resistor-transistor logic), DTL (diode-transistor logic), T^2L (transistor-transistor logic), and ECL (emitter-coupled logic).

After comparing the published data for each of these types with the system requirements, RTL and T^2L were eliminated because of RTL's limited fan-in, usually less than 4, and because of T^2L's relatively high cost. It was felt that in a system the size of the video display, line capacity would not present a problem sufficient to justify the higher cost T^2L circuits.

The remaining choices, DTL and ECL, were then evaluated for fan-in, fan-out, and relative noise immunity. For DTL circuits, similar to that shown in Fig. 2, fan-out and relative noise immunity are interdependent. Calculations show that for a noise protection of 0.22 volt, the fan-out is $N = 5.56$. If this noise protection is expressed as a percentage of the full logic swing, the circuit will have a relative noise protection of:

$$\%\ V_L = 4.4\%$$

The fan-in of a DTL circuit (Fig. 3) is dependent on the permissible turn-on delay of the gate. The delay time as a function of input capacity is given by:

$$\overline{t_{on}} = \overline{t_o} + \overline{C_s}\,\overline{R1}\ ln\left[\frac{\overline{E_1} - E_d}{\overline{E_1} - \underline{3E_d}}\right]$$

(NOTE: In these equations, overlined terms indicate maximum values and underlined terms indicate minimum values.)
where t_o is the basic transistor delay and may be taken as:

$$\overline{t_o} = 25 \text{ to } 50 \text{ ns}$$

It should be noted that C_s is comprised of the resistor and circuit diode parasitics and the fan-in diode capacities.

Assuming that the circuit parasitics account for 20 pF, 5 pF for each element, the fan-in diode capacity will be:

$$C_f = \overline{C_s} - 20 \text{ pF}$$

Since C_s may be calculated to be 67 pF, and information from the vendor's data sheets indicate that the diode capacity is $C_d = 10$ pF, the fan-in is:

$$M = C_f / C_d = 47/10 = 4.7$$

for a turn-on of 92 ns.

In the ECL circuit the noise immunity is also fan-out dependent; however it is also dependent on fan-in and reference voltage level. If the reference voltage supply is limited to a fan-out of 5, the reference voltage will be (Fig. 4):

$$\overline{E_o} = -1.01$$
$$\underline{E_o} = -1.28 \text{ volts}$$

The vendor quoted a range of −1.04 to 1.18 volts for 0 mA to 2.5 mA at +75° C. Note that in monolithic construction, diode junction drops are the same in a given circuit and the resistor tolerances are all in the same direction.

In calculating gate fan-out, two cases must be considered (Fig. 5). First, where the gate output is high, it must be more positive than the highest output of the voltage reference. The worst case unit load is:

$$\overline{I_{in}} = 0.327 \text{ mA}$$

If a noise margin of 0.05 volt (5% of full swing) is assumed for a circuit used in the *or* mode:

$$E_o = -0.96 \text{ volt}$$

The load current is:

$$I_L = 2.1 \text{ mA}$$

R2 is maximum because *R1* is maximum and they are both formed during the same diffusion. Since there is 0.327 mA per load, the circuit could drive:

$$N = 2.1/0.327 = 6.4 \text{ loads for a 5\% relative noise margin at } 0°\text{ C.}$$

The second condition which affects fan-out in ECL is that of fan-in, (Fig. 6). As expanders are added to the input, additional leakage current, from the collector to the base junction and from the substrate to the collector junction, will pass through the collector resistor. These currents must be added to those due to external gate loading.

When the ECL circuit is used in the *nor* mode, the fan-in for a relative noise margin of 5% and a fan-out of 6 is:

$$M = \frac{1}{2\overline{I_{co}}}\left\{\frac{E_o - \overline{V_{be}}}{R3} - \frac{1}{\underline{\beta}}\left[\frac{\overline{E2}}{\overline{R2}} + I_L\right]\right\}$$

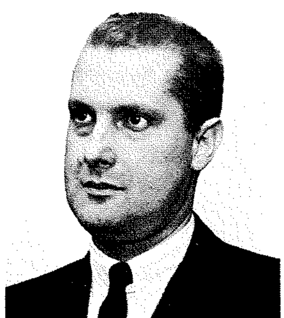
At 75° C:

$$M = 8.6 \text{ loads for a 5\% relative noise margin.}$$

R. H. NORWALT received his B.S. degree in Physics from the University of Southern California in 1961. Prior to receiving his degree, he worked for more than two years on the design and development of magnetic-drum memory systems and associated solid-state control circuitry for Litton Industries and Magnavox Research Laboratories. Since joining RCA at Van Nuys in 1961, he has been responsible for the design and development of several drum and disc memories as well as a number of coincident-current core memory systems. He is presently engaged in the design and development of a highly reliable, solid-state core memory using microelectronic circuits.

LARRY A. JONES studied electronic engineering at Northrop Institute of Technology and San Fernando Valley State College. Immediately after leaving Northrop Institute, he joined RCA. Early assignments included design and development of hybrid (tunnel diode and transistor) circuits, Saturn 110A module boards, 604 Computer high-speed arithmetic unit, BMEWS, and an integrated-circuit core memory system. Later assignments involved development of a miniature display system that is identical in function with the RCA 6050 Display System. He is presently a member of a design and development team that is developing a high-reliability, integrated-circuit core memory system.

CHARLES R. WAY is a graduate of Curtis Wright Aeronautical School. Prior to joining RCA, he was with Weber Aircraft. In his early years with RCA he was a member of the Engineering Model Shop, where he acquired an extensive background in machine tooling and fabrication. During the last 16 months, he has participated in the application of microelectronic circuits and an integrated core memory to a video display system. He also has assisted in the development of a new spiral scan memory. He is presently designing the packaging of the graphic tablet system.

R. H. Norwalt


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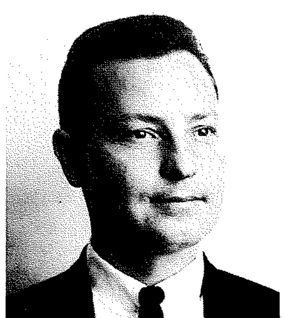


C. R. Way

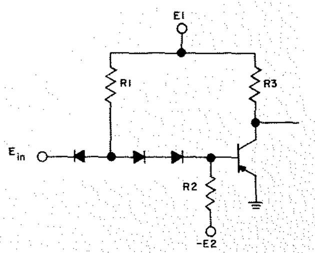



Fig. 2—Typical DTL circuit

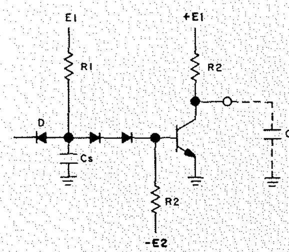


Fig. 3—DTL circuit showing capacitive loading.

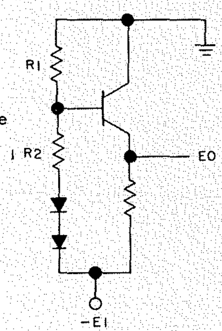


Fig. 4—Bias voltage source for ECL.

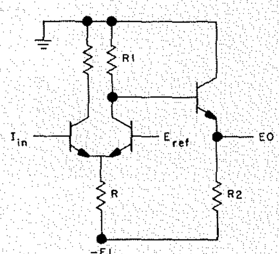


Fig. 5—Basic configuration for ECL.

Fig. 6—Portion of ECL circuit showing parasitics.

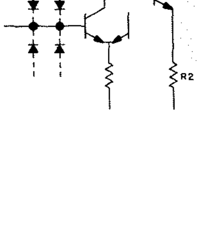
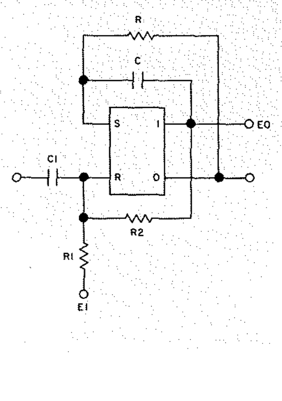


Fig. 7—Monostable multivibrator configuration.



The circuit delays of an ECL circuit are predominantly a function of fan-in, fan-out, and temperature.

Published data indicates that the turn-on and turn-off delays should be as follows for 0° C, 25° C, and 75° C if a fan-out of 5 and a fan-in of 9 are assumed.

Turn-On Delay T_1

Temp.	Maximum	Minimum
75°C	20 ns	6 ns
25°C	13 ns	5 ns
0°C	13 ns	5 ns

Turn-Off Delay T_2

Temp.	Maximum	Minimum
75°C	36 ns	12 ns
25°C	21 ns	8 ns
0°C	20 ns	7 ns

These delays seem to be well within the requirements of the system as previously outlined.

In summary, it was found that for a relative noise immunity of 5%, the DTL logic possessed a fan-out capability of 5 and a fan-in capability of 5. The ECL logic was capable of a fan-out of 6 and a fan-in of 9 with a circuit delay at least one-half that of the DTL logic under similar conditions. Based on these findings and the fact that valuable experience could be gained by the use of monolithic ECL flip-flop circuits, a decision was made to use RCA ECCSL gates and Motorola MECL flip-flops.

SPECIAL CIRCUIT DESIGN

Since the standard RCA and Motorola ECL lines contain only gate and flip-flop circuits, additional circuits were designed and fabricated to perform the special functions of timing, recording on and reading from the disc memory, and interfacing with the character generator and keyboard. These circuits used standard microelectronic circuits wherever possible, with discrete components added to achieve the desired function.

The circuits for these special purposes were as follows:

1) Monostable multivibrator with a pulse-width capability from 0.25 μs to 11 ms.
2) Disc write amplifier capable of delivering 75 mA into a 100-μH head.
3) Disc read amplifier capable of amplifying and squaring a 200-mV disc signal. This amplifier must also withstand input voltage swings of 20 volts with a recovery time of 200 μs.
4) Level shifters capable of shifting the signal swings from the 0.8-volt ECL logic values to the +6.5-volt excursion required by the character generator.
5) Keyboard interface capable of shifting the 13-volt swing available from the keyboard to the 0.8-volt swing required by the ECL logic gates.

The design of these circuits is discussed in subsequent paragraphs.

Monostable Multivibrator

The monostable multivibrator required for the system should be relatively insensitive to both temperature and voltage variations, and should require a minimum number of external components. One method of achieving these requirements is to use an RC feedback network with a standard flip-flop. It is assumed that the flip-flop will track other flip-flops and gates with respect to temperature and voltage variations.

In the circuit shown in Fig. 7, the reset input is biased to the negative logic level. A positive transient may then pass through *C1* and reset the flip-flop. As the flip-flop is reset the *0* output goes positive and the *1* output goes negative. The set input is pulled negative by the capacitor *C* which is then charged positive by *R*. When the voltage in the set input reaches the critical point, the flip-flop fires and returns to its quiescent condition.

Write Amplifier

The write amplifier circuit required for this system must be capable of delivering a current of at least 75 mA into a 100-μH disc head with a current rise time of 1 μs or less. To meet these requirements, a high-current level shifter was designed in which the *or* output of an ECL gate drives a grounded-base stage to obtain voltage gain. The output of this stage drives a transformer-coupled stage which operates in the grounded-collector mode with the disc write head in the collector circuit (Fig. 8), and the current-limiting resistor in the emitter circuit.

Read Amplifier and Read/Write Signal Limiter

The standard ECL three-input gate may be considered as a slightly unbalanced differential amplifier coupled by emitter followers to the output pins. The disc read amplifier circuit (Fig. 9) is constructed of two of these gates connected so that the high-gain side of the first-stage is fed into the low-gain side of the second stage, and the low-gain side of the first stage feeds the high-gain side of the second stage. In this way the first two stages form an amplifier with nearly symmetrical gain. One output of the second stage is fed into a standard gate input. Since these circuits are basically non-saturating, this gate serves as a quantizer as well as a logic strobe gate.

In addition to amplifying and squaring the normal small disc signal, one of the read amplifiers in the system must be able to withstand the full write voltage across its input. To achieve this, a limiting circuit was designed (Fig. 10) and inserted between the write amplifier and read amplifier (Fig. 11). The maximum

Fig. 8—Disc write amplifier.

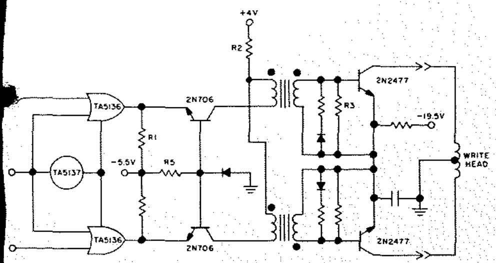


Fig. 9—Read amplifier configuration.

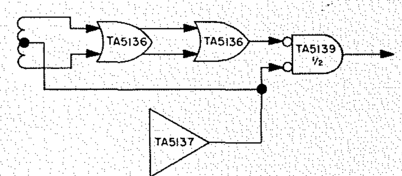


Fig. 10—Read/write signal limiter.

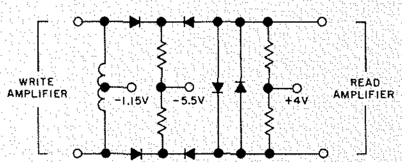


Fig. 11—Circuit configuration for data track.

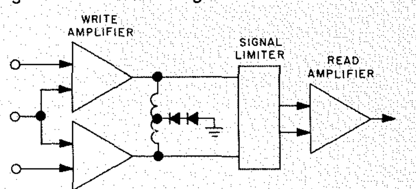


Fig. 12—Level shifting circuit.

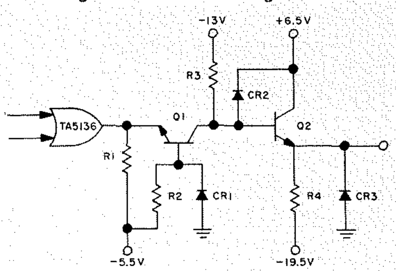
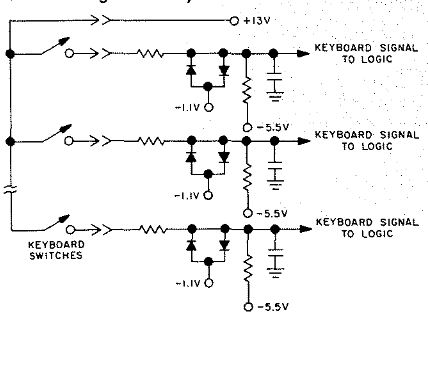


Fig. 13—Keyboard interface.



swing into the read amplifier is 0.7 volt, which will not harm the ECL circuit.

Level Shifters

The equipment with which the ECL logic must interface uses modified *pnp* logic levels. The voltage swing for this logic is +6.5 volts for a *0* and +0 volt for a *1*. In addition, the circuitry driving this logic must be capable of supplying 22 mA at the +6.5-volt level.

A circuit configuration was designed to fulfill these requirements (Fig. 12). In this circuit the output of a standard ECL gate drives a common-base stage to obtain the necessary voltage gain. The output of this stage drives an emitter follower to obtain the required current gain.

Keyboard Interface

The system keyboard is connected to the logic by a cable containing 28 lines. Each of these lines is a single wire up to 50 feet long. The keyboard itself consists basically of a number of simple switches. Because of the line length and switch simplicity, the voltage at the keyboard must be relatively high. The highest voltage, of the proper polarity, available in the system is +13 volts. This voltage must be transformed, in both amplitude and reference, to a value compatible with ECL logic. To achieve this transformation, a network of resistors and clamp diodes was designed (Fig. 13).

MICROCIRCUIT MOUNTING TECHNIQUES

In the packaging field today there are many techniques by which microelectronic flat-pack circuits may be interconnected to implement a given system. For the implementation of the microelectronic video display, a multilayer printed-circuit board was chosen for circuit interconnections, and solder techniques were used for the actual mounting of the flat pack. Both the multilayer circuit board and the soldering techniques provided economy in construction and ease of field maintenance.

Circuit Board Design

If one chooses a lead pattern so that complex lead forming is not required, it becomes evident that flat-pack leads cannot pass through the circuit board, but must lay on the circuit pattern, as is the custom when welding techniques are used. Since the display system would not normally encounter extremely high stress, this lap-type solder joint, if of sufficient dimensions, should not be objectionable.

Soldering Techniques and Fixtures

A number of soldering techniques are available today for the fabrication of standard component boards. The most promising of these techniques are hot gas, automated soldering iron, and laser-beam soldering. The devices required for each of these techniques are available in prototype or production form.

1) *Hot-Gas Soldering Unit.* Sperry Gyroscope Division of Sperry Rand publicizes a hot-gas soldering unit which will handle a 4- by 6-inch board containing 96 flat packs at a soldering rate of 1000 joints per minute. The preliminary cost of this machine in quantities of 25 or more would be $6000.
2) *Automated Soldering Device.* Weller Electric is marketing a flat-pack soldering device which consists of two temperature-controlled soldering irons with tips sufficiently wide to solder all 14 leads of a flat pack at the same time. The two irons are mounted in such a way as to allow contact and retraction from the work by means of a single lever movement. If this unit were combined with a programmed positioning table, an entire board could be soldered with minimum operator involvement.
3) *Laser-Beam Soldering Device.* A laser-beam soldering device is offered by Linde Division of Union Carbide. This device, which is basically a laser welder, suffers from some of the restrictions of reflow soldering by parallel gap techniques. However, electrode contamination is not a problem. The automation of a board-soldering process using a laser-beam device would require a very accurate positioning table, such as the Westgate Labs series 1187. This table is capable of accepting a 10-inch-square board and positioning it with an accuracy of ±0.001 inch at a rate of 30 ips.

Regardless of the technique chosen, a fixture is required to hold the packs during the soldering process. The flat packs are first mounted in the fixture in the positioning arm where they are held by magnets. Next, the arm is swung back into the lead forming and trimming die. After the trimming operation, the arm is swung over the board and clamped in place. When the board has been fully loaded, the entire fixture is placed on a positioning table and soldered. The operation of this positioning table would depend on the soldering technique employed. Hot-gas soldering would require the simplest table; laser soldering would require the most complex table.

CONCLUSION

This study confirmed that available microcircuit logic configurations can be used in most circuits. In circuits required to perform special functions, i.e., timing and recording on and reading from the disc memory, standard microelectronic circuits were used with discrete components added to achieve the desired function. Various soldering techniques were examined, the most promising being hot gas, automated soldering iron, and laser-beam soldering.

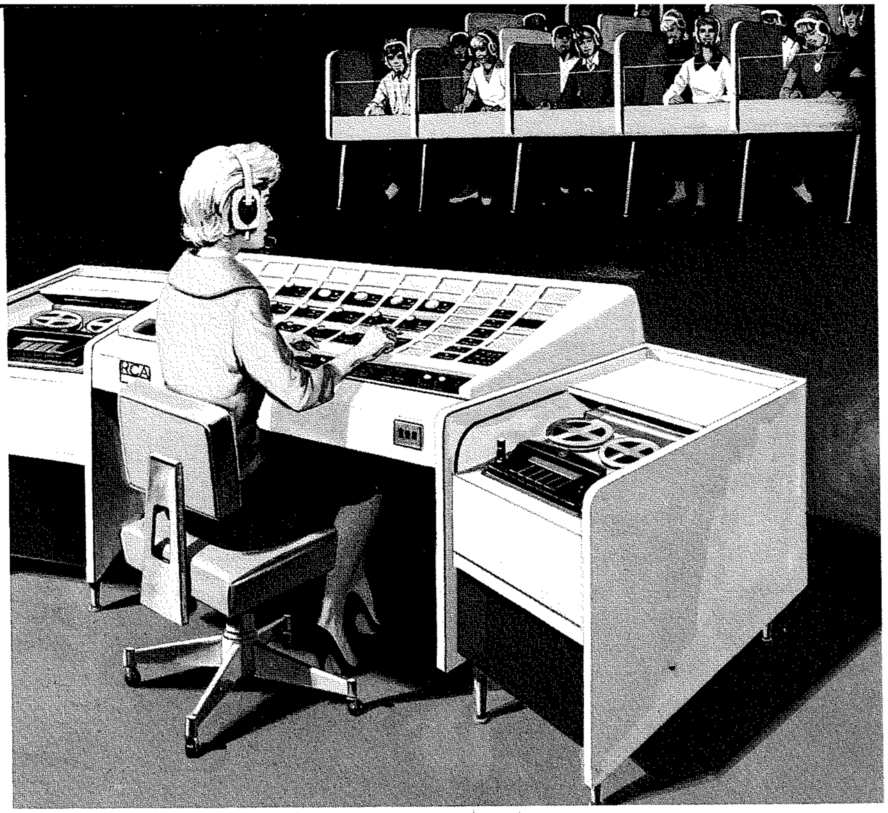


Fig. 1—Instructor's console and student booths.

THE RCA EDC-101 LEARNING LABORATORY SYSTEM

The learning laboratory is a physical facility designed for the efficient practice of languages and other repetitive learning experiences. RCA, which has been producing learning laboratories since 1958, has developed a new, flexible, integrated Learning Laboratory System, the EDC-101.

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ANYONE who has heard his own recorded voice will remember his surprise as he first listened. The human characteristic of not really being able to hear one's voice as others hear it plus the ability of the human mind to compare two sounds heard in close time sequence are fundamental to the concept of the electronic learning laboratory.

A learning laboratory is a physical facility for providing practice in languages and other repetitive learning experiences. To overcome self-consciousness and the fear of ridicule so often associated with group practice, the laboratory uses a private booth to isolate the student acoustically and visually from the remainder of the group. Without fear of embarrassment, the student can tackle freely the new and strange sounds, and soon will derive pleasure from proper repetition of the lesson material. For example, according to the theory of language instruction, the student follows the routine outlined below. He:

1) listens to a word or phrase in the foreign language
2) responds by repeating the word or phrase
3) listens to the phrase again, and then
4) compares his pronunciation with that of the repeated phrase.

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Thus, the student is learning by participation and in privacy.

The teacher is freed from the repetitive teaching chore, can monitor the class, and can give individual attention where required. In the booth the "teacher" is on tape—the machine takes over the mechanical chore of drilling the learners with different patterns again and again and again. A further advantage of the learning laboratory is the ability to provide several lesson sources, permitting students to proceed at varying rates in accordance with their abilities. This flexibility makes it particularly useful in the teaching of such subjects as typing and shorthand, as well as languages.

In early systems, used to teach languages primarily, the source material was provided by an instructor or a disc recording. With the advent of tape recorders, the instruction of languages took a giant step forward. The tape recorder made the talents of a trained linguist available to every school having a teaching system. These early systems were commonly called language laboratories. As the equipment became more sophisticated, the application was expanded from language instruction to other disciplines. The broader term *learning laboratory* replaced language laboratory.

THE EDC-101 LEARNING LABORATORY

RCA entered this field in 1958 with two systems. One, a listen/respond system permitted the student to listen through a headset to a lesson consisting of words and phrases and to repeat them into a microphone, hearing himself in the headset. The second system, called listen/respond/record, included a dual-track tape recorder at the student position. The lesson was recorded on one track and the student's response on a second track. The student could later compare his response to the original lesson material. Tapes could be retained as a permanent record of the student's progress. Over the years, the basic equipment was improved, but the need for a new, flexible, integrated system became apparent. The equipment described here, the EDC-101 Learning Laboratory System, was designed to fill this need. The EDC-101 System contains all the desired features and provides a learning laboratory that is modern in styling and, although modular in construction, retains a custom appearance.

The principal items of furniture in the EDC-101 System (Fig. 1) are the instructor's console and the student booths. The instructor's console and student booths house the amplifiers, tape recorders, and control equipment, which are inter-

Final manuscript received April 18, 1966

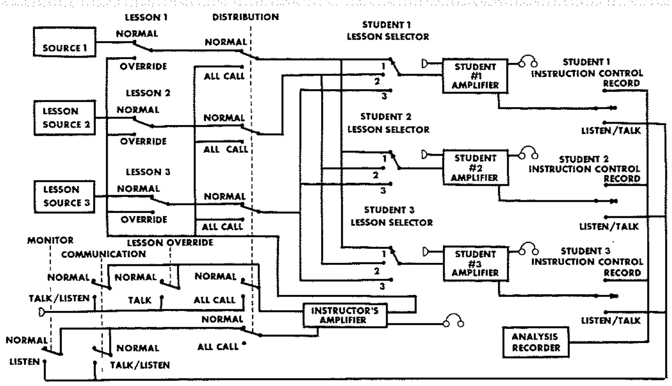


Fig. 2—Simplified block diagram of EDC-101 system.

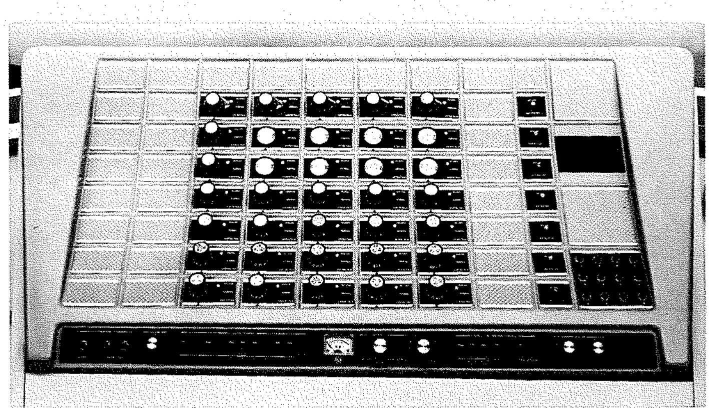


Fig. 3—Typical layout of instructor's control panel.

connected as shown in Fig. 2. With the cooperation of the Broadcast and Communications Products Division's Functional Design Activity, the styling and functional aspects of the furniture evolved through several models to the one illustrated.

Student booths contain a headset, microphone, and either a student recorder or controls for the listen/respond amplifier located in the console. A laboratory usually consists of a combination of listen/respond booths for daily practice, and listen/respond/record booths for periodic recording of student responses or for advanced students.

The instructor's console is the heart of the EDC-101 System (Fig. 2). The controls available to the instructor enable him to perform the following functions:

1) Select any of 10 different lesson sources for individual, or groups, of students.
2) Interrupt and supplement any lesson source with explanatory comments that will be heard only by students using that particular lesson source. (A student may attract the teacher's attention by using the annunciator.)
3) Interrupt all lesson sources with announcements or instructions to the whole class.
4) Monitor an individual student and, if desired, carry on a private conversation in addition to or without lesson material.
5) Record any student's recitation for analysis or record purposes.
6) Select external inputs (such as emergency announcements for the whole school) for the whole class.

SYSTEM DESCRIPTION

The positioning of controls for student functions at the console follows a geographical configuration; i.e., the control locations agree with the geographical layout of the student booths. The maximum number of student booths is 64 in a configuration eight positions wide by eight positions deep. The control panel can represent any student position layout within the eight-by-eight grid. This variation in control-panel layout is accomplished by use of a large, formed-plastic overlay with 64 rectangular recesses. In each recess is placed either a blank escutcheon or the properly labeled escutcheon with suitable control knobs representing an operating position. A typical layout is shown in Fig. 3. The operating switches are located on a subchassis. The control knobs reach through the plastic overlay to the switch shafts below. To implement the modular concept, the subchassis mounts horizontal switch banks, of eight positions each, in the number of horizontal rows required by the particular laboratory.

The listen/respond student amplifiers, one for each booth, are mounted in the console. Power is supplied through the aluminum channels to which they are mounted. The location of the amplifiers is such that the audio cable length from any amplifier to its corresponding console control is the same for all amplifiers. The console has one power supply which provides power for the lesson sources, the student amplifiers, and the annunciators. The power supply switch is positioned at installation to compensate for the number of student positions used. Fig. 4 shows the construction of the subchassis and amplifier mounting.

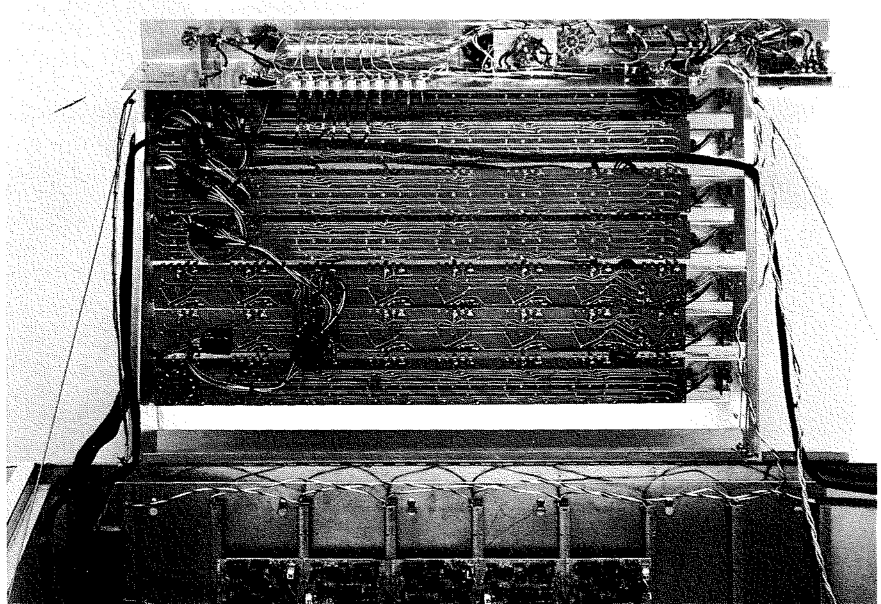
To reduce cost and increase reliability, printed-circuit wiring was used extensively in the EDC-101. The console student control switching is completely printed-circuit wired. Installation is simplified by having the console interconnected by plugs and jacks or push-on terminals. The printed-circuit wiring contains jumpers which are cut when the system is installed for listen/respond/record student positions instead of the listen/respond position, which permits stocking of one type of switch bank for both applications.

A combination of tape recorders and record players may be installed in the console to permit distribution of as many as 10 separate lesson sources simultaneously to various students. In addition, one of the tape recorders can be used by the instructor to record any student's responses and the lesson which he is using.

CONCLUSION

The EDC-101 Learning Laboratory provides a flexible teaching aid which will supplement ordinary classroom techniques and will significantly improve the effectiveness of educators by combining modern electronics with proven educational techniques. The success of the learning laboratory sets the stage for other instructional electronic devices. The future of instructional electronics includes such devices as closed circuit TV; dial access to tape, disc record, slide, and film libraries; branching learning devices; and many others.

Fig. 4—Console subchassis.



STRATEGIC VERSUS TACTICAL PLANNING IN MODERN BUSINESS

Advances being made in the area of information-processing technology involve the simulation of feedback systems such as arise in business, economics, or engineering. This article summarizes efforts to date in the application of an advanced feedback-system simulation technique as a strategic planning discipline. The results of an extensive parameter-sensitivity analysis are presented, and the utility of simulation is evaluated.

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The introduction of computer-based management techniques such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) have significantly improved management's tactical planning capability over the past five years. These techniques highlight incipient problems of a technical, manpower, cost or schedule nature. With adequate follow-through, once a pattern of corrective action has been determined, good results have been obtained. The real impetus for the development of these techniques has come from the Defense agencies of the Government. Unsatisfactory experiences with major weapon system program costs and completion dates in excess of earliest estimates are a matter of record.[1] Furthermore, the final product frequently did not perform as originally desired. Today's Government program manager has at his disposal tools which can yield him optimal results in terms of program goals.

But what about the long-term profitability of industry in the major weapon system business? Survival alone demands a radical upgrading of management's strategic planning capability. First, we must abandon today's concept of strategic planning, which is simply a continuous modification of basic policies and decision criteria in the hope that a profitable long-range strategy will evolve. The result is actually nothing more than a series of tactical plans. Then we must develop strategic planning techniques for maximizing profits which can cope effectively not only with the type of optimization afforded by today's tactical planning disciplines but also with the rapidly changing technology, increasing demands on system performance, and fixed-price procurement practices.

One way of approaching the strategic planning technique problem, stated above, is to treat the firm as a feedback system. Advances are being made in the area of information-processing technology which involve the simulation of feedback systems such as arise in business, economics, or engineering. This article summarizes efforts to date in the application of an advanced feedback-system simulation technique, MIT's DYNAMO (DYNAmic MOdels),[2] as a strategic planning discipline. The results of an extensive parameter sensitivity analysis are presented. Conclusions are drawn with regard to the utility of simulation and eventual success of present policies.

Final manuscript received February 3, 1966

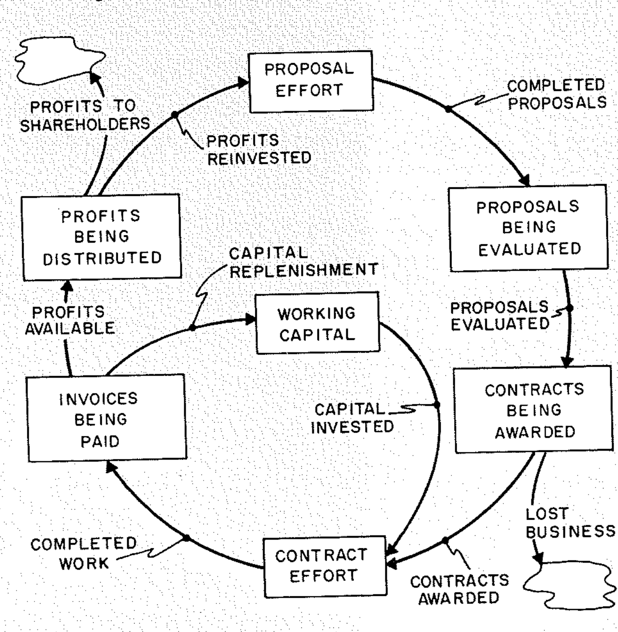
A TYPICAL BUSINESS CYCLE

Let us examine a typical business cycle and see what makes it a feedback system. Then let us see what happens when we try to simulate it for testing our strategic plans. Assume that the firm illustrated in Fig. 1 has been in business for some time and that profits are being reinvested in proposals for acquiring new business. Starting with the block labled "proposal effort," the cycle proceeds as follows:

1) Proposals are completed at a rate which is a function of the size or level of proposal effort and the time required to produce a given amount of proposal material.
2) Completed proposals are forwarded to a prospective customer where they become proposals being evaluated.
3) The evaluation of proposals is completed at a rate which is a function of the size of the customer's evaluation staff and the time required to evaluate a proposal of given size.
4) Proposals which have been evaluated are forwarded to the contracting section within the customer's organization. There, depending upon the evaluation staff's rating, a contract is awarded to the firm submitting an acceptable proposal.
5) The rate at which contracts are awarded is proportional to the size of the award and the time required to negotiate a given sized contract.
6) The firm receiving the contract award must generally invest some of its own capital in order to start work on the contract for which it will later be reimbursed, and so on.

The basic pattern is that of a feedback system because the output of a function at the present time will influence the input to that same function in the future. Consider, for example, an increase only in the efficiency of the work force engaged in the contract effort. The rate at which contract work is completed will increase, thereby increasing the amount of capital available to start new contracts. The benefit of this capital availability is not immediately felt because of the time lags involved in the series of functions that give rise to the new contracts. Determination of the overall effect of changing the behavior of just one function is called a parameter-sensitivity analysis.

Fig. 1—Simplified version of typical business cycle.



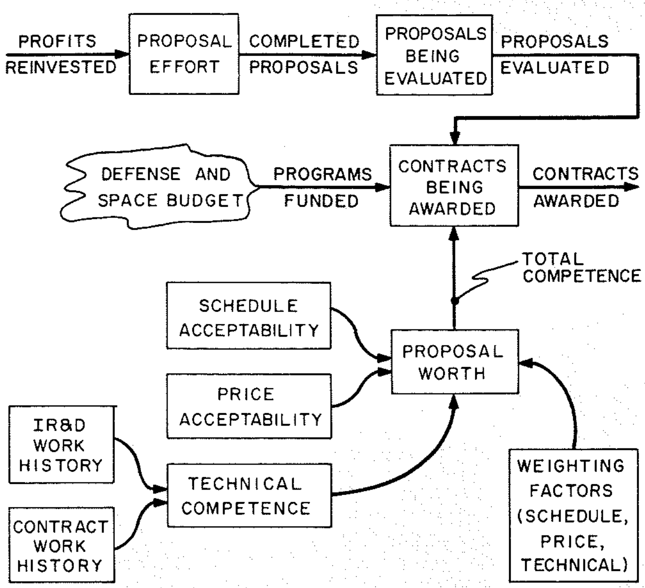


Fig. 2—Relationships in new business acquisition process.

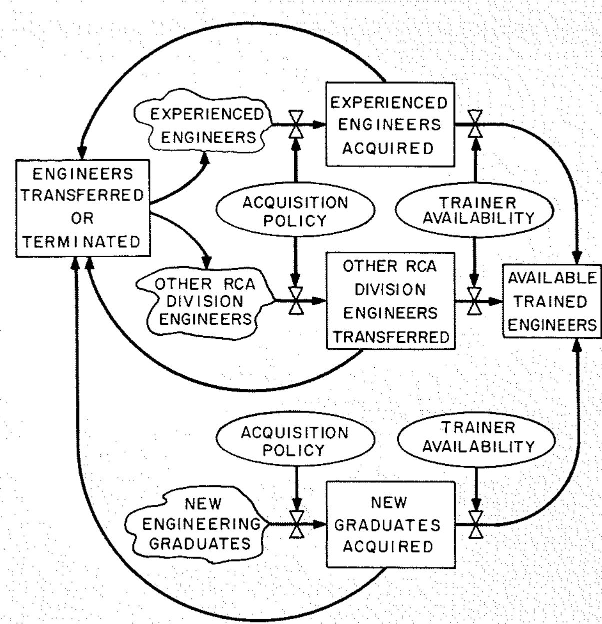


Fig. 3—Engineer acquisition, training, and termination.

The typical business cycle just described is a greatly simplified indication of the types of functional relationships that have to be simulated in a typical strategic planning situation. Simulation of such a feedback system entails setting boundary conditions, choosing the primary variables, and establishing their relationships in precise terms. Several facts of life about simulation should be explained at this point. First, the number of manipulations of the information that must be performed just to establish the reasonableness of the simulation's behavior is large. The process therefore dictates that certain simplifying assumptions be made to keep the simulation to manageable size. Second, a degree of simplification results from the fact that discrete events cannot be treated as such, but must be handled in real time as part of a continuous process. A particular simulation of a given set of relationships is called a model.

Recently a model of an RCA Division projected for the conduct of a major weapon system program was developed to aid in the establishment of basic policies and decision criteria that would assure its long-term profitability. All elements shown in the typical business cycle were included, but special emphasis was placed on simulating the engineering manpower acquisition and allocation process. The simulation technique employed (DYNAMO) requires that policies, effects, flows, levels, etc., be reduced to mathematical expressions. Subsequent paragraphs describe the assumptions upon which the present model is based. Many sources of information were considered during its development, including: historical data on the behavior of the major weapon system business, judgment estimates by mature management, and independent studies of modern organizational development theory and practices. The subsequent discussion considers the model as consisting of five major subdivisions or sectors: 1) acquisition of new business; 2) acquisition, training and termination of engineering and supervisory personnel; 3) voluntary terminations of engineering and supervisory personnel; 4) allocation of engineering personnel to the various types of effort; and 5) financial.

ACQUIRING NEW BUSINESS

The relationships that were found to exist in the new business acquisition process are shown in Fig. 2. Three important assumptions were made to effect a reasonable model:

1) The ratio of contract awards to proposal effort tends to a uniform value over a long period of time for an organization engaged in R&D work.
2) The proposal evaluation and subsequent contract-award process can be described as being an objective consideration of technical, schedule, and price factors.
3) The availability of funded programs would not be a limiting factor.

With these assumptions, the sector model then becomes simply a rate of contract awards expressed as a function of the level of proposal effort and the worth of the proposal. Even with this simple model several important parameter sensitivities can be evaluated, including:

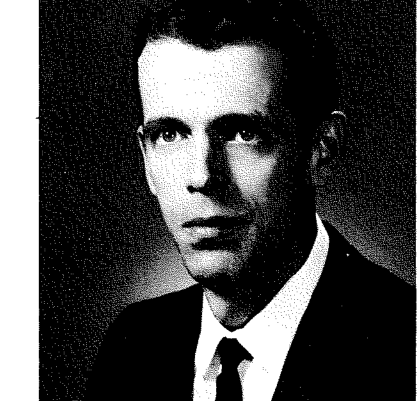
1) What benefits can be derived from increased reinvestment of profits in proposal effort?
2) What happens if the weight on the individual weighting factors (schedule, price, and technical) changes?

The answers to these questions, and others, are given following the discussion of all the sectors of the model.

ACQUISITION, TRAINING, AND TERMINATION OF ENGINEERING AND SUPERVISORY PERSONNEL

Intuitively one would expect the acquisition process to be very simple to model. In reality it was most difficult to formulate a process which was reasonably responsive to the programmed engineering manpower demand, regardless of starting work force size. Further, whatever decision rules were devised would have to be based on real world parameters, i.e., quantitative information that could actually be perceived by management. The sector, as modeled, is shown in Fig. 3. Because of the rigorous treat-

H. RICHARD HEADLEY received his BA degree in 1953 from Temple University, where he majored in Mathematics. He joined RCA's Missile and Surface Radar Div. in 1956, where he specialized in the mechanical design of antenna pedestals and precision gear train assemblies, was responsible for the development and implementation of management information systems, and directed a company-sponsored phased-array development program. He is presently Supervisor of the Colorado Springs Program Coordination Office, which is engaged in BMEWS Operational Engineering and Computer Program Configuration Management work for ADC. Mr. Headley is a registered professional engineer in the State of Pennsylvania and a member of the Operations Research Society of America and the Society of Automotive Engineers.



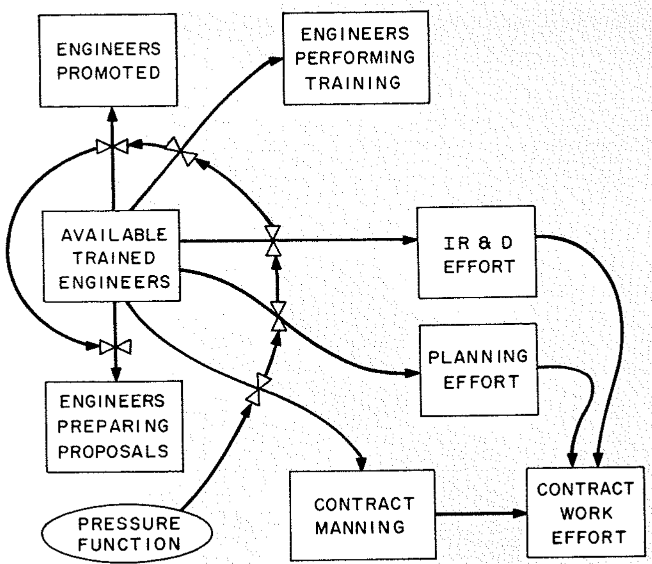


Fig. 4—Allocation of engineering personnel.

ment given the process, only the following assumptions were made:

1) An accurate, short-range forecast of engineering manpower demand (including accumulated backlog) could be made.
2) The greatest percentage of personnel would be acquired by transfers from other RCA Divisions.
3) A training or indoctrination period exists regardless of acquisition source. This period is a minimum for transfers and a maximum for new engineering graduates.

As can be seen in Fig. 3, it was necessary to segregate the sources of additional personnel because of the different delay times existing between them. This sector concludes with engineers available for specific work assignments.

The primary variable in this sector is the length of the training or indoctrination period. Since it is expressed as a function of availability of experienced personnel to act as trainers, the benefits of increased emphasis on this type of effort can be examined.

A similar process was assumed to exist for the acquisition, training, and termination of first-level engineering supervisors (leaders). Because of this similarity, a separate figure was not included. The process differs in that the sources for leader acquisition are: 1) promotion of engineers already in the organization, and 2) transfers from other RCA Divisions and hires from outside the firm. Finally, the training delay times are, in general, longer than in the engineering sector.

A considerable amount of cross-coupling exists between the parameters of the engineering and supervisory acquisition and termination processes as will be seen subsequently.

VOLUNTARY TERMINATIONS

The preceding discussion of terminations concerned only those of an involuntary nature resulting from work-force reductions. This section deals with the modeling of the process of voluntary termination. At first glance one would expect this process to be representable only by highly subjective factors and relationships. However, RCA's practice of conducting terminal interviews provided enough reliable information to establish those internal factors that were the most likely to cause voluntary terminations and the relative magnitude of the effect of each factor. The opportunity for promotion into management, the involuntary termination of other engineers, and the degree to which the engineering work force was being productively utilized were found to be the primary causes of voluntary terminations. Opportunity for promotion into management was the strongest factor, with the other two factors being about equal. In the model each factor is reflected separately to the variables of which it is a function.

Voluntary terminations of supervisory personnel were found to relate to three similar factors: 1) the degree to which the supervisory work force was being productively utilized, 2) the downgrading of leaders to engineering positions, and 3) the involuntary termination of other supervisors. The third factor was considered to be, by far, the greatest contributor to voluntary terminations of supervisors. Each of these factors was modeled separately according to its functional relationship to other parameters.

Because of the emphasis on engineering manpower acquisition and allocation, there was no attempt to establish any parameter sensitivities in this sector of the model.

ALLOCATION OF ENGINEERING PERSONNEL

There are six different types of effort to which available engineering manpower can be applied. These efforts, shown in Fig. 4, are as follows: 1) contract work, 2) planning, 3) independent research and development, 4) training of newly acquired engineering personnel, 5) preparation of proposals, and 6) training to become engineering leaders. That these six types of effort are a sufficient breakdown of an engineering department's activities is, in itself, a significant assumption. Other important assumptions are identified in subsequent paragraphs. Contract work, which produces the income necessary to support the remaining efforts, was assigned first priority for available manpower. The weighting or *pressure* which governs the application of unallocated manpower to the remainder was established as a variable. In this manner the sensitivity of the total model to various allocation policies could be observed. Provision was also made for varying the number of engineers, with the requisite skill and ability for the job to be performed, assigned at the start of the program.

1) *Contract Work.* The model assumes a basic engineering manpower demand such as would be required for the conduct of a single major weapon system program from the start of R&D through the end of full-scale production. This basic effort is augmented by new business acquired through the preparation of proposals.
2) *Planning.* A payoff clearly exists for effort spent in the planning of work to be performed at some future date. The manner finally chosen to quantify this payoff was to establish an overall contract-work-force efficiency parameter which was a function of planning and other factors. These other factors are identified in subsequent paragraphs. The level of the planning effort is functionally related to the level of contract work effort.
3) *Independent Research and Development.* The delay associated with the payoff for IR&D effort is considerably longer than for planning. Its effect is included in overall contract-work-force efficiency. There is another benefit derived from IR&D in the area of new technology for future products. From Fig. 2 it can be seen that IR&D work history is one of the important parameters of proposal worth. It is there that the long-range value of IR&D accrues. Like planning, the level of IR&D effort is a function of the level of contract work effort. Unlike planning, however, demand for IR&D effort is accumulated until engineers can be assigned to perform the work.
4) *Training of Newly Acquired Engineering Personnel.* Unallocated engineering manpower is assigned to training or indoctrinating newly acquired engineering personnel as required. The benefit of this type of indoctrination is reflected as a decrease in the length of the training period.
5) *Preparation of Proposals.* It was determined that the most reasonable way to represent demand for proposal

effort was as a function of funds available to support such effort and as a function of the rate at which contract work load is declining. The effect of this functional relationship is to put additional emphasis on preparing proposals when a declining load trend is perceived.

6) *Training to Become Engineering Leaders.* Opportunities for engineers to be promoted into supervisory positions occur in an expanding organization. Because of its observed effect on voluntary terminations, it has been quantified in this sector. The actual demand is based on an attempt to maintain an ideal control span of from five to seven engineers per leader.

FACTORS AFFECTING OVERALL CONTRACT-WORK-FORCE EFFICIENCY

In addition to the planning and IR&D functions previously described, several other factors were found to have a significant effect on contract-work-force efficiency and were included in the model. The first reflects the effect of the actual departure of the leader span of control from its ideal value. The effect included is one which attaches a greater penalty to having too many leaders rather than too few. The second is the effect of the ratio of contract-work-force size to the level of contract work required. Parkinson's study of the British Admiralty provided ample experimental evidence that work does expand to fill the time available. Another way of stating this is that a decrease in efficiency occurs roughly proportional to the unproductive portion of the work force. Finally, an organization which has a low efficiency due to the factors just discussed, will have a fairly substantial absence problem. This factor has also been quantified. In summary, the model assumes that overall contract-work-force efficiency is a product of these five factors.

FINANCIAL

A financial sector was incorporated into the model for two reasons: 1) to provide a relative financial measure of various allocation policies and decision rules elsewhere in the model, and 2) to permit the exercising of decision rules based on financial considerations. This sector has two major subdivisions: income and expenses.

Income

Income is based, in part, on the amount of contract work, planning, and supervision of engineers completed. Fixed factors representing the negotiated values of overhead, IR&D, and profit are applied to this base to arrive at a figure representing total actual income. The assumption here is that the percentage of engineering labor and overhead to total income tends to a uniform value over a long period of time. The balance is materials, shop labor, and overhead.

Expenses

Expenses are subdivided into four categories: overhead, IR&D, general and administrative (G&A), and direct labor.

1) *Overhead.* Salaries paid to personnel in management positions above the leader level and employee service expenses (including vacation, absence, termination pay, and paid lost time) are part of overhead expense. The main assumptions here are that they are the primary variables and that their variations produce linear changes in total overhead expense.
2) *IR&D.* IR&D expenses are derived directly from the amount of engineering effort expended on IR&D work.
3) *G&A.* The salaries of engineering personnel in the training and acquisition sector of the model and those preparing proposals represent a portion of G&A expense. In this case it is assumed that they are the most significant variables and that their variability accounts for linear changes in total G&A expense.
4) *Direct Labor Salaries.* The salaries paid to engineers and leaders engaged in contract manning, planning, and supervision of contract work accounts for the balance of expenses. Contract manning differs from contract work by the overall contract-work-force efficiency factor.

SIMULATION RESULTS

The model just described was programmed for a high-speed digital computer using the DYNAMO language. In all, almost 30 simulation runs were made after a valid model, involving some 500 variables in all, had been established. Each represented 10 years of simulated real-time operation. In each run, one parameter or set of like parameters was varied to determine the sensitivity of the model to that parameter.

A combined-parameter method of establishing a ranking among the several results of the parameter-sensitivity studies was established. The parameters, not necessarily listed in order of importance, were: 1) cumulative profit, 2) technical competence, 3) engineering head count, and 4) overall work-force efficiency. The run yielding the highest value of each of the four parameters simultaneously was assigned the highest rank, etc. Application of this method of ranking to the simulation runs yields the following conclusions with respect to an optimal business strategy for maximum return:

1) The level at which IR&D effort is maintained is the most important consideration for the long-term success of a business of this nature.
2) The level of planning (i.e., effective job administration, in the broad sense) is second only in importance to IR&D effort.
3) Some means must be found to eliminate the imperceptible beginnings of the degradation of organizational efficiency which follow periods of peak activity.
4) Present policies and decision criteria, as analytically described in this model, are not far from optimum, insofar as they can be tested by this type of representation of a complex and dynamic business.
5) Expedient decisions or policies which consider optimizing a single parameter, such as profit or work-force size, generally have disastrous results if followed over an extended period.
6) Apparently no set of decisions or policies will lead to the perpetuation of a division created only for a single program.

A typical reader reaction to these conclusions may be to decry the need for a simulation at all. However, the reader is cautioned to temper his reaction with the following two thoughts: 1) the fact that simulation can produce results that bear a striking resemblance to reality is encouragement enough for further effort; and 2) management's long-term performance against a predetermined set of policies, when judged as an average rather than by its extremes, is generally acceptable.

THE FUTURE

The present effort, in the writer's opinion, has established the validity and utility of simulation as a tool for management. It has indicated the desirability of increased support of IR&D with corporate funds. It has also shown the positive effects of achieving effective job administration through increased emphasis on planning. Much serious work remains in areas in which simulation can play a major role. These areas include:

1) Prediction of the passing of a period of peak activity so that countermeasures can be employed to avoid a decline in overall organizational efficiency.
2) Determination of the complex effects of customer redirection of program activity.
3) Determination of the effects of tradeoffs of in-house activity versus subcontracts.
4) Assessing the effects of varying the organizational objectives.

Simulation can be a major contributor to the future success of managers and corporations in their struggle for survival and profitability in a competitive market place.

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INDUSTRIAL AND AUTOMATION PRODUCTS—A REVIEW

Gaging systems that inspect 3000 automotive valves per hour, vehicle detectors for computer-controlled traffic systems, and TV film projectors are all products of the Industrial and Automation Products Department. This paper reviews these and other products and services offered by this fast-growing activity.

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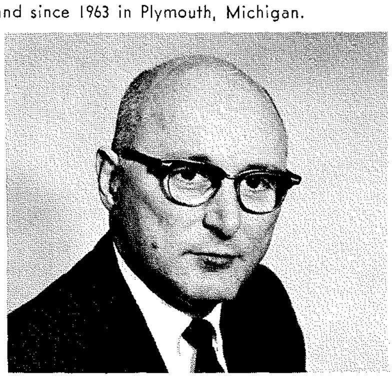
THE Industrial and Automation Products Department, which is part of the New Business Programs organization, is located in Plymouth, Michigan, about 16 miles from metropolitan Detroit. It now has over 250 employees as contrasted with approximately 60 three years ago. Among the products manufactured are customized electronic gaging systems, assembly machines, and parts feeder-orientors for the metalworking industry; vehicle detectors for automotive traffic counting and control, and for railroad-car detection in classifying yards; and tramp metal detectors for the food, chemical, mining, and textile industries. In addition to these products, the Industrial and Automation Products Department does a substantial amount of work for other divisions of RCA, particularly the Broadcast and Communications Division, for which it manufactures the TP-66 television film projector.

Final manuscript received March 30, 1966

N. R. AMBERG received his B.S. degree in Mechanical Engineering in 1938 from the Armour Institute of Technology, Chicago. For 12 years he was with General Motors, where he was employed in various engineering and managerial capacities in the Allison and Electro-Motive Divisions before becoming Master Mechanic. After leaving General Motors he served for 10 years as Works Manager of the Yale and Towne Material Handling Division in Philadelphia. He joined RCA in 1961 as Manager of the Industrial and Automation Department, located at that time in Detroit and since 1963 in Plymouth, Michigan.



AUTOMATIC GAGING SYSTEMS

Production of high-speed automatic gaging systems, the major products designed and manufactured at the Plymouth plant, has almost doubled in the past year. This is understandable in view of the high level of production in the automotive industry and the trend toward long-term warranties, which require the very close tolerances and match-fitting of parts that can be assured only by extremely accurate and reliable systems such as these.

These high-speed automatic gaging machines employ electronic or air-to-electronic displacement transducers which convert the displacement caused by the size of the part into an electric signal that is directly proportional to the measurement being made. This signal is then used to actuate solenoids and gates which classify each part according to tolerance requirements.

A typical electronic gaging system is shown in Fig. 1. This unit inspects five different sizes of automotive valves at a rate of 3000 per hour. The dimensions checked by this system are shown in Fig. 2. Oversize and undersize segregations are made for each dimension; fully acceptable valves discharge at the left end of the machine shown in Fig. 1.

The piston-pin inspection system (Fig. 3) is another example of the extremely accurate inspection systems being built for automotive manufacturers. This unit checks the pins for taper, ovality, and diameter and classifies the parts according to maximum diameter into 33 categories in increments of 33 millionths of an inch. One of the demanding requirements specified for this system was that before customer acceptance, the system had to demonstrate a capability of gaging and classifying piston pins to an accuracy of 5 millionths of an inch with a repeatability of 95%. This was the first time such capability was demonstrated in this type of equipment.

At present RCA electronic gaging systems are used to inspect parts ranging in size from ⅛-inch roller bearings to automotive engine blocks.

An important "first" for Industrial and Automation Products was the recent introduction of completely solid-state gaging circuitry (Fig. 4). This equipment has made it possible to reduce greatly the space required for components, reduce costs, and increase reliability.

VEHICLE DETECTORS

Industrial and Automation Products is recognized as one of the leading manufacturers of vehicle detectors. These units consist of a small detector and a power-supply module connected to an inductive wire loop imbedded in the roadway. Cars passing over the loop produce a signal which is used to actuate counters or traffic-signal lights, or feed data to computers. Several thousand of these units are now in operation. One recent installation, using 320 vehicle detectors, provides all the pertinent data for the only computer-controlled traffic system in the United States.

One of the more recent developments at Industrial and Automation Products was the adaptation of the basic vehicle-detector principle to railroad-car detection. In this application the rails themselves are used as an inductive loop to sense the presence of a car. It is used primarily in classification yards, to prevent a track switch from being thrown before cars have cleared. The first major installation of 48 units was made in June 1965.

TV FILM PROJECTORS

Production of TP-66 television film projectors for the Broadcast & Communications Division continues, and these units are now being shipped at an accelerated pace.

AUTOMATION PROGRAMS

Recently a new activity, Automation Programs, was established in Plymouth to make available to other RCA divisions the unusual electrical, hydraulic, and electro-mechanical engineering skills and production facilities of this department. Typical areas of interest include the automating of such operations as packaging, assembly, and circuit-board soldering. Another function of this activity is to convert specialized prototype equipment developed by other divisions into commercial products.

Although Industrial and Automation Products anticipates substantial growth in all its present product lines, it is believed that Automation Programs will develop rapidly into one of the most significant activities of the department.

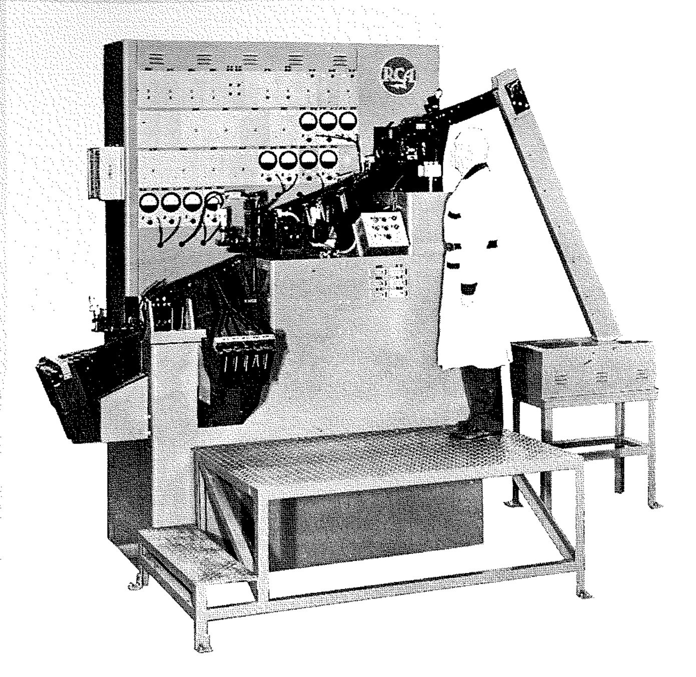


Fig. 1—Automatic electronic gaging system for the inspection of automotive valves. This system feeds, orients, inspects, and segregates more than 3000 valves per hour.

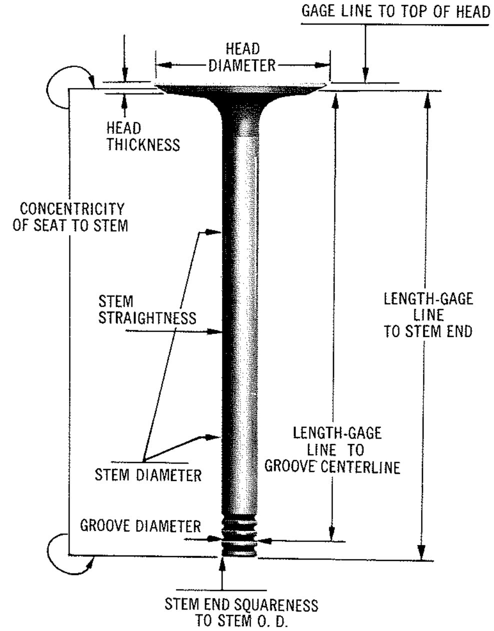


Fig. 2—Valve dimensions measured by automatic gaging system.

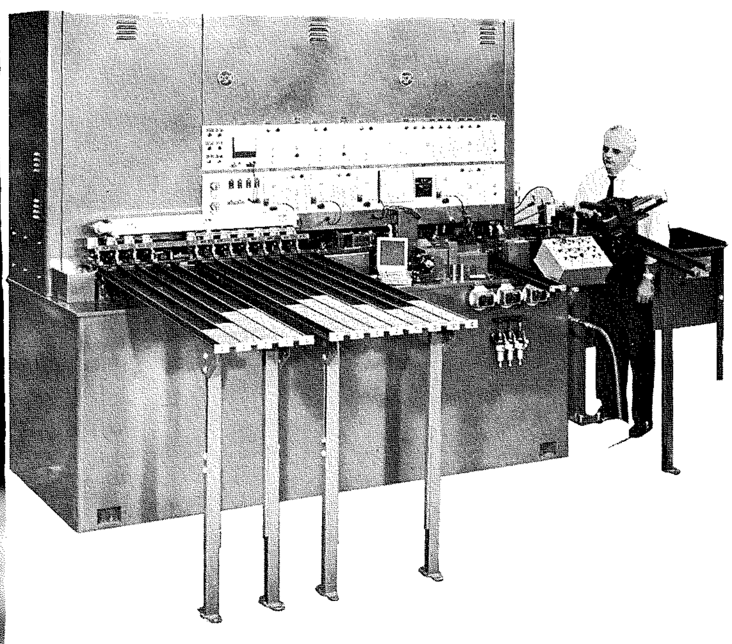


Fig. 3—This automatic gaging system inspects 4000 automotive piston (wrist) pins per hour. Parts, which are fed in a single-line, end-to-end orientation, are inspected for length, out-of-round, taper, and size. The part is rotated during the final inspection.

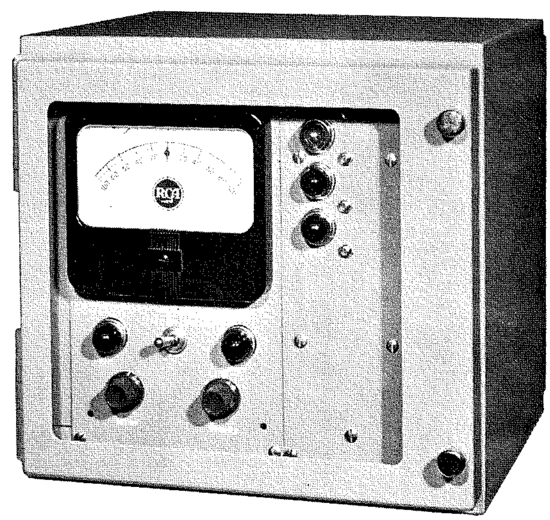


Fig. 4—This completely solid-state device (10½ x 10 x 12 inches) gages and classifies parts as acceptable, oversize, and undersize. Although less than half the size of a similar gage using standard components, this enclosure can also accommodate the circuitry required to gage and classify parts into five acceptable categories as well as oversize and undersize.

MISSILE-ATTITUDE SENSING WITH POLARIZED LASER BEAMS

An optical system has been designed to monitor the attitude of a missile during the early-launch phase. Passive reflective components, mounted on the missile, return a pair of laser beams transmitted from a ground station. The polarization state of the beams is modulated by the reflective elements so that polarization is a function of missile attitude. The returned beams are passed through a polarization-analyzing system at the ground station, and missile attitude is computed from the measured polarization parameters.

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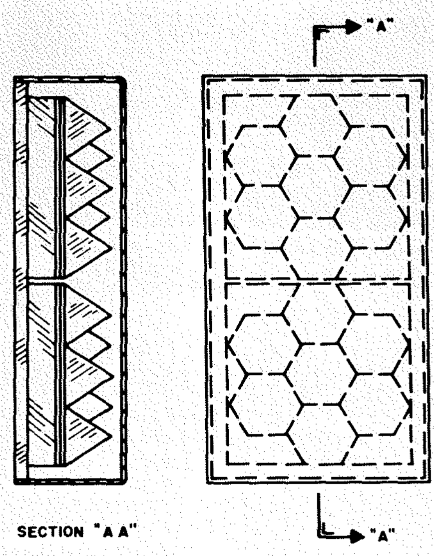
JOHN L. DAILEY received his BS degree in Physics from the University of Portland, Oregon in June 1960. He joined RCA immediately following graduation, and since September 1960 he has been a member of the Advanced Techniques Development Group of the Missile and Surface Radar Division, Moorestown, N.J. Mr. Dailey has been engaged primarily in work on light modulators, crystal optics, and laser applications.

A DESIGN study has been completed for an optical system to monitor the absolute pitch, roll, and yaw of a climbing rocket, from lift-off to 50,000 feet of altitude, and to report this data in real time at the rate of 10 readings per second. The system uses pulsed laser beams, transmitted from a single ground station, to illuminate a retroreflector package on the missile. The package contains optical cube corners faced with polarization modulating components which alter the polarization state from a linearly polarized reference state to some other state which is determined by the attitude of the missile relative to the beam and the station local vertical.

When the reflected light reaches the ground station, it is passed through a polarization analysis system which determines its polarization state and feeds this information to a computer. The computer inserts the polarization parameters into a system of simultaneous equations to find the attitude of the missile relative to the beam and the local vertical. Then, with a set of transforms involving the azimuth and elevation of the beam and survey information of the station relative to the launch pad, it transforms its results to pitch, roll, and yaw in launch-pad coordinates. To these, it adds the time of day at which the measurement was made, as taken from the range clock, and then feeds the final results to the real-time users as well as to a recording system which stores it for postflight analysis.

Final manuscript received March 23, 1966.

Fig. 1—Missile-mounted retroreflector package.



The philosophy on which this system is based may be summarized as follows. The pitch, roll, and yaw to be measured constitute three independent variables, and, since all three are to be measured simultaneously, the sensing system must have three independent variables which can be made functions of the missile's attitude. It will be shown later that the polarization state of light reflected from optical cube corners mounted on the missile can be made a function solely of the three-dimensional rotation of the missile with respect to the incident beam direction. Therefore, the polarization state of a completely polarized laser beam may be used to carry information from the missile to the ground station. However, since the polarization state of a beam of light is completely defined by the azimuth and eccentricity of its polarization ellipse, a beam can carry only two pieces of information in its polarization state. Since three pieces of information are needed, it will be necessary to use two beams of light, separated in wavelength so that they may be isolated from one another by spectral filters.

Two beams of light, with four independent variables in their polarization ellipses, contain a redundancy. This is useful in the present case since, as the eccentricity of an ellipse approaches zero (i.e., when the ellipse is nearly circular), the azimuth becomes difficult to determine accurately; in the limiting case—circularly polarized light—azimuth is not defined. There are, therefore, some polarization states for which azimuth cannot be determined accurately and one for which it cannot be determined at all.

To avoid this problem in part, the system can be set up so that both polarization ellipses have a common azimuth. This reduces the number of independent variables to three, one of which occurs twice. The azimuth of each beam serves as a backup for the azimuth of the other, hence the number of cases in which a reading is unobtainable is minimized. (In the proposed system, this is found to be 1 case in 900.)

Once the variables that are to convey the attitude information are selected, the next step is to find a method of making them functions of the missile attitude. In the method selected, each reflected beam is passed through a missile-borne sheet polarizer, giving it a fixed reference state in missile coordinates, and then passed through a special form of Savart plate, as described later.

THE RETROREFLECTOR PACKAGE

The optical components mounted on the missile are sketched in Fig. 1. The package contains two sets of reflectors, filters, and polarization components. Except for adjustments for the different wavelengths they are designed to pass, the two sets are identical. For reasons to be shown, they are rotated 90° with respect to one another about an axis normal to the face plate.

Fig. 2—Interference pattern of an uncompensated Savart plate.

In the side view of Fig. 1, the first elements (from left to right) are an array of cube corners. These, of course, are selected because they have the property of returning a beam of incident light in the direction from which it came. As shown in the front view of Fig. 1, they have hexagonal pupils for maximum efficiency. An array is used instead of a single large reflector because of size, weight, and cost considerations. Cemented to the cube corners are gelatin filters, such as Wratten filters. Their function is to isolate one set of components from its unwanted laser wavelength. That is, each filter will pass one of the laser wavelengths, but stop the other. To accomplish this, the wavelengths must be widely separated. The lasers selected are ruby, with output at 0.6943 μm, and neodymium, with output at 1.06 μm. The 3000 Å separation of these two is sufficient that two gelatin filters available will, in the two passes in and out, pass 10^4 more of the desired wavelength than of the other. This *channel separation* is adequate for the purpose at hand.

Cemented to the gelatin filters are sheet polarizers of the Polaroid type. When the laser beams leave the transmitter, they pass through a pseudo-depolarizer (of the type, for instance, described by Peters[1]) so that a constant fraction of the beam is transmitted through the missile-borne polarizer, regardless of missile attitude. The beam strikes the cube corners linearly polarized, and its polarization state is altered by the reflections within the cube. On being reflected back through the polarizer, it loses some of its intensity because of this alteration. When the reflected beam emerges from the polarizer, it has about 14% of its incident intensity. It is linearly polarized at +45° to the vertical axis of the missile, and it is directed toward the ground station.

The last component through which the beam passes as it leaves the missile is the polarization modulation plate, a modification of the standard Savart plate. This plate alters the eccentricity of the polarization ellipse, without changing its azimuth, so that it is a first-order function of the beam direction relative to the plate axes.

THE MODIFIED SAVART PLATE

The standard Savart plate, long used in interferometry and polarimetry, consists of two plates. These plates are cut from a uniaxial crystal at 45° to the optic axis, superposed and rotated 90° with respect to one another, so that the projections of the optic axes of the plates upon a common surface are orthogonal to one another. When viewed between crossed polarizers, this double plate presents an interference pattern (Fig. 2) of dark and light lines which are almost straight. (The reason for the unevenness of the image in Fig. 2 is that the sawed surfaces were not polished, but simply immersed in an index matching oil to prevent diffusion. To obtain the wide line separation, the crystal had to be sliced so thin that it was too fragile to survive polishing.)

The defects of the plate are two-fold. First, it is nonlinear. The curvature of the interference lines is quite pronounced at high angles of incidence, and the mathematical expression for the phase shift is a combination of first- and second-order terms creating ambiguities in its solution. Secondly, if the interference lines are to have enough angular separation to be easily resolved, the plate must be impracticably thin.

A detailed mathematical analysis of the Savart plate is too long for inclusion here, but it can be shown that both the nonlinearity and the angular line spacing are minimum for a standard plate when it is cut at 45° from the optic axis. The line separation can be increased by cutting the plates at a shallower angle, but this causes the line curvature to increase sharply.

It can also be shown that when two standard Savart plates are combined by superposing them after rotating one 90° with respect to the other, the interference pattern is perfectly linear; the lines are mathematically straight. Moreover, this linearity holds regardless of the angle from which the plates were cut from the crystal. It is possible, therefore, to make a plate with widely separated lines by cutting at a shallow angle and to generate a purely first-order interference pattern.

To make the modified plate, four plates of equal thickness are cut from a uniaxial crystal at some general angle ϕ to the optic axis, as shown in Fig. 3, and the four plates are superposed, as in Fig. 4, so that the projection of their optic axes on their top surfaces are at angles 0°, 90°, −90°, and 0° with respect to a vertical axis. The plates are cemented together to form a single plate, and a polarizer is cemented to the top surface with its transmission axis at 45°.

The electric vector of light transmitted through the polarizer will be resolved by the first plate into two components, one parallel to the optic axis (the vertical component) and one perpendicular to the optic axis (the horizontal component). These propagate through the plate at different velocities. The velocity of the component parallel

Fig. 3—Orientation of plates in uniaxial crystal before cutting.

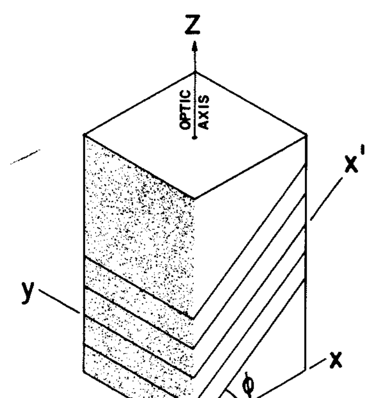
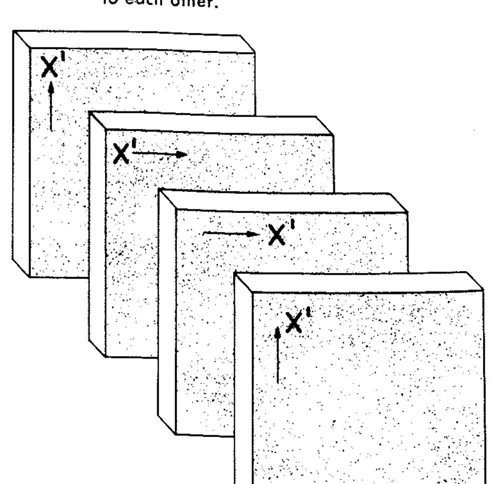


Fig. 4—Orientation of plates relative to each other.



to the optic axis, called an extraordinary ray, propagates at a velocity which varies with direction; the orthogonal component, called an ordinary ray, propagates at constant velocity. At the interface between the first and second plates, and again at the interface between the third and fourth plates, the horizontal and vertical components exchange roles as ordinary and extraordinary rays. As a result, they follow paths through the crystal plates like those shown in Fig. 5. When they emerge from the plate, one component lags behind the other by a distance d, as shown in the figure. This creates a phase shift, δ, between them given by

$$\delta = \frac{2\pi d}{\lambda} \qquad (1)$$

Fig. 5—Ray paths in the compensated linear Savart plate.

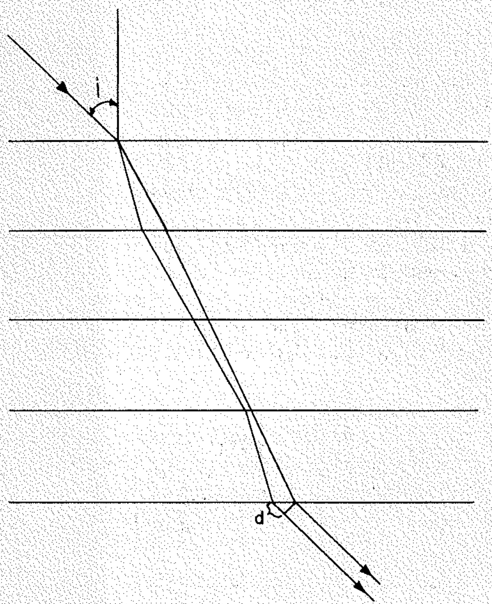
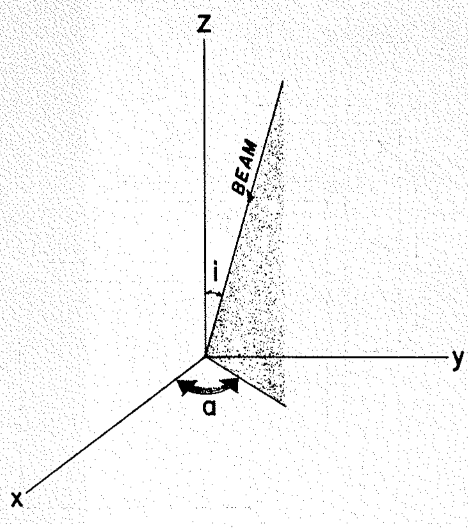


Fig. 6—Relationship of beam direction to missile coordinates.



By geometric ray-tracing techniques, the two optical path lengths may be found and subtracted one from the other, to yield an expression for δ, which is

$$\delta = \frac{4\pi T}{\lambda} \frac{(n_o^2 - n_e^2)\sin\phi\cos\phi}{(n_e^2\cos^2\phi + n_o^2\sin^2\phi)} \sin i \sin a \qquad (2)$$

where T is the thickness of an individual plate (e.g., one fourth the total thickness), λ is the wavelength of the transmitted light, n_o is the ordinary index of refraction of the crystal, n_e is the extraordinary index of refraction, ϕ is the cutting angle, i is the angle of incidence of the beam, and a is the azimuth of the beam with respect to the horizontal axis.

The significance of the angles i and a is shown in Fig. 6, which is simply a set of spherical coordinates without the vector length shown. The x and y axes are parallel to the plate edges and the y is parallel to the missile vertical axis. It can be seen from Fig. 6 that if the beam direction is one axis of a coordinate system, and the projection of the local vertical at the station upon a plane normal to the beam is another, with their mutual normal as the third, the attitude of the missile coordinates is defined in beam coordinates by i and a plus the rotation of the missile about the beam. These, then, are the three parameters that the system intends to measure.

Equation (2) may be abbreviated to

$$\delta_1 = k_1 \sin i \sin a \qquad (3)$$

with the subscripts referring to plate number one in the missile-borne package. The second plate is like the first, but is rotated 90° from it about a normal to its surface. For the second plate, the angle a has become (a + 90°). Making this change in equation (3) gives the phase shift equation of the second plate,

$$\delta_2 = k_2 \sin i \cos a \qquad (4)$$

and since the angles i and a are the same for both plates, equations (3) and (4) form a simultaneous system; if k_1 and k_2 are known, measuring δ_1 and δ_2 will yield i and a. Therefore, it is possible to find two of the three attitude parameters of the plate by measuring the phase-shift angles of the two beams reflected through them.

It is not possible to measure the phase angle between two vectorial components of a beam of light unless the directions of the two components are known. It is necessary to find, in ground coordinates, the directions of the horizontal and vertical components of the polarized beams as they are defined in missile coordinates. To show that this can be done, consider the general equation of the polarization ellipse.

$$\frac{E_x^2}{a_x^2} + \frac{E_y^2}{a_y^2} - \frac{2E_xE_y}{a_xa_y}\cos\delta = \sin^2\delta \qquad (5)$$

in which $E_{x\ or\ y}$ is the instantaneous component of the electric vector in the x or y direction, $a_{x\ or\ y}$ is its maximum amplitude, and δ is the phase angle between the named vectors.

It has been stipulated that, in missile coordinates, the incident vector is at 45° to the x axis, and, therefore, $a_x = a_y$ in the system under consideration. Noting that $a^2 = I$, the intensity, equation (5) may be cast into polar form as

$$\rho^2 (1 - 2\sin\psi\cos\psi\cos\delta) = I\sin^2\delta \qquad (6)$$

This is the equation of an ellipse whose azimuth is at ψ_{max}, the angle at which ρ is a maximum and where

$\frac{d\rho}{d\psi} = 0$. But,

$$\frac{d\rho}{d\psi} = \frac{I\sin\delta\cos\delta\cos 2\psi}{(1-\cos\delta\sin 2\psi)^{3/2}} \qquad (7)$$

This has a zero value when (ignoring the trivial solution $I = 0$): $\delta = 0°$ or 180°, $\delta = 90°$ or 270°, and $\psi = 45°$ or 135°. Inserting these values in turn into equation (5) yields: a straight line of azimuth 45° or 135°, a circle without azimuth, and an ellipse of azimuth 45° or 135°.

A more detailed analysis reveals that when $-90 < \delta < +90$, the azimuth angle is 45°, and when $+90 < \delta < 270°$, the azimuth is 135°. Fig. 7 shows a general polarization ellipse, defined in θ, the azimuth, and β, the angle whose tangent is the ratio of the minor to the major axis and is therefore an eccentricity parameter. It has just been said that, in missile coordinates, θ is a constant over a half cycle of δ. The directions of the horizontal and vertical components in missile coordinates are therefore known when the azimuth is found in ground coordinates, since they are always at ±45° to the azimuthal angle, although an ambiguity exists. It is possible, therefore, to measure δ in the proper coordinate system. In practice, since the azimuth is fixed in missile coordinates, only the eccentricity of the ellipse can vary, and therefore a relationship must exist between phase shift and eccentricity that will make it possible to find one by measuring the other. The azimuth of the ellipse is measured in ground coordinates, not to help in the determination of i and a, but because it is itself the third independent variable in the system.

The Cycle Angle.

It has been pointed out that the system is unable to distinguish between a polar-

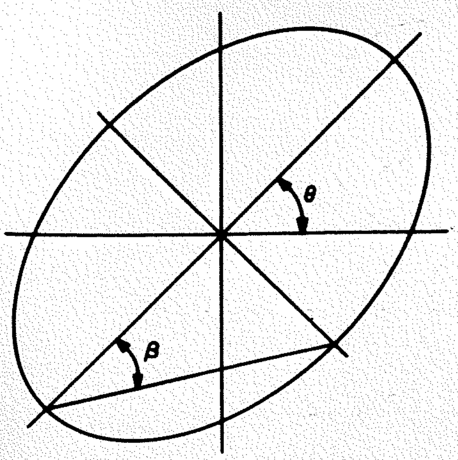


Fig. 7—Polarization ellipse.

ization ellipse whose phase shift is δ and whose azimuth is θ, and one whose phase shift is $(\pi - \delta)$ and whose azimuth is $(\theta + 90°)$, because these produce the same combination of θ and β in Fig. 7. In addition to these two ambiguities in one cycle of δ, further ambiguities arise from the possibility of multiple cycles of δ. Although the polarization analysis system detects a phase shift between 0 and 2π, the actual range of δ is between 0 and $2N\pi$, where N is integral.

To consider this problem and the method of dealing with it, note that the direction of maximum phase variation with direction is given by equation (3) at beam azimuth $a = 90°$, for which

$$\delta = k \sin i \qquad (8)$$

In this direction, δ completes one cycle at an incidence angle

$$i_o = \frac{2\pi}{k} \qquad (9)$$

and every integral multiple thereof. This angle is designated the cycle angle. In an operating system, the choice of cycle angle is quite important for two reasons. First, the anticipated accuracy of the polarization analysis system is about ±1%, and some simple algebra will show that the accuracy of the system as a whole is about 1% of the cycle angle, ignoring the nonlinearity of the sine functions. Since the absolute accuracy of the system is determined by the cycle angle, the cycle angle is determined by the specifications.

Secondly, resolving the ambiguities arising from multiple half cycles within the angular range of the system must be done on an historical basis; i.e., before launch, the measured phase shift is arbitrarily assumed to be in the first cycle. Since the angular separation of cycles is constant, this is permissible. From this point on, a careful track is kept of the number of cycles through which the missile rotates, so that by this counting method the computer knows which of several ambiguous solutions is the correct one. This is possible only if the maximum permissible rotation of the missile between measurements is very much smaller than a cycle angle. The permissible rotation rate varies from missile to missile, but is of the order of magnitude of 10° per second. Since a tenth of a second elapses between measurements, the cycle angle should be at least 10° so that each half cycle may be sampled about five times to permit reliable resolution of ambiguities. However, 10° is an inordinately large cycle angle for a Savart plate and this is one reason the standard plate is unsuitable. (The other reason is that it contains second-order terms in its phase-shift equation.)

The modified four-layer plate can be made to arbitrarily large cycle angles, and 10° cycle angle is a very reasonable figure for such a plate.

Before leaving the subject of the plate and its functions, it should be noted that for a constant specification of thickness, flatness, and surface parallelism, the phase-shift accuracy and uniformity across the face of the plate increases as cycle angle increases. That is, the precision of the plate goes up as the cutting angle goes down, since the birefringence along a plate normal, which determines its performance, decreases as the plate normal approaches the optic axis of the crystal. In the field of crystal optics, it is axiomatic that the lower the birefringence of a material, the more accurate the wave plate which one may cut from it. Cutting the plates at a shallow angle of θ, as shown in Fig. 3, is a way of reducing the effective birefringence of the individual plates, so that a highly accurate plate may be made without resorting to stringent specifications during fabrication.

THE RECEIVER SYSTEM

The Mathematical Basis of Polarization Analysis

There are several systems of parameters used in the various common methods of polarimetry. The one chosen for this system is the Stokes vector, which is mathematically the simplest. The Stokes vector is treated as a four-component tensor, given by

$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} \qquad (10)$$

but it actually contains only three independent variables, since S_0, the intensity, is related to the others by the quadratic relationship.

$$S_0^2 = S_1^2 + S_2^2 + S_3^3 \qquad (11)$$

These components refer to the polarization equation, given previously as equation (5) in this manner

$$\begin{aligned} S_0 &= a_x^2 + a_y^2 \\ S_1 &= a_x^2 - a_y^2 \\ S_2 &= 2a_x a_y \cos\delta \\ S_3 &= 2a_x a_y \sin\delta \end{aligned} \qquad (12)$$

This set of equations may be rewritten

$$\begin{aligned} a_x &= \tfrac{1}{2}\sqrt{S_0 + S_1} \\ a_y &= \tfrac{1}{2}\sqrt{S_0 - S_1} \\ \sin\delta &= \frac{S_3}{\sqrt{S_2^2 + S_3^2}} \\ \cos\delta &= \frac{S_2}{\sqrt{S_2^2 + S_3^2}} \end{aligned} \qquad (13)$$

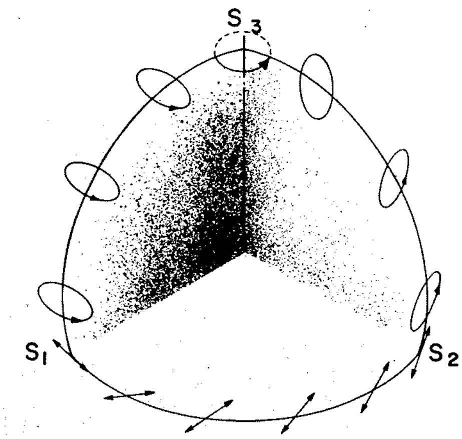


Fig. 8—Quadrant of Poincaré sphere.

To understand the physical significance of the Stokes vector, the Poincare sphere is helpful. A quadrant of this sphere is shown in Fig. 8. Each point on its surface corresponds to a specific polarization state. The three axes of the quadrant designate specific polarization states. S_1 designates linearly polarized light of azimuth 0°; S_2 designates linearly polarized light of azimuth 45°; and S_3 designates right circularly polarized light. Of the sphere in general, it may be said that azimuth varies with longitude, the azimuthal angle being one half the longitude, and eccentricity varies with latitude, being a maximum at the equator and zero at the poles. All right-handed ellipses lie in the upper hemisphere, and all left-handed ellipses lie in the lower hemisphere. Moreover, every point on the surface representing a polarization ellipse is diametrically opposed to the point representing the orthogonal polarization ellipse. Thus, the designations for linearly polarized light of azimuth 90° is $-S_1$ and of azimuth 135° is $-S_2$; left-handed circularly polarized light is designated $-S_3$. This being the case, any polarization ellipse is designated by the radius vector to its point on the sphere, which, in the manner of any vector, is defined in terms of its three orthogonal components, and polarized light may be analyzed by measuring its three Stokes parameters. If S_1, S_2 and S_3 are measured, one may use equation (13) to find a_x, a_y, and δ.

It has been stated previously that the correct value of δ can be obtained only in the coordinate system $a_x = a_y$, for which the azimuth is constant at 45°. Referring again to Fig. 7, it is obvious that if the ellipse rotates in the plane of the figure, but the indicated coordinates remain fixed, then the three parameters in equation (5), a_x, a_y, and δ, vary; from a more practical point of view, the two determining parameters, a_x/a_y, and δ, vary as functions of one another. But if the ellipse is expressed in terms of the parameters shown in Fig. 7, only θ varies, while β, the eccentricity angle, remains fixed. The angles actually available for independent measurement are therefore θ and β. Since θ is fixed in missile coordinates, θ in ground coordinates yields the rotation of the missile about the beam and one of the independent variables is found. What is needed now is δ for each beam, but what is available is β. It was stated previously that there must be a relationship between δ and β that will enable one to be found if the other is known. Before proceeding further, it is necessary to determine that relationship.

From the geometry of the ellipse and that of the Poincare sphere, it can be shown that

$$\begin{aligned} S_0 &= I \text{ (the beam intensity)} \\ S_1 &= I \cos 2\beta \cos 2\theta \\ S_2 &= I \cos 2\beta \cos 2\theta \\ S_3 &= I \sin 2\beta \end{aligned} \tag{14}$$

from which

$$\sin 2\beta = \frac{S_3}{S_0}$$
$$\cos 2\beta = \frac{\sqrt{S_1^2 + S_2^2}}{S_0} \tag{15}$$

From the specification that $a_x = a_y$ in missile coordinates, and from the definition $S_1 = a_x^2 - a_y^2$, it follows that $S_1 = 0$ in missile coordinates, though not necessarily in ground coordinates. Therefore, in missile coordinates, one may add S_1 to the equations at will without invalidating

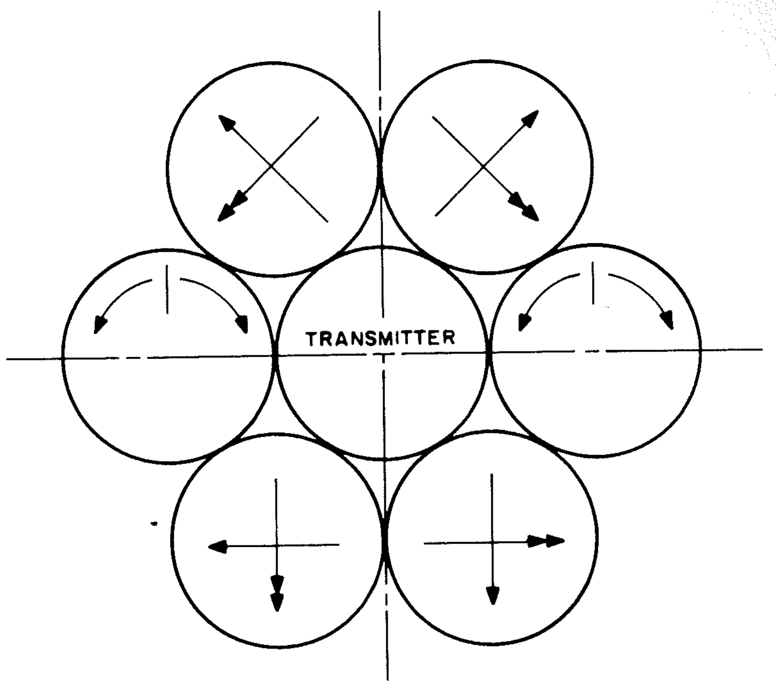


Fig. 9—Six-telescope array of optical transmitter-receiver.

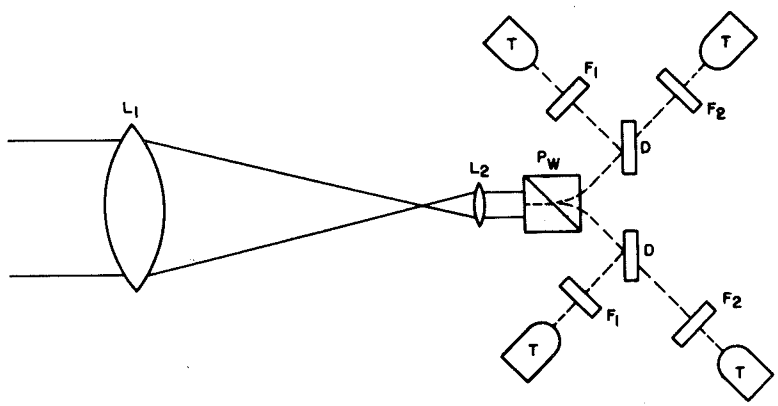
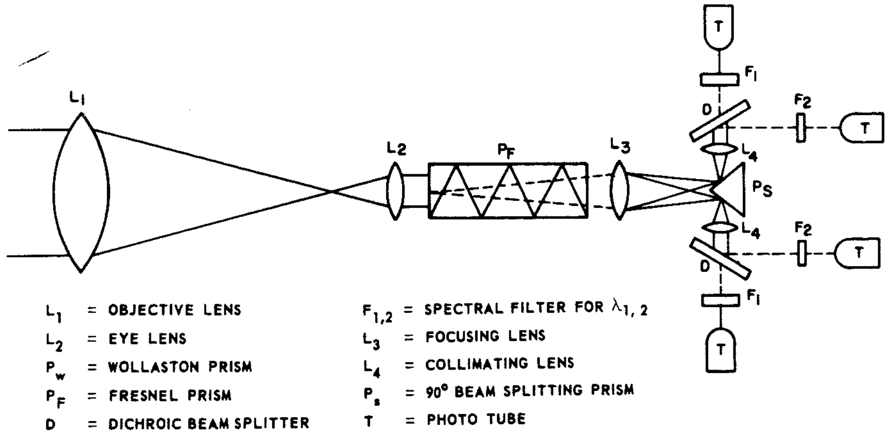


Fig. 10—Layout of optical components for Wollaston prism telescope.

Fig. 11—Layout of optical components for Fresnel prism telescope.



them. The last two equations in group (13) may therefore be written

$$\sin \delta = \frac{S_3}{\sqrt{S_1^2 + S_2^2 + S_3^2}} = \frac{S_3}{S_0}$$
$$\cos \delta = \frac{\sqrt{S_1^2 + S_2^2}}{\sqrt{S_1^2 + S_2^2 + S_3^2}} = \frac{\sqrt{S_1^2 + S_2^2}}{S_0} \quad (16)$$

Comparing (15) and (16) shows that

$$\delta = 2\beta \quad (17)$$

where δ is measured in missile coordinates and β is measured in any coordinate system. Therefore, it is possible to obtain a value for δ, the phase shift in missile coordinates, independently of any rotation of the missile coordinates about the coordinate system in which the analyzer is operating, simply by measuring the Stokes parameters, which, from equation (14) will also yield the necessary azimuth.

The Physical Components

The receiver system consists of an array of six telescopes clustered about the transmitter (Fig. 9). Owing to diffraction effects, the returned beam is spread to a diameter somewhat greater than that of the array, so that each receiver telescope intercepts some of the beam. Inside each telescope is a polarizing beam splitter whose function is to divide the received beam into two orthogonally polarized beams, each of a specific polarization state. In four of the telescopes, there is a Wollaston prism, which divides the beam into linearly polarized light parallel to an axis through the prism plus the component perpendicular to this. The other two prisms are Fresnel multiple prisms, made of crystalline quartz, which split a transmitted beam into right and left circularly polarized components. After passing through these prisms, the separated beams are divided spectrally by dichroic prisms, which separate the two wavelengths and pass them to separate multiplier phototubes. There are four of these phototubes in each telescope. The layout of optical components for the Wollaston prism telescopes is shown in Fig. 10; Fig. 11 shows the arrangement of optical components for the Fresnel prism telescopes.

When light defined by a polarization vector S_0 is transmitted through a polarizing beam-splitting prism with its axes at ζ and $(\zeta + 90°)$, the two emerging beams are described by

$$S_1' = M_{\zeta}\, S \quad \text{and} \quad S_2' = M_{\zeta + 90°}\, S \quad (18)$$

where M is the Mueller matrix of the prism for the indicated beam. The Mueller matrices for Wollaston and Fresnel prisms are available from the literature.[2]

If a Wollaston prism splits a beam into linearly polarized components with azimuths at 0° and 90°, the two outputs may be given as

$$S_1' = \tfrac{1}{2}(S_0 + S_1) \quad \text{and} \quad S_2' = \tfrac{1}{2}(S_0 - S_1) \quad (19)$$

If the azimuths are at 45° and 135°, the outputs are

$$S_3' = \tfrac{1}{2}(S_0 + S_2) \quad \text{and} \quad S_4' = \tfrac{1}{2}(S_0 - S_2) \quad (20)$$

The outputs in the case of the Fresnel prism telescopes are

$$S_5' = \tfrac{1}{2}(S_0 + S_3) \quad \text{and} \quad S_6' = \tfrac{1}{2}(S_0 - S_3) \quad (21)$$

Simply by taking the differences of these equations, S_1, S_2, and S_3 may be obtained. By adding them, S_0 is obtained. With these measured values, i, a and δ, the missile rotation parameters may be computed.

This description of the computation of the polarization components is rather simplified from the actual design system. A much longer derivation would show that the components that are actually wanted are S_1, S_2, S_3 and U, where U is the unpolarized light at the laser wavelengths collected by the telescopes; thus there are four independent variables. By carefully selecting outputs of the 12 phototubes, one may set up 12 equations in four unknowns, which may be solved independently three times. This method permits the answers to be averaged to reduce error by $\sqrt{3}$; it also provides a measure of the unpolarized background light that has gotten into the system. These three independent readings are obtained with little trouble, since four telescopes would be required as a minimum and the extra two, as Fig. 9 shows, fit into space that would otherwise be left vacant and collect light that would otherwise be lost.

CONCLUSION

The material presented in this paper is the result of a design study aimed specifically at the development of a system for monitoring the attitude of a missile during early launch phase. The objective is accomplished by polarization modulation of a beam of light at the missile and polarization analysis of that light at the ground station. The methods employed were dictated in part by the requirement for pulsed monochromatic laser beams as a carrier. Over shorter distances, and when longer integration times are permitted, white incoherent light may be used as a source and a second set of Savart plates used as the analyzer; the plates serve as compensators in the latter case. The use of Savart plates as analyzers at the detection station would eliminate ambiguities in the case of a white light source, since the phase-shift equation contains wavelength as a factor, and would also permit a higher accuracy. When full-scale polarization analysis is required, the best accuracy that can be hoped for, according to a mathematical error analysis, is about 1% of the cycle angle.

The optical approach to measuring missile attitude offers advantages other than accuracy. It does not require active cooperation from the missile, and the missile's power supplies are not involved. Also, virtually all of the system is at the ground station. Since the missile and its components are used but once, there is a decided economic advantage in placing only inexpensive reflectors on the missile.

The use of a beam of light as a carrier provides a large measure of convenience and reliability. At the Cape Kennedy launch site, the available radio spectrum is crowded with telemetering bands; an optical system does not intensify this crowding, does not interfere with other channels in the radio band, and is not affected by them.

Finally, optical interference is no problem. It might be thought that since the flame of the missile produces an intense white light not far from the reflectors, that this would jam the system, or even worse, that the optical tracking system would lock onto the missile flame instead of the reflector package. But the light from the engine flame, sunlight reflected from the missile, the skylight background, etc., are unpolarized, or virtually so. Since the receiver is designed to measure the three polarization parameters plus the unpolarized component, it is only necessary to ground out the electrical signal corresponding to the unpolarized component to eliminate practically all of the background. Thus, the computer is deceived into thinking that the system is watching a pair of Savart plates climbing against a jet black sky.

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SHIPBOARD-INSTALLED ULTRASONIC WAVE-HEIGHT SENSOR

This paper describes a self-contained electronic wave-measuring and recording system developed for the U. S. Navy Oceanographic Office. This system measures the relative displacement of the sea surface from mean sea level with an accuracy of better than 5%, in waves up to 40 feet, while compensating for all significant ship motion. Vertical distance is measured with a pulsed, ultrasonic, echo-ranging subsystem. Ship motion is measured by an accelerometer and vertical gyro subsystem. The signals from these two subsystems are combined with a fixed offset to produce a measure of true wave height.

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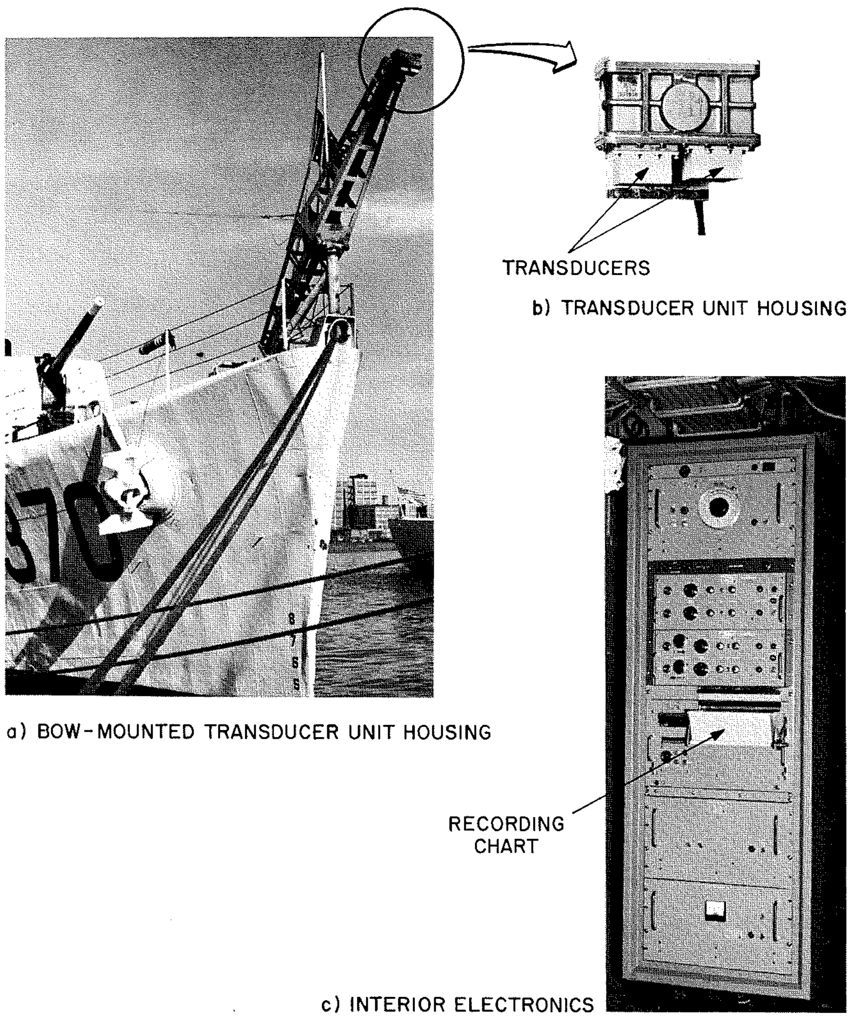


Fig. 1—Wave-height sensor equipment (shipboard installation).

THE major components of the wave-measuring and recording system are shown in Fig. 1. A rugged, watertight, stabilized housing is mounted at the bow of the ship projecting over the surface of the water (Fig. 1a). This housing (Fig. 1b) contains and protects the vertical gyro, accelerometer, and roll/pitch stabilization drives. The ultrasonic transducers are mounted on the underside of the housing. Signals from this unit are fed to an interior electronics unit (Fig. 1c) which contains the integrating, measuring, and summing circuits and the strip-chart recorder. A simplified block diagram of the system is shown in Fig. 2.

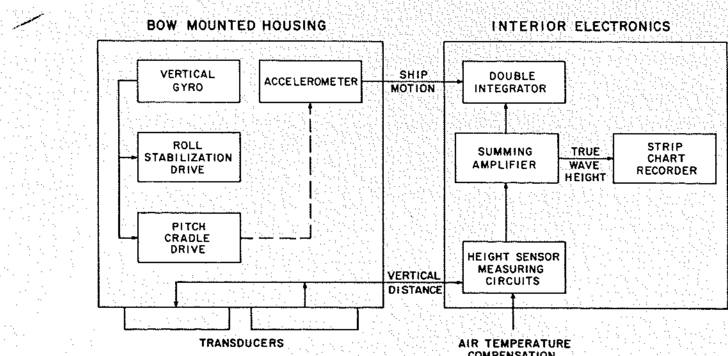
This system is capable of long-term, unattended operation in the normal shipboard environment—i.e., vibration, temperature change, and primary power variations. Data representing the displacement of the sea surface from the mean sea level is recorded on a strip chart at a rate of 10 samples/second.

This new approach to wave-height measurement provides a resolution of 2 inches for wave heights up to 40 feet with an accuracy of better than 5%.

Long-term, stable integration of ship accelerations permits accurate recording of waves having periods of 2 to 25 seconds.

Final manuscript received January 26, 1966.

Fig. 2—Simplified block diagram of wave-height sensor system.



ROBERT B. MARK received his BS degree in Aeronautical Engineering, BS in Electrical Engineering, and MS in Instrumentation from Massachusetts Institute of Technology in 1946, 1954, and 1960, respectively. From 1946 to 1954 he served as an engineer with the U. S. Navy on the development of prototype guided missiles at NADC and acted as supervisor of maintenance, operation, and repair of fire-control systems. He was employed by the MIT Servomechanisms Laboratory from 1955 to 1956 as a design engineer on transistor magnetic circuits for a fire-control computer. Since joining RCA in 1956, he has been engaged in dynamic analysis and simulation of an interceptor fire-control system, synthesis of equations for ECM simulation, analysis of ballistic missile range determination from angle measurements, antisubmarine warfare, ultrasonic height-sensor development, gravitational gradient studies, development of pulse rebalanced inertial measurement equipment, and supervision of analyses, design, and fabrication of a redundant gyro and voting amplifier antenna servo system.

FUNCTIONAL DESCRIPTION

The vertical gyro, which has a low erection rate after spinup, acts as a long-period pendulum and provides a vertical reference accurate to $\frac{1}{8}$ degree in spite of normal motions of the ship's bow and independent of the accuracy of the mounting surface. The housing is roll stabilized and the inertial-quality, temperature-regulated accelerometer is additionally stabilized in pitch. It is mounted on a small servo-driven pitch cradle that is erected by synchro signals received from the vertical gyro.

The DC output of the accelerometer is proportional to the true vertical acceleration (including the effects of gravity). The current is passed through a precision resistor, located in the interior electronics package, which provides a point for voltage pickoff. Gravity effects are compensated out of the voltage signal, and the signal is integrated twice to produce a DC voltage proportional to the vertical displacement of the gyro housing.

The distance between the bow-mounted housing and the surface of the sea is measured by a pulsed, ultrasonic, echo-ranging height sensor previously developed for control applications in hydrofoil craft.

The ship-motion and vertical-distance signals are subtracted and combined with an adjustable bias. The resulting signal is a measure of the instantaneous displacement of the local sea surface from mean sea level.

Variations in the velocity of sound (due to temperature change) are compensated for by means of a single dial setting. This setting can be made completely automatic by the addition of a thermistor temperature-sensing circuit.

DESIGN ANALYSIS

Most of the problems encountered in developing the wave-height sensor were due to such properties of the ocean surface as its local slope, reflectivity, displacement, and velocity. The first two properties primarily affect the design of the echo-ranging part of the wave-height sensor. As shown in Fig. 3, the apparent profile of a wave is distorted by an excessively wide beamwidth. The error due to beamwidth in the presence of sloping wave surfaces is shown quantitatively in Fig. 4. The lower group of curves corresponds to the shortest range within the beamwidth, and the upper group corresponds to the longest range. For pulsed

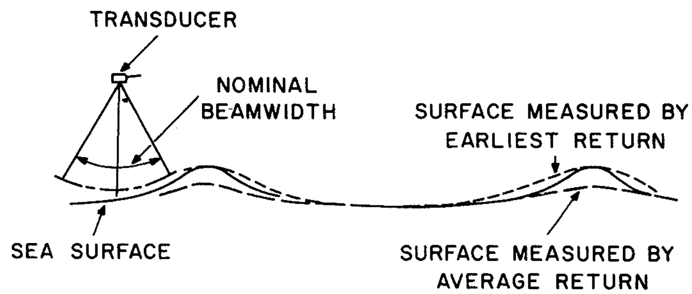


Fig. 3—Effect of excessive beamwidth on height error.

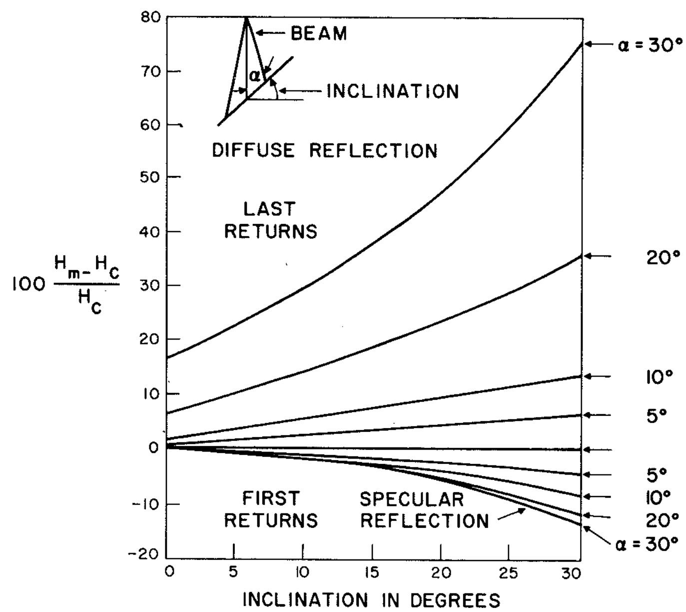


Fig. 4—Error in height due to beamwidth and wave slopes.

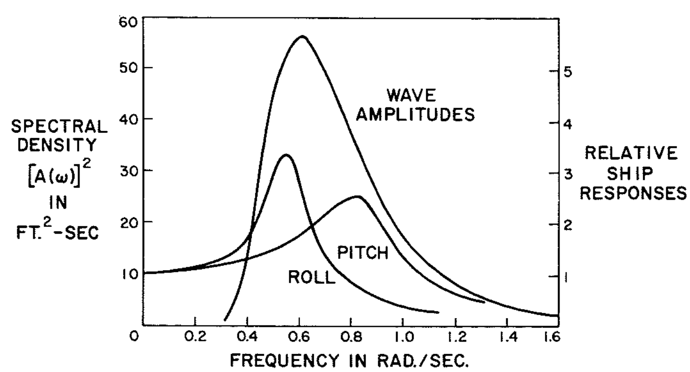


Fig. 5—Neumann spectrum of sea state 6.

operation, the lower group represents the first return. The bottom curve of the lower group shows the return for specular reflection, which is necessarily at perpendicular incidence. It implies operation on sidelobe reflections or, alternatively, loss of signal when the wave slope exceeds half the beamwidth.

It is apparent from Fig. 4 that very narrow beamwidths would minimize the errors due to wave slopes, but a compromise must be made if loss of signal is to be kept within allowable bounds. Such loss occurs when the slope of the entire surface in the area encompassed by the beam exceeds one-half the beamwidth. Fortunately, large slopes are statistically improbable under conditions of light wind and smooth surfaces. Moreover, the presence of wind roughens the surface and diffuses the return reflection, causing an increase in beamwidth without an attendant loss of accuracy.

Statistical measurements of the slopes of waves have been made.[1,2] The distributions are approximately Gaussian with parameters as shown in Table I.

TABLE I. Distribution of Inclinations of Reflecting Facets

Direction	Cross-wind		Upwind	Down-wind
Wind velocity, knots	10	20	10	20
Bias, degrees	0	0	—0.5	—1.0
Standard deviation, degrees	5	7.5	7	10

Since the measurements were made from photographs taken at substantial altitude compared with wavelength, the slopes represent the superposition of ripples and chop on the larger waves. From Table I it is apparent that a slope of ±20°, corresponding to sinusoidal waves of length-to-height ratio of 9:1 or greater, would include all the statistically significant cases. However, a half beamwidth of 20° would produce a range error of about 6%.

In practice it is feasible to operate at a frequency of 38 kHz (Kc) and reduce the beamwidth to ±8° between nulls, a value that can be obtained with commercially available transducers of 5 inches diameter. The RCA hydrofoil, ultrasonic height sensor has undergone many hours of successful testing with such transducers. Sea conditions ranged from glassy calm to white caps with waves up to 5 feet. Relative winds from 0 to 50 knots were encountered. Although receipt of 80% of return pulses is sufficient for proper operation, usually more than 90% and often more than 98% were received.

Selecting the Type of Modulation

Of the types of modulation applicable to distance measurement, two of the simplest are short-pulse and sinusoidally modulated cw. The measures of range are respectively the time interval between transmission and reception and phase shift of the sinusoidal envelope. For a maximum range of 40 feet, the total transit time is about 0.1 second and the highest nonambiguous envelope frequency is about 10 Hz (c/s). A carrier frequency in the neighborhood of 35 to 40 kHz is suitable for either type of modulation, since it is high enough to avoid machinery noise interference and low enough to avoid the effect of the rapidly increasing attenuation in the region of 50 kHz and above.

For a relative horizontal velocity of 2 feet per second, the 38 kHz transmitted frequency is shifted by ±19 Hz for a half beamwidth of 8°. A continuous spectrum is generated by echoes from various points within the beam. The envelope of such a signal approaches 100% modulation at noise frequencies up to 19 Hz and interferes with the necessary signal modulation of 10 Hz. Pulse modulation was chosen for the RCA height sensor to avoid this source of noise and to obviate heavy filtering with attendant low response. Operation on the leading edge of the return pulse eliminates the effects of doppler shift.

Minimizing the Effects of Spray

The effect of spray on the distance measurement is minimized by the action of a slow, automatic, gain-control loop. Spray droplets are generally small compared to the transmitted wavelength and, therefore, tend to scatter the energy incident upon them. If a sheet of spray is sufficiently dense, the true echo may be so reduced in intensity that it will not exceed the automatic gain-control threshold and hence will be lost. To provide for this case, the previous correct range must be held. Since the height sensor measures range by counting clock pulses, the previous count can be held exactly for any desired period of time. If the spray persists, the automatic gain-control loop gain is automatically adjusted (within limits) to pass the true signal. It is unlikely that a persistent wind-borne spray would produce a sharply defined echo at sufficient intensity to exceed that of the true echo because the particles of such a spray are finer and more uniformly distributed than those which occur momentarily in dense sheets near the surface of the water.

Ship Motion Compensation

Ocean waves further affect the design and performance of the wave-height sensor by causing motions of the ship's bow upon which the wave-height sensor is mounted. The principal motions are pitch, roll, and the attendant translations of the housing. The ultrasonic transducers and the input axis of the accelerometer must be maintained approximately vertical, but the accuracy required for the accelerometer is much greater than that required for the transducers. Consequently, the accelerometer is pitch stabilized while the transducers are not. Surge and sway accelerations are eliminated by keeping the accelerometer vertical. Heave acceleration is used to derive the heave displacement height component which is subtracted from the echo-ranging height.

The Neumann spectrum for a fully developed sea state 6 and the rough relative response curves for pitch and roll of a typical oceanographic ship are shown in Fig. 5. To the right of the appropriate natural frequency the ship response is 180° out of phase with the slope of the waves, and to the left it is in phase. Maximum amplitude of pitch response is expected to be less than 8°, and roll response ordinarily will not be of much greater magnitude because the ship is usually hove to and headed into the sea during wave measurements. Since the major portion of the pitch response is in phase with the wave slopes, the incidence of the echo-ranging beam will usually be near perpendicular and signal loss will be minimized. For higher frequencies, corresponding to pitching that is out of phase with the wave slope, the pitch amplitudes and wave slopes are smaller.

To provide the necessary roll-stabilization accuracy at the frequencies near the peak of the spectrum, the servo bandwidth has been set considerably higher than the frequency of peak wave response. The accelerometer pitch-cradle servo bandwith is several times that of the roll servo.

CONCLUSIONS

The shipboard wave-height sensor has been designed for accurate wave measurement at sea. It is believed that this design provides capabilities far exceeding those of existing systems, particularly with respect to measurement of large waves in deep water.

ACKNOWLEDGMENT

Development and construction of the equipment described herein was supported by the U. S. Navy Oceanographic Office under contract number N62306-932.

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A DIRECTORY OF TECHNICAL INFORMATION CENTERS

What They Are, and How to Use Them

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Product Engineering, Research and Engineering
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Much attention has been focused recently upon the problems of retrieving *pertinent* technical information from the mass of available literature. As one solution, government, professional societies, and industry are today devoting extensive funds and manpower to the operation of various types of *technical information centers.*

Appended to the text of this paper is a directory of those centers—some relatively new and novel—that are potentially significant to RCA work. RCA scientists, engineers, and managers should become aware of the scope and services of these centers—for they are, in fact, useful tools in performing research and engineering tasks.

It should *not* be assumed that these information centers, individually or collectively, are the last word in fulfilling technical information needs. They are affected by trade-offs in their operation analogous to those compromises involved in any practical engineering system design. No one source provides everything in the way of documents or data. They vary in the fields they cover, the types of documents or data they handle, the type and quality of services they offer, and the criteria for using those services. RCA engineering and research groups must be the final judge of a center's pertinence to any given technical task—*a judgment possible only through experience in actually using these centers* within the bounds of their individual capabilities.

Much of the future success (or failure) of these centers will depend on *greater* involvement of technical people as users and critics—just as the quality of traditional technical journals and societies has always depended on the participation of readers and members.

INFORMATION CENTERS AND NATIONAL INFORMATION NETWORKS

The current trend involves three types of information centers:

1) *referral services,* which direct an inquirer to the best source for a given type of information;
2) *document repositories,* which acquire, index, store, and distribute technical documents on a national scale (usually technical reports and translations of foreign literature);
3) *data (or information-analysis) centers* which apply professional subject-matter competence to available information in a given field in order to evaluate it, organize it, and supply specific data in response to requests (rather than documents only).

Government and professional society groups plan eventually to build all three types of activities into a *national information network.* Such a network would act as an information system for all fields of science that could coordinate storage, indexing, and retrieval activities in such a way as to:

1) insure availability throughout the U.S. of all significant technical information;
2) avoid duplicate effort in handling information within specific technical fields;
3) allow efficient "switching" among various information sources, especially when information from one discipline may be needed by another (for example, as between electronics and biology).

But such an ideal national network is not yet in existence. At least for the next few years, engineers and scientists will have to maintain familiarity with the different kinds of information coverage and services offered by various activities. In other words, there is as yet no *one* place to which a technical question or a document search can be directed with the expectation that a comprehensive answer can be obtained.

INFORMATION CENTERS—REFERRAL ORIENTED

Since there are so many possible sources of technical information available, services are needed to refer a user to the most useful source of the specific information sought. Such a referral center acts as a kind of "switchboard" or "information desk." On a national scale, there are two major efforts concentrating on this type of service: The *National Referral Center,* and the *Science Information Exchange.*

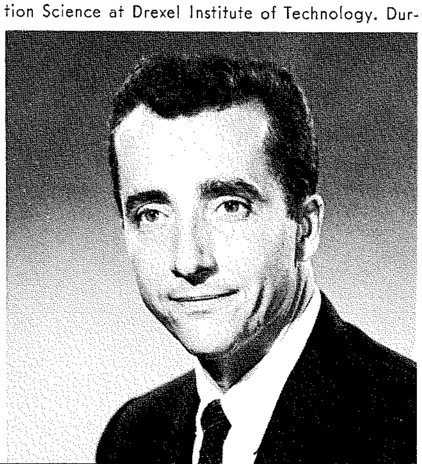
The National Referral Center maintains files of the information resources of libraries, information and data centers, research organizations, etc. When asked "Where can I find information on . . .", the answer will be an identification of one or more sources, along with guidance on how to use them. The requestor then contacts the selected source directly. *RCA Libraries are, of course, the first place where such questions should be asked.* The Referral Center is an extension of a local library's capability to identify sources of information.

The Science Information Exchange maintains records of R&D work *in progress,* results of which are as yet unpublished. It attempts to answer "who is doing what." At present, its coverage concentrates on unclassified government-sponsored R&D in a wide variety of technical fields. For example, the recent question "What research is underway on the electrochemistry of iron prophin complexes," turned up 23 active projects with 8 different sources of support. Answers to such queries are in the form of project summaries that also identify the organization doing the work, and its scope and sponsorship.

Final manuscript received May 6, 1966

*Mr. Jennings is also Associate Editor, RCA ENGINEER. At present, he is conducting a study of RCA technical libraries and related services, under the guidance of a steering committee consisting of Dr. R. Guenther (CSD), W. O. Hadlock (Staff), G. A. Kiessling (Staff), and Dr. J. Kurshan (Labs), and with the cooperation of RCA Librarians.

ED JENNINGS received his BS in Mechanical Engineering from Illinois Institute of Technology in 1950, and is currently pursuing an MS 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, responsible for editorial preparation of technical reports on nuclear-weapon effects. He joined the RCA Astro-Electronics Division early 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. His current responsibilities include study of technical library and information retrieval methodology. Mr. Jennings is a member of the IEEE and of the American Documentation Institute.



Privately-supported, proprietary research of industrial organizations will *not* usually be identified by this service; but the unclassified R&D of government laboratories and industrial contractors working under government funds, as well as university research on government grants, will be included.

In addition to these two formal referral centers, many of the document and data centers (discussed in the next sections) will refer a user to another source if they cannot supply the needed information. This service will receive greater emphasis in the future as information centers become part of the more formalized national network mentioned earlier.

INFORMATION CENTERS—DOCUMENT ORIENTED

The most familiar type of information center acquires and stores documents (mostly technical reports) that are not published in the "open literature" such as periodicals or books. It indexes them, and then provides various search services so that a user can identify pertinent documents in its collection.

This type of center began after World War II when German and Japanese technical documents were brought to this country, and a method was needed to rapidly disseminate them to certain technical activities here. The concept received further emphasis in the early 1950's when the tremendous growth of the technical-report literature in the military-systems and atomic-energy fields (often classified) created major storage and retrieval problems. Yet, at the same time, technical reports had become a vital information source, simply because they were the primary medium by which government-funded R&D was reported—often the *only* medium. This dilemma produced several information centers, of which the *AEC Technical Information Service* and the *Defense Documentation Center* (originally called ASTIA) are familiar examples.

Generally, such document-oriented information centers have the following characteristics:

1) They acquire and store copies of reports generated under specific types of programs (rather than in specific technical fields). For example, DDC handles reports generated as a result of Department of Defense projects, which may cover a very wide range of technical fields.
2) They use relatively sophisticated indexing methods, usually stored and manipulated with digital computers.
3) They publish periodic abstract-index bulletins and distribute them to potential users and libraries.
4) Most offer computer searches of their collection based upon technical problems or questions from a user. The output is a compilation of document titles (and perhaps abstracts) for the requestor to scan. They also supply the documents the user may order based on his scan of the search results.
5) Document centers *do not* technically evaluate either the material entering their collection or the material identified in a search. The responsibility of evaluating significance of the material is totally on the user—similar to the way one uses a traditional library. (In contrast, the data-oriented information center *does* provide such evaluation, as the next section will describe.)

These document centers handle an enormous quantity of material—hundreds of thousands of documents in the case of the larger ones. Most are government-subsidized, and their services are available at little or no charge to industry—especially to groups working on government contracts.

INFORMATION CENTERS—DATA AND ANALYSIS ORIENTED

Recently, the concept of data-analysis centers has proved valuable in specialized fields, and scores of such centers have been established. Typically, they provide specific *answers* to technical questions, not just copies of possibly useful documents. They also prepare compilations of data, and provide critical evaluation of information by subject specialists. These centers have become important in fields where:

1) a great quantity of data on a given subject has been reported in various literature, but is not well evaluated or interrelated;
2) the data was gathered in rather expensive experiments, perhaps difficult to reproduce;
3) the data involved is a type that can be compiled and integrated for use by other scientists, rather than remaining reported piecemeal and unevaluated in perhaps thousands of separate papers and reports.

Most data centers operate as follows:

1) A staff of scientists or engineers experienced in the field involved evaluate the various sources of the data (published or unpublished literature, compilations of experimental results, etc.).
2) Schemes for organizing the data are designed, and specialized indexing methods are developed, often for the retrieval of individual data values.
3) The evaluated and reorganized data is then stored in some machine-readable form, and often periodically published in a new media such as specialized handbooks or data sheets.
4) The services of the center often include technical evaluation of the questions of a user by professionals in the field, and the evaluation of the relevance or quality of the data provided as an answer.

The great advantage in dealing with such data centers, from the engineer's or scientist's viewpoint, is that the request will be handled in most cases by *another scientist working in the field involved.*

Additional services of the data center are the preparation of state-of-the-art reports, critical reviews, and bibliographies of evaluated literature. They often can also help direct a user to contacts with on-going activity in the field involved—activity that may *not* yet be published—as a further attack on the vexing problem of learning "who is doing what."

TRANSLATIONS OF FOREIGN LITERATURE

Many information centers are heavily concerned with making available technical information generated in foreign countries. For example, the *Clearinghouse for Federal Scientific and Technical Information* acts as a central source for translations of foreign journal articles and reports, in a cooperative effort with many other activities. (For details, see the description of the *Clearinghouse* in Section 2 of the directory at the end of this article.) Their activities include maintaining records of translations that are in progress in various other locations, and providing guidance on arranging to have special material translated. In addition, many of the information centers listed (both document and data types) handle translations of material of special interest—for example, NASA for aerospace information, AEC for nuclear technology, and many of the data centers where worldwide literature forms an important input.

RELATIONSHIP OF RCA LIBRARIES TO INFORMATION CENTERS

In any search for a fact or "package" of information, a logical initial step (after exhausting one's own desk drawer, office files, and perhaps some associates) is to consult an RCA Technical Library. They have many of the published indexes of the document-oriented information centers for on-the-spot reference and will demonstrate their use. They can advise on differences in coverage and can help decide which document center may be the best to utilize. The professional librarian can help in arranging for formal searches and can supply the forms required by some of the centers. Also, they are usually responsible for ordering any pertinent documents identified.

Actual contact with the data-analysis type of center should usually be made by the scientist or engineer; but even in this instance, the Library may be able to assist in defining the question or in selecting an appropriate center.

Finally, it is particularly valuable for the Librarian to get feedback on how well the centers are serving specific RCA information needs.

CONCLUSION—USING THE INFORMATION CENTERS

The directory of information centers appended to this paper is organized in three sections: 1) referral-oriented centers; 2) document-oriented centers, and 3) data-analysis-oriented centers. The information on each was compiled from several sources (see *Bibliography* and *Acknowledgments*). Fig. 1 is a checklist of important things to remember about using these centers.

The technical information sources of the future will very likely be built around a national network comprised of centers like the ones listed herein, and operated through the coordinated efforts of government, professional societies, industry, and universities. Today, their scope and services are changing and expanding rapidly. *Only by using them* will engineers and scientists be able to *influence their development and improve their future services*—as well as learn how to best apply their present services to RCA work.

ACKNOWLEDGMENTS

Gratefully acknowledged are the contributions made to the preparation of this paper by: Jean M. Steever, Librarian, and Olive Whitehead, Ass't. Librarian, Camden Library; Fern Cloak, Librarian, RCA Labs., Princeton; Veronica Hsu, Librarian, ASD Burlington; and Judith McGowan, Librarian (formerly), CSD, N.Y.

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Fig. 1—Using information centers: A checklist.

....Predict information needs whenever possible (e.g., at the beginning of a new project) and discuss information needs thoroughly with your RCA Technical Library.

....Remember to allow the information center time to answer your requests. Some data centers can answer certain specific questions over the telephone, but most need a few days to several weeks, depending on the complexity of request. It takes about two weeks to get copies of documents from document centers, more if classified material is involved.

....Make search questions as specific as possible to reduce the amount of irrelevant material uncovered. But remember that any literature search (especially from a computer) will return some irrelevant or fringe-value results as a kind of "safety factor."

....Specify the time span of material desired, if pertinent; (e.g., information no older than 2 years, etc.)

....Specify criteria for unwanted material; (e.g., data on a certain topic except that done on ABC project, or by XYZ company, etc.)

....Indicate how much material you will accept in answer to a search; (e.g., not more than 40 abstracts, etc.) If the search initially uncovers more than this, the center can contact you to refine the search.

....Specify whether foreign literature is desired, and if so, whether it must be translated; much foreign literature is available, but not all of it is translated.

....Be willing to feed back to information centers your comments on or criticisms of their services. Keep RCA Librarians informed of this, also.

....Don't expect perfect results from any center on every request. Remember that the scope and quality of their services is changing and improving rapidly. By actively using them, you are helping to shape their future operations.

DIRECTORY

1. INFORMATION CENTERS (Referral Oriented)

These may be contacted directly, but first consult with your RCA Technical Library for initial guidance.

NATIONAL REFERRAL CENTER

Science and Technology Div.
Library of Congress
Washington, D.C. 20540
Tel: 202, 967-8087 (general inquiries)
202, 967-8265 (referral service)

Scope: A national center to advise where technical information may be found. Covers libraries, information centers, indexing services, data banks, and analysis centers.

Services: Gives the identity and capabilities of information sources in response to a statement of information needs. Also publishes comprehensive directories. All services are free. Consult your Technical Library to arrange inquiry, which may be by mail, phone or visit.

SCIENCE INFORMATION EXCHANGE

Smithsonian Institution
Madison National Bank Bldg.,
Suite 300
1730 M Street N.W.
Washington, D.C. 20036
Tel: 144, 381-5511

Scope: Information on unclassified R&D programs in progress or planned. Currently indexes over 100,000 summaries of research plans annually in all basic and applied sciences. Uses computer and professional staff for analysis of input and search requests. Strong on unclassified government-funded work, but also covers some industrial and university R&D.

Services: Supplies summaries of active R&D projects in the subject area named by the requestor. Queries may be broad or quite specific. Also issues catalogs of work going on in broad fields. All SIE services are free to RCA, as a major government R&D contractor. Contact your RCA Technical Library for assistance in defining your question, which can be submitted by mail, phone, or visit.

2. INFORMATION CENTERS (Document Oriented)

RCA Technical Libraries arrange for utilization of these Centers, and should be contacted first in all cases, unless otherwise noted. Addresses are not given for those Centers which should be utilized through RCA Libraries.

CLEARINGHOUSE FOR FEDERAL SCI. & TECH. INFORMATION

Scope: Acquires and indexes many (but not all) of the unclassified technical reports submitted to the government by contractors and those prepared by government agencies. Covers unclassified work of AEC, DoD, NASA, and other agencies. Merges indexes prepared by those agencies into a central computer index, and adds index data on special material. Also is the primary source for translations of foreign literature. Has many working arrangements with major translating activities in the U.S. and abroad. (Formerly Office of Technical Services, Dept. of Commerce.)

Services: Issues following periodic subject indexes: *U.S. Government R&D Reports* (government-originated reports); *Government-Wide Index to Federal R&D Reports* (merging of unclassified DDC, NASA, AEC, and Clearinghouse indexes); and also issues index of *Technical Translations* and selective bibliographies on subjects of current interest. Performs literature searches for a fee. Supplies copies of requested documents at cost. Will answer inquiries directly as to whether a translation exists or is in progress on a foreign report or periodical article. Contact your RCA Technical Library for all services and indexes. Many Clearinghouse reports (which average from 50 cents to $10 in price) will be available to some RCA groups free through NASA or DDC because of their contract arrangements. However, Clearinghouse coverage goes beyond DDC or NASA, particularly with respect to translations.

DEFENSE DOCUMENTATION CENTER (DDC)

Scope: Acquisition and indexing of technical reports from DoD-sponsored projects, both classified and unclassified. Prepares deep indexes and abstracts, computer-maintained. (Formerly called ASTIA)

Services: Issues the *Technical Abstract Bulletin* (*TAB*) which abstracts and indexes of newly received reports. Performs searches on specific subjects on request, resulting in a set of abstracts. Prepares bibliographies in subject areas of current interest. Availability of documents and services from DDC is controlled by a "field of interest register" form that must be submitted to DDC for each government R&D contract that RCA is awarded. These forms specify what classes of DDC documents can be sent to a given RCA requestor. All DDC services are free to those RCA groups qualified as a DoD contractor. Your RCA Technical Library has DDC indexes and is responsible for obtaining all DDC services. For literature searches, contact the Library to fill out the search request form which the Library then sends to DDC. Library also handles all orders for specific reports.

NASA SCIENTIFIC AND TECHNICAL INFORMATION FACILITY

Scope: Acquires and indexes technical literature from NASA or NASA-sponsored activities. Also handles documents on interagency agreement with over 150 organizations in 40 countries, and selectively includes them in the system if they pertain to aerospace work. The indexes and abstracts are stored on computers.

Services: Distributes copies of many current reports directly to NASA contractors, based on a pre-filed interest register, the scope of which depends on the subject matter approved by NASA as significant to the contract cited. Supports two abstract-index bulletins: *Scientific and Technical Aerospace Reports* (*STAR*, issued by the NASA TIF) which primarily covers report literature, and *International Aerospace Abstracts* (*IAA*, issued by the American Institute of Aeronautics and Astronautics) which covers periodical literature. Either may announce foreign literature of significance. NASA publications are available in or through the RCA Technical Library. Library should be contacted to determine best methods for literature searches, since the services of NASA-ARAC (see below) utilize all the NASA facilities and resources described here.

NASA AEROSPACE RESEARCH APPLICATIONS CENTER (ARAC)

Indiana University Foundation
Bloomington
Indiana 47405

Scope: Provides to industry subscribers (RCA is one) technical information of potential industrial value developed in the space program. Acts as an analysis, awareness, and searching service. Uses both subject-matter specialists and computer techniques.

Services: RCA subscribes to ARAC services, which include: retrospective search service, selective dissemination service (SDS), industrial applications service, and marketing information service. Some special services include announcements of available computer programs for solution of engineering problems, *Flash Sheets* for fast reporting of detailed new innovations and discoveries of interest to industry; special *Industrial Applications Reports* for fast announcement of full reports on significant aerospace technical developments. The SDS service is based on an interest profile, against which new documents are matched by ARAC and a selection made of those most pertinent. Abstracts of those matching the interest profile are automatically mailed to users. RCA Libraries receive the various ARAC publications noted above. To arrange a literature search, first contact your RCA Library to assist in constructing the search request. ARAC works by mail, telephone, or personal visit. Several RCA divisions have an ARAC coordinator; he or your RCA Librarian can provide complete information on ARAC services. The ARAC coordinators in RCA are:

ECD: D. H. Walmsley, Somerville.
RCA Labs: J. Kurshan, Princeton.
Home Inst.: C. W. Hoyt, Indianapolis.
BCD: J. E. Young, Camden.
AED: S. H. Fairweather, Princeton.
CSD: T. T. N. Bucher, Camden.
ASD: K. E. Palm, Burlington.
Cent. Eng.: D. I. Troxel, Camden.

AEC TECHNICAL INFORMATION SERVICE

Scope: Acquires and indexes technical documents relating to nuclear weapons, nuclear power, nuclear radiation effects, and various applications to all fields. Documents include classified and unclassified AEC and AEC-contractor reports, published papers, translations, data compilations, etc.

Services: Publishes *Nuclear Science Abstracts*, the primary index to worldwide literature in fields of AEC interest. Work in progress is covered in *Summaries of Physical Research*, (monthly), and *Monthly Proposal Status Reports*. Also publishes a wide variety of special *Technical Progress Reviews* and special bibliographies. Supports comprehensive translation programs of pertinent foreign literature. Operates several data analysis centers. Contact your RCA Technical Library, which has or can obtain the basic AEC index-abstract bulletins, and which can order any AEC documents required.

ENGINEERING INDEX, INC.

Scope: In cooperation with the Engineering Societies Library and the Engineers Joint Council, indexes, annotates selectively, abstracts, and stores technical journals, monographs, selected books, and publications from technical symposia. Concentrates on the literature (other than technical reports) of most engineering fields.

Services: Publishes the *Engineering Index* and special abstract-index bulletins for *Electrical and Electronics*, and *Plastics*. Many new services are under development, including searching and selective dissemination, which will become available through 1966 and 1967. (RCA is investigating the potentials of these new services.) Is also very active in the conceptual planning of a "national engineering information center." Contact your RCA Technical Library, which receives their indexes, and can usually supply copies of documents cited therein.

MIT INDUSTRIAL LIAISON PROGRAM

Scope: Provides to industrial subscribers (RCA is one) reports on MIT research projects, and some consultation and tutorial assistance on research subjects in which MIT is active.

Services: Distributes MIT technical reports to various RCA Libraries, based on subject matter. Provides copies of other MIT publications on request. Also provides an annual *Directory of MIT Research*. Consultation on technical problems and attendance at special MIT tutorial symposia can be arranged. Contact your RCA Technical Library for MIT reports and other publications. Contact G. A. Kiessling, Corporate Staff Product Engineering, 2-8, Camden, PC-5650, to arrange consultation or tutorial visits to MIT.

3. INFORMATION CENTERS (Data-Analysis Oriented)

These centers should generally be contacted directly by the technical group or individual—although your RCA Technical Library may assist in identifying an appropriate center. NOTE: Criteria for use of these centers vary widely—some have fees, some are available free to certain government contractors, and some are free to all. In making initial contact with these centers, check your status as a user.

ATOMIC AND MOLECULAR PROCESSES INFORMATION CENTER

PO Box Y, Oak Ridge National Lab.
USAEC, Oak Ridge, Tenn. 37831
Tel: 615, 483-8611
(Ext. 3-7558)

Sponsor: National Bureau of Standards and USAEC.

Scope: Heavy-particle–heavy-particle interactions; heavy particle interaction with electric and magnetic fields; and particle penetration into matter. Collects published and unpublished data, which is then critically evaluated.

Services: Evaluates data and prepares compilations in form of graphs, tables, and review papers. Provides literature searches within specific categories. Answers inquiries for specific data. Will supply copies of obscure papers. Available to government agencies, industry, research, and educational institutions.

ATOMIC TRANSITION PROBABILITIES DATA CENTER

National Bureau of Standards
Connecticut Avenue and
Van Ness Street, N.W.
Washington, D.C. 20234

Scope: Atomic transition probabilities and cross sections. Evaluates data and disseminates it to researchers in plasma physics and astrophysics. Data are collected on numerical values for specific transitions. Foreign literature includes material in Russian, French, German, and Dutch. A Bibliography on Atomic Transition Probabilities, NBS Monograph 50, 1962 has been published. An Addendum to the bibliography is available upon request to the Center. Has evaluated groups of elements to determine best values of transition probabilities.

Services: Literature searches are made and data supplied from the Center's files without charge. Bibliographies are available on request.

BALLISTIC MISSILE RADIATION ANALYSIS CENTER

University of Michigan
Ann Arbor, Michigan 48104
Tel: 313, 483-0500
(Ext. 307)

Sponsor: DoD Advanced Res. Proj. Agency.

Scope: Theory and technology associated with ballistic missile phenomena that may be useful in the design of defense systems. Evaluate theory and measurements of radiation emanating during launch, midcourse, and re-entry.

Services: Brief answers to technical inquiries. Extensive literature-searching services. Users must be cleared for secret material and have a need-to-know.

BATTELLE-DEFENDER INFORMATION ANALYSIS CENTER

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Tel: 614, 299-3151
(Ext. 2671)

Sponsor: DoD, Advanced Res. Proj. Agency.

Scope: All disciplines involved in R&D on defense against ballistic missiles. Provide a functional information system required to monitor existing and proposed work. Perform analyses and undertake studies of critical system problems.

Services: Prepares state-of-the-art reports, technical summaries, compendia, and annotated accessions lists. Service limited to users specified by the Advanced Research Projects Agency (DoD) and ARPA-approved visitors.

CERAMICS & GRAPHITE INFORMATION CENTER

Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio 45433
Tel: 512, CL 3-7111
(Ext. 3-6123)

Sponsor: DoD, USAF

Scope: Unified source of collated scientific information on ceramics, graphites, and other inorganic nonmetallic refractory materials for structural, nonstructural, electronic, and other applications. Defines deficiencies in available information and recommends effort on pertinent technical programs. Input is from DDC, open literature, foreign technology, and direct contact with the scientific and industrial community.

Services: Reports, summarizing analyzed and evaluated data. Consulting and reference services. Available to users in defense, industry and government.

CRYOGENIC DATA CENTER

Naional Bureau of Standards
325 South Broadway
Boulder, Colo. 80301

Scope: Compiles tables and charts of thermophysical property data based on selected values from the literature for wide ranges of temperature and pressure. Codes the world literature on cryogenics on magnetic tape for automated preparation of bibliographies. Also prepares magnetic tapes of thermodynamic properties of gases, and issues selected entropy Mollier diagrams of cryogenic fluids, as well as technical information sheets, including graphs on thermal conductivity and data on thermal expansion.

Services: Information services are extended to NBS scientific personnel and to the cryogenic industry. Technical inquiries and problems are answered. Consulting services are also available.

DEFENSE ATOMIC SUPPORT AGENCY DATA CENTER

TEMPO, General Electric Company
735 State Street
Santa Barbara, California
Tel: 805, 965-0551
(Ext. 501)

Sponsor: DoD Defense Atomic Support Agency.

Scope: Central reference for effects of nuclear explosions on electromagnetic propagation, on electronic materials, hardened instrumentation, ionospheric instrumentation, etc. Rapid access to data from many sources; announces (through its own publications) projected data collection programs, theoretical investigations, and experiments; frees other agencies from servicing requests for data; and forms a permanent archive of these data.

Services: Brief or detailed answers to technical inquiries. Consulting or advisory services. Experimental data to qualified users. Literature-searching services. Project records and technical reports according to pre-established distribution lists. Services are available to organizations conducting scientific investigations on nuclear weapon effects and their implication for military systems. Users must file clearance in accordance with *DoD Industrial Security Manual*.

DEFENSE METALS INFORMATION CENTER

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Tel: 614, 299-3151

Sponsor: DoD Directorate of Res. and Engrg.

Scope: Data on structural metals and closely related areospace materials (properties, fabrication, and applications). Makes technical evaluation of the accuracy, quality, and significance of information that has already been introduced into the system. Provides technical advisory services to producers and fabricators of defense metals, and to DoD and the military services.

Services: Answers technical questions. Information on current R&D projects and specific data or data compilations upon request. Conducts searches. Prepares state-of-the-art reviews, correlations of information, etc. Services are free to government agencies, their contractors, subcontractors, and suppliers.

ELECTRONIC COMPONENT RELIABILITY CENTER

Battelle Memorial Institute
505 King Ave.
Columbus, Ohio 43201
Tel: 614, 299-3191

Sponsor: Government agencies and industrial companies on contract basis.

Scope: Electronic components: data on failure, deterioration, heat and current effect, durability, and techniques for reliability analysis. Also has research program on reliability analysis techniques, screening procedures, accelerated life testing, statistical test design, and physics of aging of semiconductor devices.

Services: Information services and consultations available on contract fee basis only. Contract services include a *Newsletter,* summary sheets, indexes, and special reports.

ELECTRONIC PROPERTIES INFORMATION CENTER

Hughes Aircraft Company
Centinela & Teale Streets
Culver City, California 90232
Tel: 213, 391-0711
(Ext. 6596)

Sponsor: DoD, USAF Materials Laboratory, Wright-Patterson AFB.

Scope: Experimental data and literature on electronic properties of semiconductors and insulators; also concerned with electroluminescent materials, thermionic emitters, ferroelectrics, ferrites, ferromagnetics, superconductors, metals, ceramics, etc. Selected literature is abstracted and indexed into an automated search system. Extracted data are evaluated and compiled into series of data sheets. Summary and state-of-the-art reports are also issued.

Services: Requests for bibliographies produce abstract, which identify the materials and indicate the experimental data contained in the cited literature. Requests for specific or related data are likewise honored. Provides data sheets. Consulting and reference services. Primarily for DoD agencies and contractors. Data sheets and state-of-the-art summary reports are disseminated at time of publication according to a distribution list; requests to be placed on this list should be directed to the Center.

HUMAN ENGINEERING INFORMATION AND ANALYSIS

Tufts University
Bolles House
Medford, Mass.
Tel: 617, 776-2100
(Ext. 336)

Sponsor: DoD Army Research Office.

Scope: Indexes information on human engineering, including systematic scanning of over 450 journals. Retains copies of pertinent material.

Services: Consulting, reference, and document services. Prepares annotated bibliographies and critical reviews.

INFRARED INFORMATION ANALYSIS CENTER

University of Michigan
Box 618, Willow Run Labs.
Ann Arbor, Mich. 48104
Tel: 313, 483-0500

Sponsor: DoD, Office of Naval Res. (Physics Branch).

Scope: Infrared research and technology, including solid-state physics, radiation physics and optics, infrared spectroscopy, atmospheric phenomena, information processing, military infrared equipment, and industrial and medical infrared.

Services: Consultation and reference services. Publication of annotated bibliographies, state-of-the-art reports, the *Proc. of the Infrared Information Symposia,* and a classified handbook on military infrared technology. Sponsors symposia.

INSTRUMENTATION INFORMATION CENTER

National Bureau of Standards
Connecticut Avenue and
Van Ness Street, N.W.
Washington, D.C. 20234

Scope: Measuring instruments, controls, and data handling devices.

Services: Information and advice on instrumentation is provided to the public without charge, within limits imposed by priority demands. Consultations and literature searches are provided to the NBS staff and to other Government agencies and their contractors on a contract or no-cost basis. The reference file is open for search purposes. Prepares state-of-the-art reviews, technical reports, and bibliographies.

INSTITUTE FOR TELECOMMUNICATION SCIENCES & AERONOMY

Environmental Science Services Administration
South Broadway
Boulder, Colo. 80301

Scope: Central repository for data and reports, on ionospheric radio wave propagation. Conducts basic research on the propagation of radio waves as affected by the ionosphere and on the nature of the media through which radio waves are transmitted. Prepares predictions of radio wave propagation and forecasts of geomagnetic activity.

Services: Consulting service for government, industrial, and scientific agencies on a contract or no-cost basis. A warning service of disturbances to radio signals is provided. *Ionospheric Predictions* (monthly bulletin) provides information necessary for calculating the best frequencies for radio communication between any two points in the world at any time during a given month.

ISOTOPES INFORMATION CENTER

PO Box X, Oak Ridge National Lab.
USAEC, Oak Ridge, Tenn. 37831
Tel: 615, 483-7611
(Ext. 3-1742)

Sponsor: USAEC

Scope: Isotope production, applications, and safety.

Services: Answers inquiries for technical data; prepares bibliographies and brochures. Publishes quarterly technical progress review, *Isotopes and Radiation in Technology* and other irregular publications available from Clearinghouse or USAEC sources. Answers direct inquiries for specific information.

MECHANICAL PROPERTIES OF MATERIALS

Belfour Engineering Company
13919 West Bay Shore Drive
Traverse City, Michigan 49684
Tel: 616, 947-4500

Sponsor: DoD

Scope: Compiles, evaluates and organizes data on mechanical properties of aerospace structural materials, with primary emphasis on metals secondary on plastics including test procedures and results, material formulation, processing, and environments.

Services: Provides specific graphical, numerical, or descriptive data. Also provides consulting and reference service. Questions answered to representatives of government agencies and researchers without charge.

NONDESTRUCTIVE TESTING INFORMATION CENTER

U.S. Army Materials Research Agency
Watertown, Massachusetts 02172
Tel: 617, 926-1900
(Ext. 655)

Sponsor: DoD.

Scope: Nondestructive testing (radiography, ultrasonics, electromagnetics, etc.). Uses information from reports, open literature, and other sources in a rapid retrieval system.

Services: Answers technical inquiries. Consulting or advisory services. Prepares analyses or evaluations. provides extensive literature-searching services. Permits on-site use of collection. Disseminates abstracts or indexes in response to specific requests and newsletters according to pre-established distribution lists. Services are free of charge.

PLASTICS TECHNICAL EVALUATION CENTER

Picatinny Arsenal
Dover, New Jersey
Tel: 201, 328-4222

Sponsor: DoD, Army Material Command.

Scope: Data on plastic materials of interest to the DoD. Emphasis on structural applications (particularly weapons systems), electrical and electronic application, packaging and mechanical goods applications.

Services: Distributes evaluated data to DoD activities, their designees, or other organizations with demonstrable defense-supporting interests, upon request. Render technical advice and assistance on plastics to DoD activities upon request. Consulting, reference and document services. For use of government agencies, contractors, and suppliers.

PREVENTION OF DETERIORATION CENTER

National Academy of Sciences
National Research Council
2101 Constitution Ave., N.W.
Washington, D.C. 20418
Tel: 202, 961-1356
(Ext. 356)

Sponsor: National Academy of Sciences

Scope: Effects of natural and induced environmental effects on materials and equipment, and methods of deterioration control and prevention. Collection includes over 70,000 documents and screening data on 15,000 candidate fungicides. Coverage includes thermal, mechanical and space environments, as well as natural earth-associated environments.

Services: Consultation, answers to specific questions, bibliographies, and special state-of-the-art reports. Loans documents and permits onsite use of collections. Publishes monthly *Environmental Effects on Materials—Abstracts* in two sections: Sec. A, for natural earth environments; Sec. B, for thermal, mechanical, and space environments. Services available to government and industry.

RADIATION CHEMISTRY DATA CENTER

Radiation Laboratory
University of Notre Dame
Notre Dame, Indiana 46556
Tel: 219, 284-6527

Sponsor: USAEC and NBS.

Scope: Reactions of chemical systems brought about by ionizing radiation, including chemical reaction yields, effects on physical properties, and rates of elementary processes.

Services: Provides critical reviews on selected topics, and plans expanded services in future. Contact this new center direct concerning services available and means for utilizing. Intended to be widely available to scientists in the field.

RADIATION EFFECTS INFORMATION CENTER

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Tel: 614, 299-3151
(Ext. 2923, 2553, or 2354)

Sponsor: DoD, USAF Materials Lab., Wright-Patterson AFB.

Scope: Radiation effects on aerospace materials. Makes available all pertinent engineering data concerned with radiation effects that may be applicable to nuclear-propelled flight vehicles as well as the effects of nuclear weapons-burst radiation and space radiation; defines technical areas in which research should be initiated and calls attention to research duplication.

Services: Provides answers to technical questions, information concerning current R&D projects, and data or data compilations upon request. Performs literature searches. Prepares state-of-the-art reports. Services available to government agencies, contractors, subcontractors, and suppliers; partial service available to others.

RARE EARTH INFORMATION CENTER

Ames Laboratory
Ames, Iowa 50010
Tel: 515, 294-2272

Sponsor: USAEC

Scope: Eventually to serve as international center for information on rare earths. Initial emphasis is on physical metallurgy and solid-state physics of these metals and semimetallic alloys.

Services: Collects literature, including translated foreign papers. Prepares bibliographies. Answers requests for specific information. Plans to publish a newsletter. Services available to government agencies, industry, research labs, and educational institutions. No fee specified as yet.

RESEARCH MATERIALS INFORMATION CENTER

Solid-State Division
Box X, Oak Ridge National Laboratory
Oak Ridge, Tenn. 37831
Tel: 615, 483-8611
(Ext. 3-1287)

Sponsor: USAEC

Scope: Emphasis on high-purity inorganic metals, alloys, semiconductors, refractory or insulating compounds, laser and maser and other optical materials, and magnetic materials. Not included are structural materials when studied as such, fabricated devices, radiation damage, and radioactive isotopes. Data sheets are submitted to the Center by individuals or commercial producers of materials.

Services: Answers telephone inquiries, provides literature searches, and photocopies of documents in files. Any research group is qualified for services. Bulletins and newsletters are free.

SHOCK & VIBRATION INFORMATION CENTER

U.S. Naval Research Laboratory
(Code 4020)
Washington, D.C. 20390
Tel: 172
(Ext. 2220)

Sponsor: DoD

Scope: Environmental factors of shock and vibration.

Services: Consulting, analysis, and reference services. Organizes symposia. Principally for U.S. government agencies and their contractors.

THERMOPHYSICAL PROPERTIES RESEARCH CENTER

Purdue University, Research Park
2595 Yeagor Road
Lafayette, Indiana 47906
Tel: 317, 743-3827

Sponsor: DoD, USAF Materials Lab., Wright-Patterson AFB.

Scope: Critical evaluation of data and new measurements or calculations of thermophysical properties. Makes technical evaluation of the accuracy, quality, and significance of information on thermophysical properties of matter. Performs experimental and theoretical research on thermophysical properties. Maintains a mechanized bibliographic index of all world literature on thermophysical properties of all materials.

Services: Performs literature searches. Provides answers to technical questions, information concerning current R&D projects and data compilations. Prepares state-of-the-art reviews and correlations of information. Disseminates data in publications. Consulting services are performed through arranged conferences. Fee to nonsponsors for searching; depends on extent of effort. Collection is available for use directly by qualified visitors.

TRANSDUCER INFORMATION CENTER

Battelle Memorial Institute
505 King Ave.
Columbus, Ohio 43201
Tel: 614, 299-3191

Sponsor: DoD, USAF

Scope: Transducers for telemetry applications. Includes evaluation of testing programs, environmental effects, new transducer developments, techniques, and systems.

Services: A new center; contact directly to determine status of services. For use by government agencies and contractors, and others in industry.

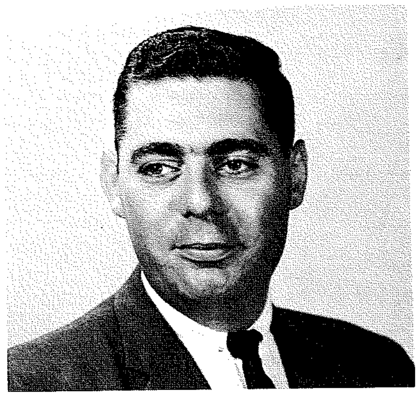
THE ESSA SATELLITE—
A NEW ROLE FOR TIROS

The TIROS Operational Satellite (TOS) System will provide real-time cloud pictures to field stations around the world as well as global cloud-cover and heat-balance data to the National Environmental Satellite Center. This paper reviews the history of the TIROS satellite, discusses the TOS system and its operations, and describes the TOS spacecraft design.

DR. L. KRAWITZ and R. W. HOEDEMAKER
Meteorological Systems Engineering
Astro-Electronics Div., DEP, Princeton, N.J.

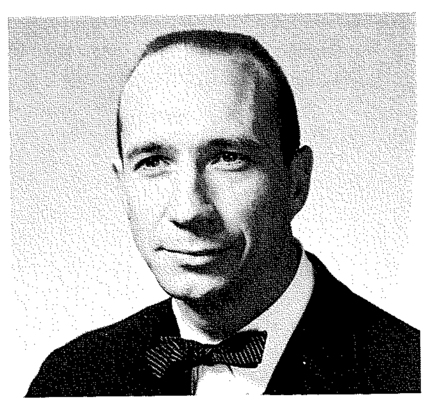
TABLE I—TIROS Orbital Performance Data

TIROS SATELLITE	USEFUL LIFE (DAYS)	TOTAL TV PICTURES	PERFORMANCE
I 4-1-60	89	23,000	• PROVED TV OPERATION IN SPACE FEASIBLE
II 11-23-60	376	36,100	• ICE FLOES • MAGNETIC ATTITUDE CONTROL
III 7-12-61	230	35,000	• FIRST HURRICANE OBSERVATION • ADVANCE STORM WARNING
IV 2-8-62	161	32,600	• INTERNATIONAL USE OF DATA • PROJECT TIREC
V 6-19-62	321	58,200	• BROADER COVERAGE • HURRICANE WATCH
VI 9-18-62	389	66,600	• HURRICANE WATCH • MERCURY MA-8, MA-9
VII 6-19-63	1000*	122,910	PROJECT BRIGHT CLOUD INDIAN OCEAN EXPEDITION
VIII 12-21-63	815*	97,610/4,100	• WORLD-WIDE USE DIRECT-READOUT APT SYSTEM
IX 1-22-65	415*	71,130	• WHEEL CONFIGURATION • NEAR POLAR ORBIT • DAILY GLOBAL COVERAGE
X 7-1-65	257*	64,500	• HURRICANE WATCH • NEAR POLAR ORBIT
XI 2-3-66	40*	17,000	• ESSA-1 FIRST GLOBAL OPERATIONAL SATELLITE
XII	15*	1,000	ESSA-2 FIRST GLOBAL APT OPERATIONAL SATELLITE
TOTAL	4,108	629,750	* STILL OPERATIONAL AS OF 3-15-66



DR. LOWELL KRAWITZ received his BS and Ph.D degrees in Meteorology from Pennsylvania State University in 1954 and 1958, respectively. He received an SM degree in Meteorology from MIT in 1955. From 1954 to 1958 he was engaged in research on the relationship between tropospheric and lower stratospheric circulations and on the development of procedures for forecasting low-level atmospheric turbulence. He was appointed Instructor in Meteorology at Pennsylvania State University in 1956. He joined RCA's Ground Data Processing Group in the Astro-Electronics Div. in 1958 and engaged in studies of the application of earth satellites for meteorology. He conducted experiments in the meteorological interpretation of satellite imagery and in the effects of image-enhancement techniques on these interpretations. He studied problems involved in the operational use of meteorological satellite pictorial data and in the processing and handling of these data for meteorological research. He was lead engineer of an operations analysis study for a military direct-readout weather satellite system. Recently he has served as a consultant to the U.S. Weather Bureau on planning and conceptual system design studies for the World Weather Watch. Dr. Krawitz is a member of Sigma Xi, American Geophysical Union, American Meteorological Society, and American Institute of Aeronautics and Astronautics.

R. W. HOEDEMAKER received his BSEE degree from Princeton University in 1951 and his SM degree in the same field from MIT in 1956. From 1956 to 1958, he worked for Gulton Industries as a project engineer and was responsible for the development of the electronics in a multiple pressure measuring system and two subminiature magnetic tape recorders. Since joining RCA's Astro-Electronics Div., he has worked on computer equipment design for Project ACSI-MATIC. He was lead systems engineer for the design and development of a special-purpose digital computer for satellite use on a classified program. Currently a member of the AED systems engineering group, he has been responsible for the systems engineering and evaluation effort on a number of classified programs. He is now lead systems engineer for the TIROS operational satellite system. Mr. Hoedemaker is a member of the IEEE.



MORE than 6 years ago, the first TIROS weather satellite dramatically opened a new dimension in meteorological observations. For the first time, within one day, man got a view, on a scale and in detail never before achieved, of cloud and weather systems existing over much of the world. Prior to this historical event, weather conditions over approximately 80% of the earth either were totally unobserved, or were inadequately observed for any practical purpose. In this light, the inadequacy of weather forecasts over much of the earth can be readily understood.

FROM TIROS I TO ESSA I

In the years since TIROS I was launched (April 1, 1960), nine additional "experimental" TIROS spacecraft (of which no two were exactly alike) were successfully orbited. During this time, experiments in the use of meteorological observations from satellites and in satellite technology were continued, and invaluable operational data was obtained. The accomplishments of the TIROS satellites are summarized in Table 1. The impact of this data on operational weather analysis and forecasting in the U. S. and certain other nations was so great that the United States decided to establish a National Operational Meteorological Satellite System. The observational capabilities desired for this system, and hence the complexity of the system, are such that several years will be needed to complete the system planning, to develop the required hardware, and to develop adequate data processing techniques. The United States, however, cannot afford to be without an operational meteorological satellite capability during these intervening years. To maintain such a capability, the Environmental Science Services Administration (ESSA), of the Department of Commerce, has initiated an interim operational system — the TIROS Operational Satellite (TOS) System. The TOS system began operations with the launch of ESSA-I on Feb. 1, 1966 and ESSA-II on Feb. 28, 1966. The TOS system will temporarily serve the needs of the U. S. Weather Bureau (an agency of ESSA) and satisfy our internal and international commitments until implementation of the National Operational System is complete.

LIST OF ABBREVIATIONS AND ACRONYMS

Systems and Equipment

APT.........Automatic Picture Taking (camera)
APTS...Automatic Picture Transmission System
AVCS.........Advanced Vidicon Camera System
ESSA-I ..First Environmental Science Services Administration survey satellite orbited
QOMAC........Quarter Orbit Magnetic Attitude Control
TIROS..........Television Infrared Observation Satellite
TOS.................TIROS Operational Satellite

Agencies and Facilities

CDA..........Command and Data Acquisition (station)
DAPF...Data Analysis and Processing Facility
ESSA..........Environmental Science Services Administration
GSFC...........Goddard Space Flight Center (of NASA)
NASA.........National Aeronautics and Space Administration
NESC........National Environmental Satellite Center
NMC..........National Meteorological Center
TEC....................TOS Evaluation Center
TOC..................TOS Operational Center

Final manuscript received March 30, 1966.

The mission of the TOS system has been defined by the Weather Bureau to be:

1) Once-a-day direct readout of local cloud-cover data to weather stations located anywhere in the world.
2) Complete global cloud-cover data daily to the National Environmental Satellite Center's Data Analysis and Processing Facility at Suitland, Maryland. Maximum permissible delay between observation and receipt of data is 4½ hours.
3) Observation of every point on earth with a resolution of at least 5 nautical miles per TV line.
4) Observation of every point on earth at a zenith angle of less than 65°, the zenith angle being formed by a perpendicular to the earth's surface at the observed point and the line of sight from that point to the spacecraft.
5) Global measurements of the earth's heat balance.

It is planned that spacecraft will be launched as often as necessary to maintain the full in-orbit operational capability required by the mission at all times.

THE TIROS OPERATIONAL SATELLITE (TOS) SYSTEM

The TOS mission can be divided into two distinct segments: 1) provide real-time cloud-cover pictures to local field stations scattered throughout the world, and 2) provide global cloud-cover and heat-balance data to the National Environmental Satellite Center (NESC).

The Spacecraft and its Coverage

Early in the system design study, it was decided to design a separate spacecraft for each segment of the mission. This decision permitted complete redundancy of major equipment within each spacecraft and still permitted reliance on past TIROS technology. The ESSA-I spacecraft used conventional TIROS camera subsystems, ESSA-II carried the Automatic Picture Transmission System (APTS), and ESSA-III will use the Advanced Vidicon Camera System (AVCS). Future TOS satellites will use either the APTS camera or the AVCS, both of which were initially developed for the NIMBUS Meteorological Satellite. Both cameras use a 1-inch vidicon with an 11.2-mm square picture format, together with a 5.7-mm focal length Tegea lens. This lens-camera combination yields an 89° side-to-side field of view and a 108° field of view across the diagonal of the picture format. At an altitude of 750 nautical miles, continuous coverage from orbit to orbit at the equator will be obtained. The area covered by each frame with the cameras at 750 nautical miles is shown in Fig. 1. The center line dimensions of the picture are approximately 1700 × 1700 nautical miles. The resolution at the center of the picture is 1.8 nautical miles per TV line and, at the side, 2.8 nautical miles per TV line. The zenith angle at the sides of the frame is approximately 59°.

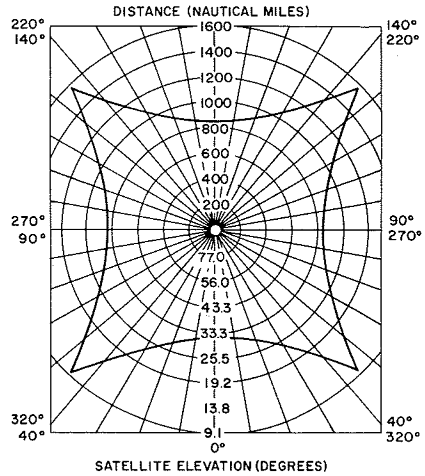


Fig. 1—Field of view of TOS cameras.

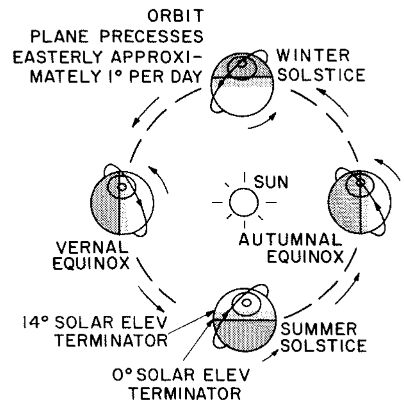


Fig. 2—Geometry of sun-synchronous orbit.

A spacecraft equipped with AVCS also carries a sensing subsystem to detect the solar energy in that region of the spectrum reflected by the earth and its atmosphere, and the infrared energy emitted to space by the earth and the atmosphere.

The Spacecraft Orbits

A near-polar orbit was chosen for TOS to provide global coverage. This orbit was made *sun-synchronous* so that in addition to global coverage, the illumination seen by the vidicon cameras as a function of latitude during each pass of the spacecraft over the illuminated portion of the earth would remain fixed for the lifetime of the spacecraft. A spacecraft in a sun-synchronous orbit will always cross the equator at the same local time.

A true polar orbit would remain inertially fixed in space. As the earth revolves around the sun once each year, the illumination of the earth as viewed by the spacecraft would have large seasonal variations. Because the earth is not a true sphere, for an orbit inclined to the equator at an angle different from 90° (true polar), the orbit nodal points (the intersections of the orbit plane with the earth's equatorial plane) will drift along the equatorial plane. The direction and rate of this drift, or precession, is a function of orbit inclination with respect to the equator and the average orbit altitude. The orbital parameters can be selected so that this nodal precession is approximately 1° eastward each solar day, resulting in the angle with which the sun's rays strike the orbit plane remaining essentially constant throughout the year. Such an orbit is termed *sun-synchronous* and is illustrated in Fig. 2.

The orbit altitude was selected as the lowest altitude at which global coverage could be achieved with a readily available lens within the geometrical constraints imposed by the mission requirements.

The orbit parameters selected for the TOS system are as follows:

Altitude	750 nautical miles
Period	113.5 minutes
Inclination	101.4°
Nodal Regression	0.986° eastward per solar day

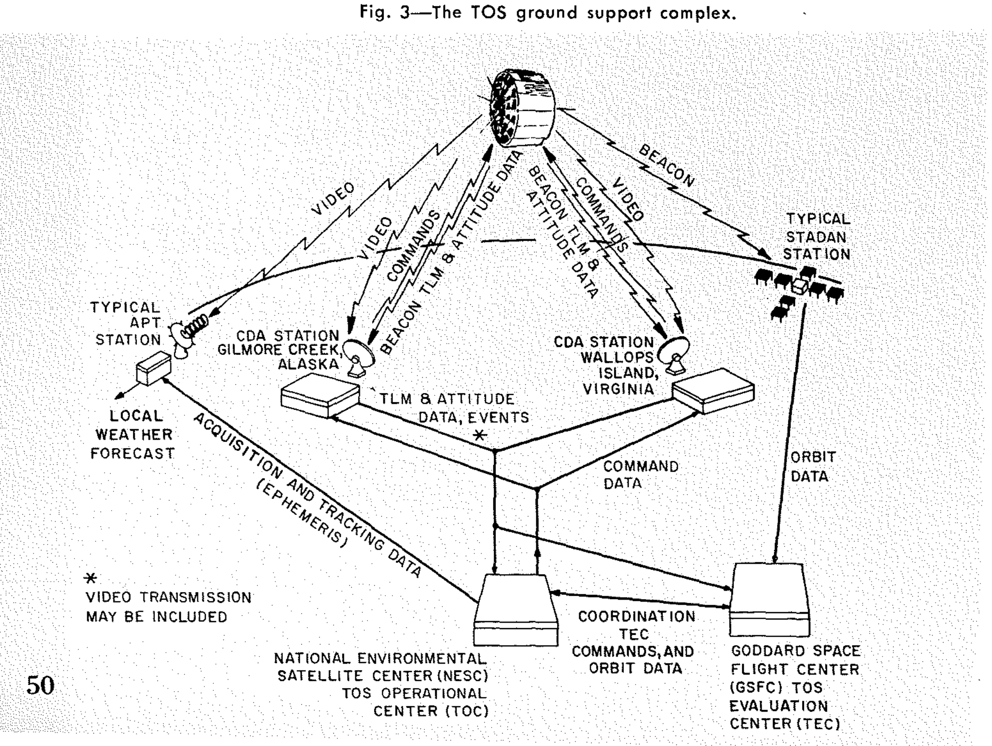
The TOS spacecraft will be launched into orbit planes 45° from the plane containing the earth-sun line, which will provide the optimum solar array output and good ground illumination conditions. It is planned that the APTS-TOS spacecraft will be placed in orbit with the descending node (the nodal point at which the spacecraft moves from the Northern Hemisphere to the Southern Hemisphere) at 9:00 AM local time. The AVCS-TOS spacecraft will be placed in an orbit with the ascending node (satellite moves from south to north) at 3:00 PM local time.

TOS System Ground Complex

All of the mission requirements can be satisfied with the selected orbits and instrumentation. However, as indicated in the mission requirements, the time limit on the usefulness of observed data is such that it must be in the hands of weather analysts within 4½ hours. One or another of the Command and Data Acquisition (CDA) stations located at Gilmore Creek, Alaska, and at Wallops Island, Virginia can view the spacecraft for a portion of every orbit except one. Therefore, the maximum time that *remote* observations will be stored onboard the spacecraft is two orbit periods. The maximum delay in receipt of the data at the Weather Bureau's National Meteorological Center (NMC) is two orbit periods plus the transmission time from the (CDA) station to the Data Analysis and Processing Facility (DAPF) in Suitland, Maryland.

The TOS ground station complex is shown in Fig. 3. The facilities at the two CDA stations are identical and provide the means for automatic and manual tracking of a spacecraft. An 85-foot parabolic antenna receives the video and spacecraft telemetry data; a lower gain antenna is used for transmitting commands to the spacecraft. Telemetry data is transmitted real-time on telephone lines to the TOS Operational Center (TOC), located at the National Environmental Satellite Center (NESC), and to the TOS Evaluation Center (TEC) at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Md.

Fig. 3—The TOS ground support complex.



The stored cloud-cover pictures and heat-balance radiometer data received from the AVCS-TOS spacecraft is recorded on tape at the CDA station and transmitted over telephone lines at one-eighth the recording speed to the DAPF. For the APTS-TOS spacecraft, the ground complex also includes individual field stations equipped with a broad-beam helical antenna, a receiver, and a facsimile recorder. These stations are capable of manually tracking the spacecraft and receiving direct readout pictures of local cloud cover from the APT camera at a low data rate. This data is used for local weather analysis.

The necessary tracking data for computing the spacecraft ephemeris is provided by NASA's Satellite Tracking and Data Acquisition Network to GSFC. The ephemirides provide the necessary orbit data for the tracking of the satellite by the CDA and the APTS field stations.

THE TOS SYSTEM OPERATIONS

Data Flow

The data flow within the TOS system is shown graphically in Fig. 3. For an initial period following the launch of either type of TOS spacecraft, the operations control center for the system is the TOS Evaluation Center (TEC) located at the NASA Goddard Space Flight Center (GSFC). During this post-launch phase, the TEC is responsible for programming the initial attitude orientation of the spacecraft, the spin-rate adjustments, and an evaluation and verification of the operation of the spacecraft subsystem. The TEC generates and transmits to the Command and Data Acquisition (CDA) station whatever camera-system, attitude-control-system, and spin-rate-control programs are necessary to establish, from an engineering standpoint, that a given spacecraft is performing its mission satisfactorily. At that point, the TOS Operations Center (TOC) at the National Environmental Satellite Center (NESC) assumes control of the spacecraft and performs all routine programming functions throughout the operational life of the spacecraft. Technical support is available from the TEC as needed.

The spacecraft control programs are

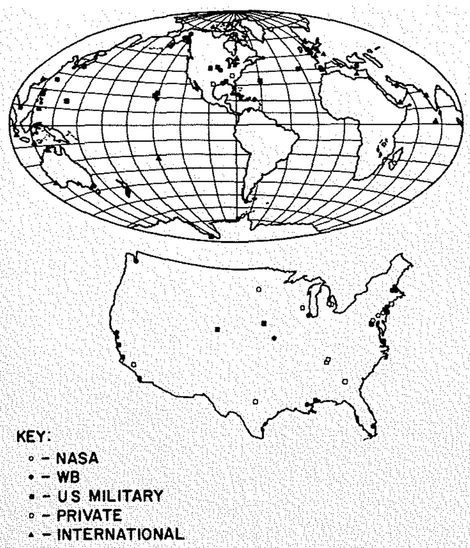


Fig. 4—APTS field stations (as of September 1965).

prepared at the TOC and relayed to the CDA stations well in advance of contact with the satellite. At the CDA station, the programs are punched onto paper tape, relayed back to the control center for verification, and automatically transmitted to the spacecraft at the appropriate, pre-set time. The spacecraft provides verification of the commands received to the CDA and, by ground relay, to the control center as well.

In addition to the spacecraft command data, the control center must provide the CDA stations (and the APTS field stations, too) with spacecraft ephemerides and tracking data. The spacecraft ephemerides are generated at GSFC from orbit data provided by NASA's global Satellite Tracking and Data Acquisition Network. The TOC also is responsible for monitoring the status of the spacecraft power supply and managing the expenditure of the available power, as well as for coordinating the activities of the two CDA stations. There are many passes of the spacecraft each day during which it is contacted by both ground stations.

During each pass over a CDA station, either type of Tos spacecraft will transmit equipment-status telemetry and spacecraft spin-rate and attitude data to the ground. This data, together with an events recording (i.e., a record of the time of occurrence of significant events during the pass) are transmitted to both the TOC and the TEC, so that the performance of all parts of the system can be properly monitored and the spacecraft attitude and spin-rate correction programs can be written.

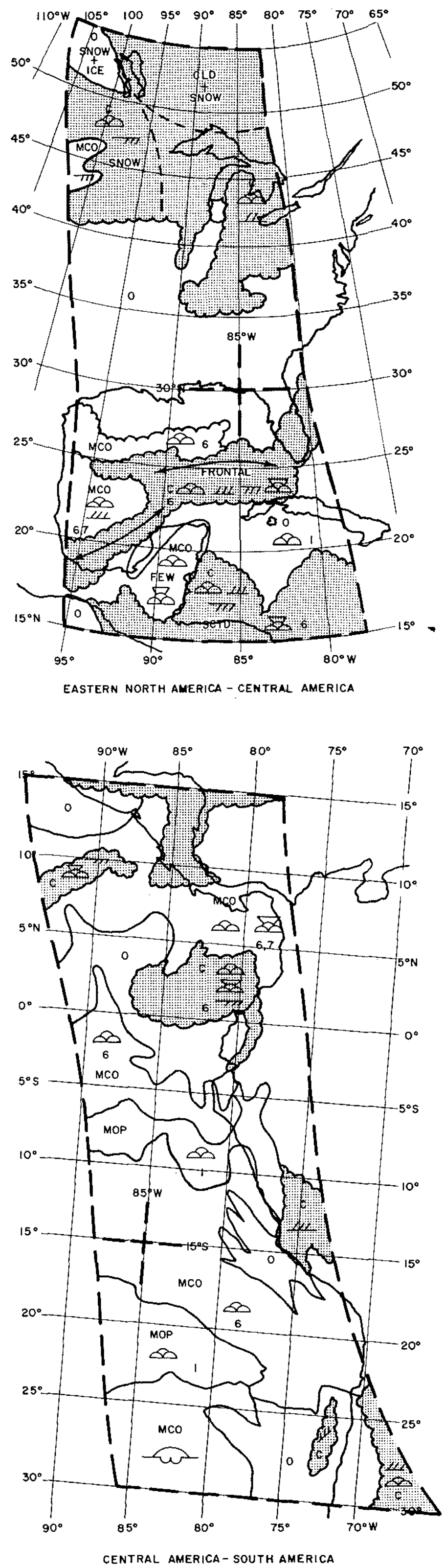
The video data flow is entirely different for the two types of Tos spacecraft. The AVCS-Tos provides either 6 or 12 pictures per revolution around the earth. These pictures are read out to the designated CDA station and recorded on magnetic tape. The pictures are retransmitted at one-eighth the recording speed to the Data Analysis and Processing Facility (DAPF), also located at the NESC. At the DAPF, the video data is processed for meteorological analysis.

The APTS-Tos spacecraft transmits either 4 or 8 consecutive pictures during each revolution, starting at a programmed time. This program repeats itself at fixed intervals (approximately 1 orbital period) until a new program is inserted by a CDA station. The pictures are received by any APTS field station within view of the satellite for the duration of line-of-sight contact — approximately 2 or 3 frames. The APTS field stations manually track the spacecraft, using the ephemeris data received from the TOC. The video data, which is recorded on a facsimile machine, is used strictly for local weather analysis. The locations of the APTS field stations are shown in Fig. 4, a composite plot of all NASA, U.S. Weather Bureau, Air Force, Army, Navy, and private U.S. and foreign APTS users. The APTS data is not relayed to the TOC; however, since both NASA-GSFC and the NESC have APTS ground stations (Fig. 4), spacecraft performance can be fully monitored. Field stations in temperate latitudes contact the spacecraft two or three times during each daylight period.

Meteorological Operations

The meteorological use of the Tos pictures is a direct outgrowth of the experience gained and the procedures established in the TIROS and NIMBUS meteorological satellite programs. The major impact on meteorology of the Tos system, as compared to the experimental TIROS system, is the continuous, reliable global coverage provided. The meteorological information contained in the Tos pictures is not too different from the TIROS and NIMBUS video data. It has already been noted that pictures from orbiting spacecraft have provided meteorologists with striking views of the earth's cloud cover on a scale and in detail never before possible. For example, certain scales of convection and certain unique convection patterns never before seen were revealed. It has been possible, from the physical appearance of the clouds, to identify specific cloud types including fog and thunderstorms. Storm centers, both tropical and extratropical (occurring outside of the tropics) are easily recognized on the pictures, with specific vortex sizes, band-

Fig. 5—Nephanalysis prepared by NESC from TIROS X data.



ing patterns, and overall cloud patterns being correlated with storm intensity in the case of tropical storms, or life-cycle phase, in the case of extra-tropical storms. Small vortices have been noted in the cloud patterns that appear to be correlated with circulation or vorticity centers. It has been possible to deduce some horizontal wind patterns from certain distinctive cloud patterns, such as cumulus cloud *streets*, the streaking of cirrus clouds, and the orientation of cloud bands and mountain wave or *billow* clouds. Vertical wind shear has been deducible, at times, from: 1) the observed tilt of vertically developed clouds as compared to the known direction of circulation around high- and low-pressure areas, 2) the wavelength of mountain waves as revealed by billow clouds, or 3) the shearing of cirrus clouds from the tops of thunderstorms. It has also been possible to identify upper troposheric jet streams from the nature of the cirrus bands frequently associated with them. Also, because the mid-latitude jet normally is oriented east-west, the shadow cast by the high clouds south of the jet stream axis on the low clouds north of the jet stream axis has very frequently permitted accurate location of the jet stream axis. Major cloud bands associated with fronts, squall lines, and the intertropical convergence zone are routinely identified as are areas of significant thunderstorm activity. Some success has been achieved in locating upper level trough and ridge lines, of particular importance in relating the satellite data to numerical weather analyses. The distribution of certain surface features of meteorological significance, such as snow cover and sea ice, has been successfully mapped.

AVCS-TOS Spacecraft. The AVCS video data received at the Data Analysis and Processing Facility (DAPF) from either Command and Data Acquisition (CDA) station is fed into a CDC model 6600 Computer, digitized, and then displayed on 35-mm film as individual gridded frames (i.e., with latitude and longitude lines superimposed), or as a mosaic of the entire swath rectified to any given map projection. The adjustment to a specific map scale is performed photographically. The individual frames can be produced in analog form, again with latitude and longitude lines superimposed, for use in the interpretation of the meteorological information in the mosaic.

The computer-produced mosaic is available in less than 1 hour after the spacecraft readout to the CDA station. An additional 15 minutes is required to produce a print of the mosaic. Approximately 30 minutes is spent in interpreting and analyzing the meteorological information. A symbolic analysis of the clouds, called a *nephanalysis*, is superimposed on top of the digitized picture mosaic. The time required to perform this function varies according to the actual scene content. A typical nephanalysis is shown in Fig. 5.

The combination mosaic and nephanalysis is hand-carried to the National Meteorological Center (NMC) of the U. S. Weather Bureau. The NMC adjusts its analysis based upon conventional observations so as not to conflict with the spacecraft observations. The conventional weather analyses of large segments of the Northern Hemisphere are based on very sparse observations; in the case of the central Pacific Ocean, they are 12- or 24-hour forecasts based on the circulation features previously observed over the Asia continent. Alteration of these analyses to qualitatively reflect the information seen in the spacecraft pictures, significantly improves the quality of the upper-level analyses. In turn, the continuous collaboration of the spacecraft-picture analysts with NMC personnel assists in improving the quality of the nephanalysis. Presently, only the symbolic nephanalysis is transmitted over facsimile circuits to the various Weather Bureau and U. S. Military forecast centrals around the world for application to specialized forecasting problems.

The heat-balance radiometers carried on the AVCS-TOS provide heat balance data along with the video information (although coarser in resolution by at least an order of magnitude) by measuring total reflected energy in the spectral region between 0.4 and 5 microns, and total emitted energy between 5 and 30 microns. Although the operational use of these observations is not yet clear, it is important that consistent climatological data be compiled on the earth's heat balance and the global distribution of net radiation losses and gains. It is possible that, in time, significant variations of heat-balance values from the climatological means will prove to be a valuable input concerning the motion and intensity changes of major circulation features. The extended forecast section of the Weather Bureau will attempt to use this heat balance data at least on an experimental basis. It is doubtful that night-cloud-cover maps useful to the NMC can be constructed from the long-wave sensor data because of the very low resolution of the sensor.

APTS-TOS Spacecraft. The impact of the APTS video data on local forecasting is even greater than that of the AVCS video data. The pictures received at the field stations are of the same quality as those transmitted by the AVCS camera, although the quality of the hard copy from a facsimile machine might be a bit less than is achievable with a kinescope and 35-mm film. It is likely that the APTS output will have the same visual quality as the digitized AVCS outputs.

The APTS products are most useful to the local or tactical forecaster in that he has the first-generation hard-copy picture to use in real time, at a scheduled time each day that remains nearly fixed for the life of the satellite. The meteorological information deducible from the pictures is the same as that delineated for the AVCS video data, and it is significantly more valuable for local analysis than are the symbolic nephanalyses relayed from the NMC.

At present, the APTS data are not meshed into a mosaic, but are viewed separately, although the passes over Suitland, Md. each day provide the NMC with contiguous observations extending from Bermuda to the Pacific Coast, and from Venezuela to Hudson Bay. This data, without formal symbolic analyses, will supplement the analyses and forecasts being prepared for North America. Again, there is no ground transmission of the APTS video data; each user site has its own ground station.

The qualitative nature of the video data is less important to the local user of APTS than to the AVCS data applications. For the most part, the local forecaster is responsible for producing short-term forecasts of small-scale phenomena which are extremely dependent on the interaction of the prevailing circulation with local topographic features. This type of forecasting is not yet amenable to numerical techniques; analyses and prognoses are still prepared subjectively. The TV observations of APTS-TOS provide local forecasters with an excellent immediate presentation of the occurrence and distribution of significant "weather" occurring in his region of interest, rather than a set of numbers from which he must deduce local weather that can vary considerably within distances much smaller than the usual distance between surface weather stations. By recognition of local topographic features, such as rivers, lakes, or coast lines on the pictures, he can locate with fair precision the meteorological features of interest to him without employing elaborate rectification techniques. The Weather Bureau has, however, provided each APTS field station with a fairly simple graphical procedure for placing latitude and longitude lines on the APTS pictures if they so desire. There are instances when the cloud cover is so extensive over a given

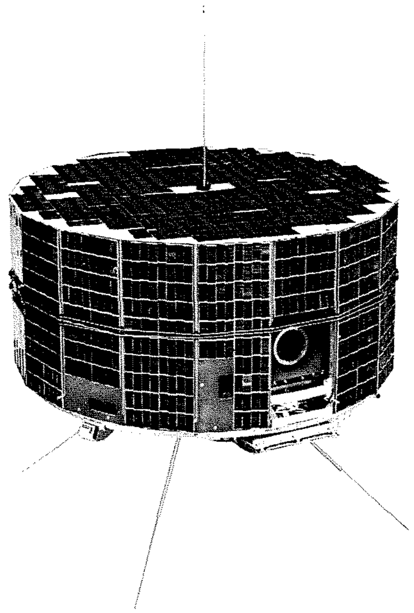


Fig. 6—A TIROS spacecraft.

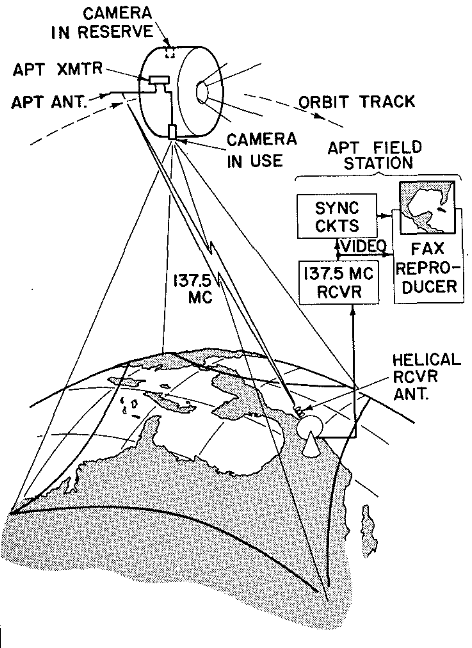


Fig. 7—Orientation of TOS cameras.

region that all local topographic features become obscured and graphical rectification of the pictures is necessary.

Spacecraft Replacement

At the time a spacecraft is declared unable to perform its mission, because of catastrophic failure or gradual deterioration in performance, control of the spacecraft is returned to the Tos Evaluation Center for engineering test and experimentation. A new spacecraft is launched and the procedure described previously is followed so that full mission capability is maintained as continuously as possible. If a catastrophic failure occurs, short periods with less than full mission capability will occur until a spacecraft can be launched, oriented, checked for technical performance, and declared operational. The present spacecraft replacement philosophy does not call for maintenance of in-orbit redundant spacecraft, which would be one way to assure that absolutely no gaps in mission performance are experienced.

SPACECRAFT DESIGNS

The Tos spacecraft have power-supply systems and structures very similar to previous Tiros spacecraft and hence, are similar in appearance (Fig. 6). The satellites are powered by a solar-cell array and nickel-cadmium storage batteries. The solar cells cover the top and sides of the spacecraft *hat*. Maximum power output from the array is achieved when the angle of solar illumination on the top and side of the spacecraft is approximately 45°. The spacecraft is designed to operate with its spin axis, which is perpendicular to the plane of the baseplate, perpendicular to the orbit plane. The components are mounted on a baseplate and covered with the hat, which supports the solar array. The result is a polyhedron which approximates a right circular cylinder 42 inches in diameter and 22.5 inches high. On both spacecraft, the major subsystems are duplicated and may be connected in any desired combination to produce an operating system with maximum reliability.

APTS-TOS Spacecraft

The APTS-Tos spacecraft carries two Automatic Picture Taking (APT) cameras, one of which is redundant. The video signal is presented as an amplitude-modulated 2.4-kHz subcarrier to one of two 5-watt FM transmitters. The subcarrier deviates the 137.5-MHz transmitter carrier by 9 kHz. The demodulated signal received on the ground consists of 5 seconds of 300-cycle start tone and 3 seconds of phasing pulses with a repetition rate of 4 per second, followed by the 200-second readout of the picture. The picture readout consists of 800 TV lines read at the rate of 4 lines per second. At the standard field station, the video is recorded on a facsimile machine.

Each picture readout is separated in time by approximately 352 seconds. This timing produces an overlap of successive pictures along the orbit track on earth of approximately 35%. A total of 8 pictures is normally taken during each revolution, providing coverage for the entire illuminated portion of the orbit track (although the option to take fewer pictures can be chosen). Any receiving station is able to obtain a minimum of 4 complete pictures each day, combining the spacecraft output for successive passes. Stations at higher latitudes will be able to receive more than 4 pictures.

Ideally, at the time a picture is taken, the camera should be pointed toward the center of the earth. The cameras are mounted in the spacecraft perpendicular to the spin axis, as shown in Fig. 7. As the spacecraft spins at a rate of 10.9 r/min, the camera will alternately view the earth and outer space once each 5.5 seconds. The timing for the picture to

Fig. 8—Geometry of horizon-crossing indicator.

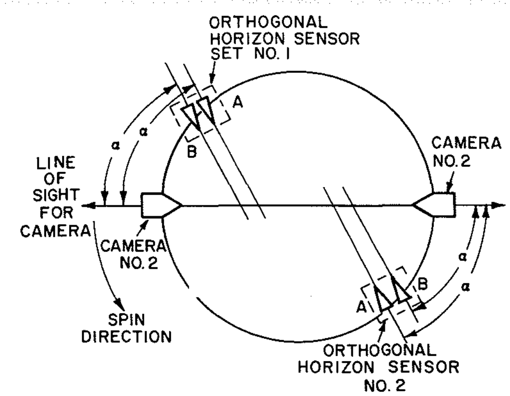


Fig. 9—TOS attitude control and spin-rate control components.

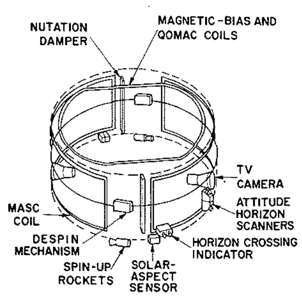
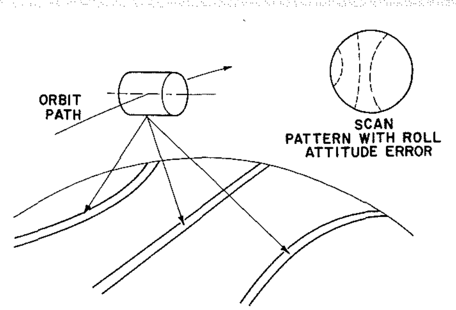


Fig. 10—Geometry of attitude horizon sensor and horizon-crossing indicator.



be taken when the camera is looking straight down is obtained with a horizon-crossing indicator mounted with its optical axes perpendicular to the spin axis, and radially located to view the earth's horizon at the time the camera optical axis is coincident with the line between the center of the earth and the satellite. These relationships are shown in Fig. 8. The signal produced by the horizon-crossing indicator triggers the camera shutter. The horizon-crossing indicator is composed of a bolometer with a 1.3° field of view, an amplifier, and threshold circuit. The spectral response of this indicator ranges from 1.8 to 23 microns. The bolometer output is amplified and processed by a threshold circuit to provide an indication of the time of horizon crossing.

As stated previously, the orbit is chosen to precess in synchronism with the earth's motion around the sun. Hence, the spacecraft spin axis, which is fixed in inertial space, must also be precessed at the same rate. In addition, the spacecraft is launched with its spin axis in the plane of the orbit and must be torqued 90° to achieve mission orientation. The spin-axis position is controlled by magnetic torquing, which involves programming proper electrical currents through coils placed on the spacecraft. The magnetic torquing coils lie in a plane perpendicular to the spin axes, as shown in Fig. 9. There are two sets of coils, the magnetic bias coil and the Quarter Orbit Magnetic Attitude Control (QOMAC) coil. The current through the magnetic bias coil generates a magnetic field which establishes the correct magnetic dipole, interacting with the earth's magnetic field, to produce the 1°-per-day spin-axis drift required to keep up with the orbit precession. The QOMAC coil generates the magnetic field which reacts with the earth's magnetic field to produce the initial 90° spin-axis orientation and then provides the fine control for precision positioning of the spacecraft spin axis during the operational life of the satellite.

As the name implies, QOMAC achieves its objective by reversing the current in the coil (the direction of the magnetic dipole) each quarter orbit. The direction of spin-axis motion is controlled by adjusting the phasing of the start of a QOMAC cycle.

The attitude of the spacecraft is measured by two attitude-horizon sensors, each canted 43° out of the orbit plane and mounted on the spacecraft as shown in Fig. 9. As the satellite spins, each horizon sensor views a segment of the earth, as shown in Fig. 10. A time plot of the difference in the earth-scan of the two sensors permits computation of the attitude of the satellite spin axis in inertial space. The spacecraft also carries a digital solar-aspect sensor for measuring the angle between the sun and the spin axis. This is useful during the initial orientation maneuver.

The spacecraft spin rate is also controlled magnetically. Without intervention, the spin rate of the vehicle would gradually decrease because of drag from the circulating electric currents induced in the spacecraft by the earth's magnetic field. Magnetic spin-control coils are mounted so that the plane of the coil is essentially parallel to the spin axis. Current is commutated in the coils every half spin. When current is applied, the spacecraft behaves like the armature of a motor and reacts with the earth's magnetic field, causing the spin rate to increase or decrease. Immediately after injection, the spin rate is approximately 135 r/min and (as on previous TIROS spacecraft) a *yo-yo* despin mechanism is used to reduce the spin rate to a nominal value. From then on, the magnetic spin-control coil is used to control the spin rate precisely. Wobble or nutation of the satellite spin axis, which results in uncertainties in camera-aiming accuracy, is reduced with a mechanical damper and a liquid damper. The combination of the two rapidly reduces spacecraft nutation well below a measurable value.

The command subsystem uses digital commands which are punched into paper tape, read by the ground station equipment, and automatically sent to the spacecraft. Most of the commands are used to select specific units of the redundant equipment; however, one command, a 28-bit data word for the spacecraft programmer, contains information for controlling the camera and the attitude-control-system sequences. Commands are also used to set the current in the magnetic bias coil, actuate the magnetic spin-control coil, and actuate the telemetry commutator.

The AVCS-TOS Spacecraft

The AVCS-TOS spacecraft carries two cameras and two tape recorders. (The AVCS was developed initially with a trimetrogen camera array for use on the NIMBUS spacecraft. However, the cameras aboard TOS are single units.) Either camera can be used with either tape recorder to accomplish the global cloud-surveillance mission. The camera takes a total of 12 pictures during each revolution, with an interval of 260 seconds between each picture. If desired, a rate of 6 pictures per revolution can be chosen. The picture overlap along the orbit track is approximately 50%. Each picture is scanned off the vidicon, recorded on the magnetic tape recorder, and played back when the satellite is in view of the Command and Data Acquisition station. The satellite spin period is set to 6.5 seconds (9.2 r/min) to provide camera vertical scan timing.

The camera output is a composite video signal containing horizontal sync pulses and the cloud-picture information. The video data consists of 833 scanning lines with a maximum video frequency of 60 kHz. The data is transmitted by FM/FM at an RF carrier frequency of 235 MHz. A constant tone is recorded with the video on a separate tape-recorder track and, during playback, is multiplexed with the video for use as a tape recorder wow and flutter correction signal.

The AVCS-TOS spacecraft also carries a heat-balance radiometer subsystem which includes sensors, electronics, and a tape recorder. The sensors are of the thermistor type with a wide field of view and measure heat balance by sensing the solar energy reflected and the radiant energy emitted by the earth and atmosphere. The sensors are read once every 30 seconds. Each reading is averaged over a 6-second period and the result is loaded into the tape recorder. Each measurement contains 12 bits of binary data. The system runs continuously, recording 13,620 bits per orbit. The tape recorder is played back approximately twice per day.

The rest of the subsystems are similar to those of the APTS-TOS spacecraft. The command system decodes a few additional commands which are necessary to control the tape recorder and transmitter. The IR equipment requires commands to turn it *on* and *off* and to request playback. The AVCS-TOS power supply has less battery-storage capacity because the video transmitter is required to operate only during playback.

CONCLUSION

The global observational capability provided by the TOS system has already resulted in measurable improvements in the weather analyses and forecasts of the U. S. Weather Bureau and other users of local readout data. The development of the National Operational Meteorological Satellite System will continue to contribute to the extension of the range and accuracy of weather forecasts to their theoretical limit. The TOS system is an outstanding example of the peaceful use of space technology for the direct benefit of people everywhere on earth. This aspect of the ESSA mission is not a new role for TIROS but only a continuing motivation.

NEW DEVELOPMENTS IN PRECISION CONTROL SYSTEMS

This paper discusses some of the more recent developments in precision control systems. The advantages of various components, such as printed-circuit motors, optical tachometers, and digital phase detectors, are considered, and experimental data is presented indicating the improvements obtainable in system performance by the incorporation of these components in a practical application.

L. P. DAGUE

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Modern electromechanical systems, as typified by wideband instrumentation recorders and the digital computer, have generated increasingly stringent requirements for precision control systems. In the areas of rotating mechanical components, conventional techniques (such as hysteresis synchronous motors, once-around sampling, and multiple interacting loop servo systems) are limited in the bandwidths attainable and in the complexity of the equipment required. This article outlines significant improvements made possible by the use of some of the more recent developments in the control field, i.e., DC direct-drive printed-circuit motors, optical tachometers, and associated electronics.

PRINTED-CIRCUIT MOTOR

The printed-circuit motor is constructed with a flat, disc-shaped, printed-circuit armature (Fig. 1), as opposed to the conventional cylindrical armature winding. This unique construction provides the following advantages:

1) Reduced armature inertia and inductance due to the elimination of iron from the armature.
2) Increased pulse-power-dissipation capabilities as a result of the exposed, uninsulated, printed-circuit conductors which provide more cooling area.
3) The increased number of commutator segments and commutation directly on the printed-circuit armature conductors results in smoother, more efficient operation (cogging disturbances are reduced as is the tendency of the motor to assume preferred armature positions).

This motor possesses improved speed of response, small electrical time constant, high torque-to-inertia rating, improved peak-torque capabilities, and smoother torque output. Therefore, for many applications it is a closer approximation to the ideal servomechanism component than other types which have previously been available.

When combined with appropriate position and/or velocity sensors and control electronics, the printed-circuit motor can provide a precision control system with bandwidths to 1,000 Hz. It should be obvious that such systems can easily correct once-around disturbances.

The capabilities of this motor type are functions of its size. Let K be the ratio of a given dimension of a particular motor to the corresponding dimension of a standard motor. Investigation reveals that the different motor performance parameters are exponential functions of the constant K. Torque per ampere and induced EMF are both proportional to K^2, while continuous torque is proportional to $K^{3.5}$. Armature resist-

Final manuscript received March 10, 1966

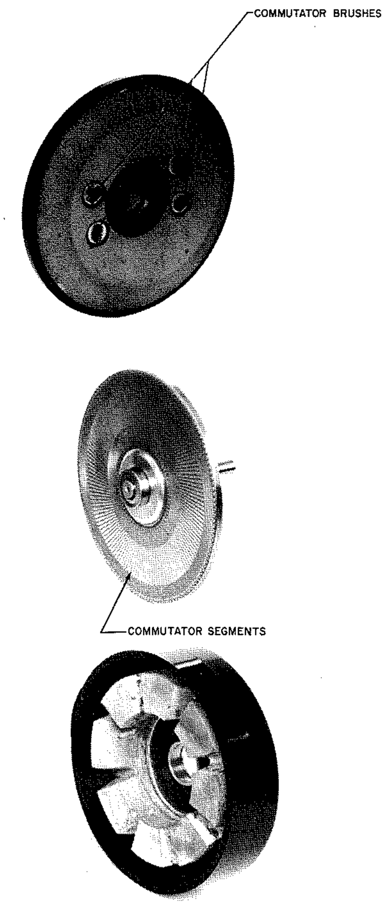


Fig. 1—Typical printed-circuit-motor construction.

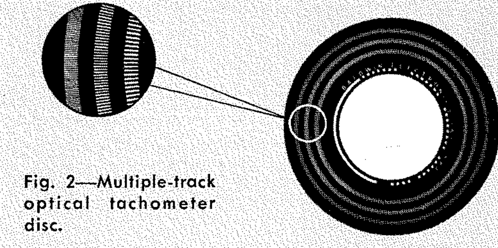


Fig. 2—Multiple-track optical tachometer disc.

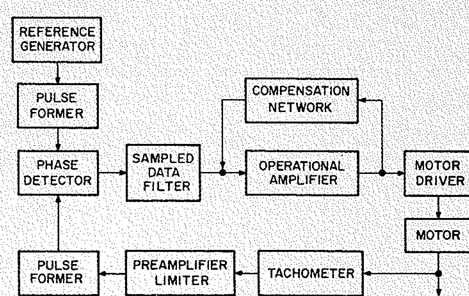
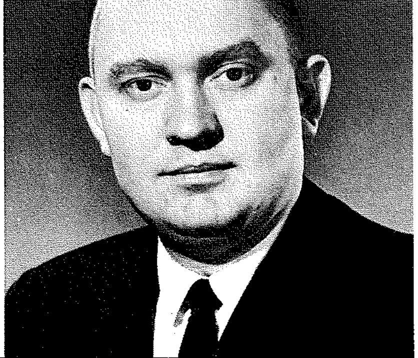


Fig. 3—Block diagram of phase-locked control system.

L. P. DAGUE received his BSEE degree from the University of New Mexico and the MSEE from the University of Pennsylvania. While on active duty with the U. S. Navy he attended Electronics Officers School and served as a staff communications and electronics officer. Prior to joining Applied Research, he worked for RCA's M&SR Div., where he contributed to the design of transistor and SCR regulated power supplies and solar-cell power supplies for satellites. His experience with Applied Research includes the design and development of precision, continuous and sampled-data control systems with bandwidths from DC to 3 MHz; sine- and square-wave transistor and SCR inverters; high-voltage, solid-state AC switches for cadmium selenide electroluminescent displays; and investigation of an optical information transmission system (200-MHz bandwidth) using recombination diodes. He was responsble for the successful use of AC line-operated motor drivers for capstan, headwheel, and tension servo systems in wideband magnetic tape recorders, and he has initiated the use of integrated units for space reduction in control systems. Mr. Dague is a member of the IEEE and Sigma Tau.



ance is inversely proportional to K, and the slope of the speed-torque curve varies as K^{-5}. As a result, large increases in performance can be obtained by small increases in size. Conversely, there is also a minimum practical size for motors of this type, roughly, 2.75 inches in diameter.

In such motors, speed and torque capabilities extend to 4,000 rpm and to 700 in.-oz., respectively. Brush life is rated at 3,000 hours and armature life at 10,000 hours, both for continuous operation. The motor is designed with a permanent-magnet field which is usually provided by magnets of the Alnico type for maximum flux density. However, where lower flux densities are permissible and minimum cost is desired, barium ferrite can be used. For a more complete discussion of the printed-circuit motor, consult Reference 1.

OPTICAL TACHOMETER

For maximum exploitation of the wideband capabilities of printed-circuit motors, an appropriate output sensor must be used. For instance, at a 30-rpm shaft rotation rate, once-around sampling, such as that provided by a magnetic tone wheel, would limit the control system bandwidth to less than 0.2 Hz. The problem resulting from such a low bandwidth is the inability to remove disturbances of even moderate frequencies (e.g., between 0.2 and 10 Hz). A practical solution to this problem can be achieved by the use of a Moire-fringe-effect optical tachometer. This type of tachometer consists of a coded (alternating opaque and clear sections) glass disc, a grating with an identical code pattern, a light source, and a photodetector. Rotation of the disc past the grating modulates the light beam and produces the desired sine-wave output. With a 5,000-line track in the above situation, the system bandwidth may be increased by a factor of 5,000. This combination is similar, in some respects, to a 5,000-pole AC motor with a 2.5-kHz to 250-kHz carrier frequency. Such an AC motor is not practically realizable.

Since such motors may be operated satisfactorily over a 100-to-1 speed range, and since some of the more commonly-used photodetectors, such as solar cells, have a rapid roll-off in their response at rates above 100 kHz, the optical discs usually contain multiple tracks to allow selection of an optimum tachometer rate. Fig. 2 illustrates a typical multiple-track disc containing 500-, 2,000-, and 5,000-line tracks which facilitate operation at any speed within the motor capabilities.

This type of motor-tachometer combination permits a precisely controlled shaft speed to be varied merely by varying the system reference frequency. The characteristics of the combination are such that, with the use of precision ball bearings or even air bearings, the limiting factor in system accuracy is the concentricity of the mounting of the tachometer disc with respect to the shaft. Improved accuracy may be obtained by the use of multiple pickoff systems and/or *shaftless* encoders[2]. Where a more rugged design is required, a multiple-line magnetic tachometer may be used. Reference 3 discusses in more detail the theory of the Moire fringe effect in optical tachometers.

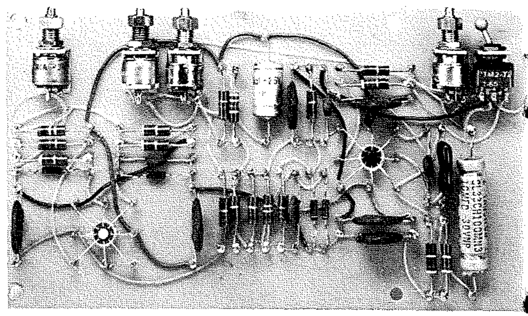


Fig. 5—Integrated-circuit version of optical tachometer preamplifier, operational amplifier, and frequency compensation networks for motor control system with 1,000-Hz bandwidth.

PHASE-LOCKED CONTROL SYSTEM

For requirements dictating the ultimate in precision, a phase-locked control system is the logical choice. Fig. 3 is a block diagram of a type-one, sampled-data, control system with a sampling rate of the same frequency as the output of the tachometer. In such control systems the bandwidth greatly exceeds the mechanical breakpoint of the motor-load combination. The Bode plot of the uncompensated system falls off at 40 dB/decade at the unity gain crossover frequency. Therefore the system is inherently unstable. Adequate compensation must be provided by either series or parallel compensation in the control electronics.

A description of system operation follows. The tachometer output is amplified and processed by a pulse former to generate a trigger pulse train. In addition, the output of a reference generator is processed by a second pulse former to generate a second trigger pulse train. A signal proportional to the phase difference between the two pulse trains appears at the output of the phase detector. This sampled data output is converted into a continuously varying DC level by a low-pass filter and then is applied to the input of an oper-

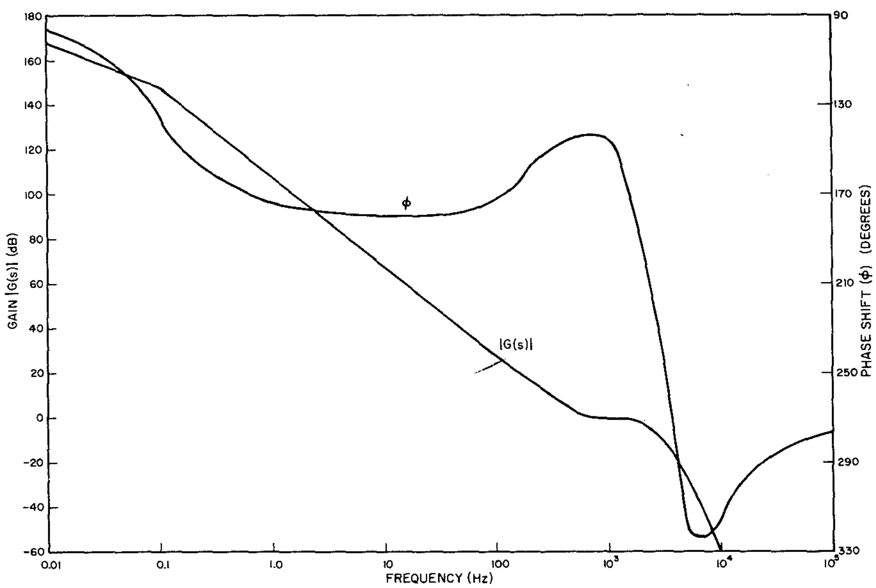


Fig. 4—Bode diagram for phase-locked control system.

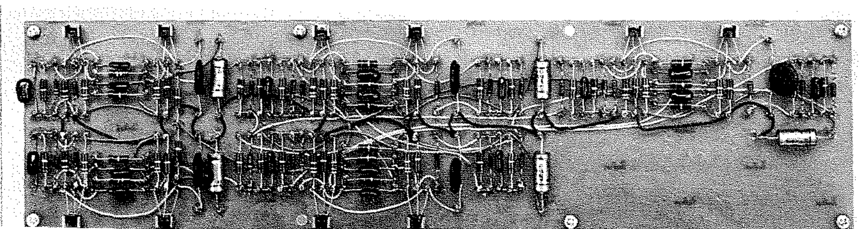


Fig. 6—Discrete-component phase detector.

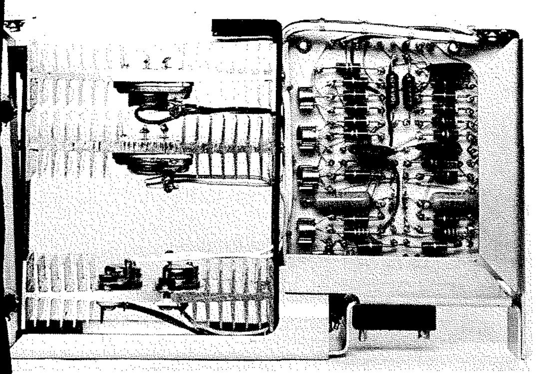


Fig. 7—Minimum-size driver with electronic-interlock overcurrent protection and adjustable crossover distortion.

ational amplifier. The operational amplifier provides most of the system gain required for the desired amount of error reduction. The system gain-versus-frequency characteristic is shaped by the compensation networks to ensure adequate gain and phase margins for system stability. The motor driver provides additional gain as well as a low-impedance output to drive the motor.

The bandwidths of such systems are so great that design compromises may be required to place the frequencies of shaft torsional resonances (between the tachometer, armature, and load) above the given system bandwidth. The Bode plot in Fig. 4 indicates the open-loop gain and phase-shift-versus-frequency characteristics of the compensated system.

Fig. 5 is a photograph of a tachometer preamplifier, operational amplifier, and the frequency compensation networks used in a motor control system having a 1,000-Hz bandwidth. Integrated circuits were used to reduce the size of the electronics package. A mathematical analysis of this type of system is provided in Reference 4; Reference 5 indicates some of the problem areas involved in the design of a sampled-data control system.

VELOCITY-SENSITIVE PHASE DETECTOR

The successful use of the wideband phase-locked system can be attributed in large measure to the development of an error detector which is simultaneously phase- and velocity-sensitive. Error detection is accomplished entirely with digital circuits which contain memory storage elements; the accuracy of these circuits is not dependent upon the accuracy or adjustment of individual time constants. Such an error detector has a reference trigger input and a signal trigger input; it provides the proper output signal by sequentially determining, upon the arrival of each pulse, whether the preceding two pulses were from the same or the opposite trigger line. When the motor shaft is not at the proper speed, the detector drives the system in the appropriate direction to attain nominal speed. As nominal speed is approached, the detector adjusts the motor drive for the proper phase relationship. In effect, this provides electronic *gearing* between the reference and the motor shaft. This device eliminates: 1) any requirement for combining outputs of separate detectors, 2) interaction between multiple loops, and 3) any dependence on time constants. It also provides a much larger frequency range over which phase lock can be acquired. With proper design, the accuracy of this system is dependent primarily on the accuracy of the reference frequency generator.

Fig. 6 shows a discrete-component phase detector which achieves phase lock at rates from 2 kHz to 200 kHz. Integrated-circuit versions of this detector have also been built.

SOLID-STATE MOTOR DRIVERS

Several motor drivers have been developed for use with the motor control systems described previously. They are all basically bidirectional drivers of either the complementary or quasi-complementary types. The quasi-complementary type is used for low-power systems where cost considerations are paramount. The recent availability of 10-A silicon *pnp* power transistors has made the complementary-type design (with its advantages of simplicity due to symmetry) practical for driving 1-ohm motor loads. Since these drivers are bidirectional, the motor is driven down in deceleration (as opposed to coasting down), and the direction of shaft rotation is easily reversed. However, the systems described herein are normally run in only one direction. Variations of these drivers have been built which provide negligible crossover distortion and flat frequency response to 40 kHz. All such drivers use electronic interlocks to prevent simultaneous conduction of complementary output transistors and resulting failures due to overdissipation. Power amplifier boosters have been built which provide driver capabilities to 60 volts and 80 amperes. Fig. 7 shows a minimum-power version of the driver built for use in a miniature tape recorder.

Such systems require dual-polarity power supplies with large pulse-current capabilities. Regulation requirements are not severe, and pulse currents may be provided by large capacitor filters.

EXPERIMENTAL RESULTS

Several systems using the previously described techniques have been built and tested. Comparison with a hysteresis-synchronous type of motor system in a precision tape-recorder-capstan application revealed a 10-to-1 improvement in peak-to-peak time base jitter of the played-back control track. This achievement corresponds to control of the tape position to within 150 μin.

In incrementing service, these motors have provided acceleration and deceleration times between full stop and nominal velocity of 5 ms and less than 15° of shaft rotation. Dissipation capabilities allow up to 50 start-stop cycles to be performed per second on a continuous basis.

SUMMARY

This paper has discussed some of the components available today for use in control sytems. Unique advantages of the individual components were noted, including the reduced inertia of the printed-circuit motor, the increased sampling rate made possible by the multiple-sample tachometer disc, the capability of the digital phase detector to generate both phase and velocity information, and the electronic-interlock overcurrent protection of the motor drivers. The use of these components was illustrated for a typical high-performance phase-locked system. This system demonstrates how the capabilities of the various components complement and enhance each other. For instance, the wide bandwidth made possible by the reduced inertia of the printed-circuit motor could not be used successfully without the increased sampling rate provided by the optical tachometer. Experimental data has shown that major improvements in system performance may be obtained by incorporating one or more of these versatile control-system components.

ACKNOWLEDGMENTS

The techniques described above are the results of several projects supported by Applied Research, EDP, and CSD Magnetic Recording. Many individuals in these areas have made valuable contributions, particularly R. F. Kenville and D. J. Woywood of Applied Research, and D. J. Poitras of EDP.

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PHASE-ANGLE STABILIZATION TECHNIQUES FOR FEEDBACK CONTROL SYSTEMS

A hypothetical control system having an attenuation characteristic of 30 dB/decade and a constant phase margin of 45° is analyzed. A technique is presented by which the characteristics of actual systems can be made to approximate those of the hypothetical system over a limited frequency range. This phase-angle stabilization technique is demonstrated by applying it to improve two simple control systems and a third system with an open-loop gain variation of 46 dB. A precise approach is provided for applying the phase-angle stabilization technique to the design of feedback control systems.

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The goal of stabilization techniques used in feedback control systems is to enable the characteristics of a given system to be altered to maintain performance within a predetermined set of performance specifications. Specified performance is generally achieved if the gain of the feedback loop does not vary significantly from the nominal design value. As higher performance is required, the system may become conditionally stable (i.e., a decrease in the overall loop gain may cause instability). In such cases, additional dependability of the gain characteristics of amplifiers and other elements comprising the system loop are required. Methods of ensuring stable gain characteristics in these high-performance systems are often costly and require the use of heavier, space-consuming elements. In certain cases, variations in loop gain of the system may have to be accepted as inherent in the system design.

If it were possible to design a feedback control system so that its performance was relatively independent of the loop gain over a wide range of frequency, the design of the elements comprising the system would be greatly simplified. Moreover, a control system of this type could provide acceptable performance in those cases where a uniform gain characteristic over the frequency range is not possible.

This paper describes a stabilization technique that can be employed in control system designs to establish an independent relationship between performance and loop gain over an extremely wide range. In using this technique, the phase-angle characteristics of a given control system are manipulated in a prescribed manner to obtain stabilization; thus, it has been designated the *phase-angle stabilization technique.*

Final manuscript received March 2, 1966.

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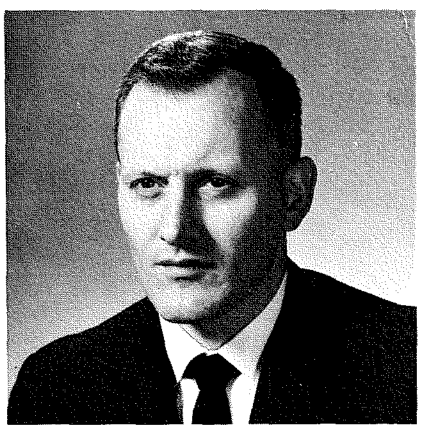


List of Figures and Related Equations

Fig. No.	Applicable Equation
2	$G = \frac{K}{j\omega(1 + j\omega T)}$
3a	$\frac{E_o}{E_{in}} = \frac{1 + 0.625j\omega}{1 + 2.5j\omega}$
3b	$\frac{E_o}{E_{in}} = 0.25\,\frac{1 + 1.56j\omega}{1 + 0.39j\omega}$
3c	$\frac{E_o}{E_{in}} = \frac{(1 + 1.25j\omega)(1 + 0.078j\omega)}{(1 + 5j\omega)(1 + 0.0195j\omega)}$
6	$G_1 = \frac{6.4}{j\omega(1 + 0.156j\omega)}$, $G = \frac{6.4(1 + 10j\omega)(1 + 0.625j\omega)}{j\omega(1 + 40j\omega)(1 + 2.5j\omega)(1 + 0.156j\omega)}$
7	$G_1 = \frac{640}{j\omega(1 + 0.156j\omega)}$, $G = \frac{640(1 + 0.625j\omega)(1 + 0.039j\omega)}{j\omega(1 + 2.5j\omega)(1 + 0.156j\omega)(1 + 0.0098j\omega)}$
8	$G_{1H} = \frac{22{,}000}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)}$, $G_H = \frac{2200(1 + 0.008j\omega)}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)(1 + 0.0008j\omega)}$, $G_L = \frac{11(1 + 0.008j\omega)}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)(1 + 0.0008j\omega)}$
9	$G_{1H} = \frac{22{,}000}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)}$, $G_H = \frac{22{,}000(1 + 2.05j\omega)(1 + 0.128j\omega)(1 + 0.008j\omega)}{j\omega(1 + 20.5j\omega)(1 + 0.512j\omega)(1 + 0.032j\omega)(1 + 0.002j\omega)(1 + 0.0002j\omega)}$

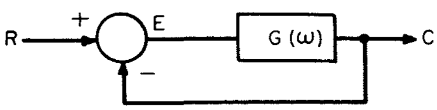


Fig. 1—Simple closed-loop control system with direct feedback.

REVIEW OF CONTROL SYSTEM CONCEPTS

Various methods may be used to study the behavior of feedback control systems. The Nyquist stability criterion and the associated complex plane diagrams provide a straightforward means of system analysis; however, this type of analysis does not clearly define the quantitative effect of parameter changes. For example, the close interrelationship between the two conditions of high accuracy and adequate stability is evident in the complex-plane approach, but the results are not in a usable form.

A more definite and quantitative relationship of system parameters is obtained by the application of the Bode attenuation concepts. These concepts provide a convenient shorthand method of attenuation and phase representation that is very useful for describing system performance. The two pertinent Bode theorems, which relate the phase and amplitude characteristics of networks operating with sinusoidal operation, are:

1) The phase shift of a network or system can be determined at any frequency from the slope of the attenuation (or gain) characteristic in the vicinity of that frequency.
2) The attenuation may be chosen as the governing characteristic in one portion of the frequency spectrum, and the phase-shift is chosen as the governing characteristic in another portion of the spectrum.

The first theorem indicates that the phase-shift characteristic of a system is unique for the attenuation characteristic selected, and vice-versa. Since these characteristics are a function of frequency, some method must be employed to ensure that the characteristics obtained throughout the specified frequency spectrum will provide a satisfactory compromise between high accuracy and adequate stability. The application of the second theorem provides such a method. Although the gain at low frequencies and the stability of a system are not entirely independent, an optimum design can be achieved by selecting the attenuation as the governing characteristic in the lower portion of the frequency spectrum and the phase shift as the governing characteristic at the higher frequencies.

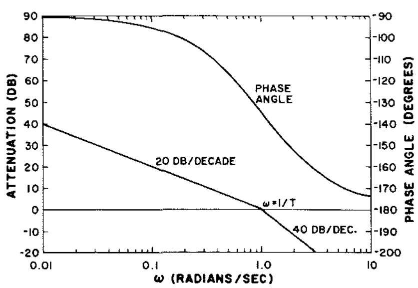


Fig. 2—Attenuation and phase characteristics of simple control system.

Attenuation Diagrams

The transfer functions of a control system or phase-shift network may be represented graphically by plotting the attenuation and phase-shift as functions of frequency. These plots are referred to as attenuation diagrams or Bode plots. The use of these diagrams is simplified by approximating the exact attenuation plots, which are smooth curves, with straight lines. These straight lines are constructed as asymptotes to the straight-line portions of the actual characteristic. No approximations are used in plotting phase shift as a function of frequency.

Application of Bode Attenuation Concept

The Bode attenuation concept can be conveniently illustrated by applying it to simple closed-loop control system with direct feedback shown in Fig. 1. The controlled variable, C, is compared to the reference input, R, by means of an error-measuring element. The error signal, $E(\omega)$, is related to the controlled variable, $C(\omega)$, by the forward transfer function, $G(\omega)$. Thus

$$G(\omega) = \frac{C(\omega)}{E(\omega)} \qquad (1)$$

where ω is the frequency. If the forward transfer function selected is expressed by

$$G(\omega) = \frac{K}{j\omega(1 + j\omega T)} \qquad (2)$$

where K is the forward gain constant, and T is the time constant, then the system shown is representative of a control system that has a single motor time constant T. For the special case where

$$|K| = \frac{1}{T}, \qquad (3)$$

the attenuation and phase characteristics of the resultant system are shown in Fig. 2.

The Bode approximation consists of the following assumption for the magnitude of the denominator term, $1 + j\omega T$, in equation 2:

$$|1 + j\omega T| = 1 \text{ when } \omega \leq \frac{1}{T}$$
$$|1 + j\omega T| = \omega T \text{ when } \omega \geq \frac{1}{T} \qquad (4)$$

As shown in Fig. 2, the plot of the asymptotic attenuation characteristic exhibits a slope of 20 dB/decade extending from the low frequencies to the frequency $\omega = \frac{1}{T}$. At this point, the slope of the attenuation characteristic increases abruptly (breaks) to 40 dB/decade. The maximum error of the asymptotic plot occurs at this break frequency and is 3 dB, which can be seen by comparing it with the actual (dotted) attenuation curve. A plot of the phase-shift characteristic of the system is also shown in Fig. 2. As shown by the curve, the phase shift increases from −90° at low frequencies to −135° at the break frequency $\omega = \frac{1}{T}$ and asymptotically approaches −180° with increasing frequency.

A form of the phase characteristic that is more convenient for analysis purposes is the phase-margin characteristic. The relationship of the phase margin, ϕ, to the phase shift, θ, is expressed by:

$$\phi = 180 + \theta \qquad (5)$$

A Bode plot incorporating a phase-margin curve can be used to determine the stability of a system by applying the following criterion, which is valid for the majority of control problems: "Systems having positive phase margin at the frequency where the attenuation plot crosses the zero-decibel axis are stable, whereas systems having negative phase margin at that point are unstable." It is evident that the system depicted in Fig. 2 is stable, since the phase margin is plus 52° at the 0-dB crossover point.

Although the stability of systems meeting only the "positive phase-margin" requirement is ensured, an additional rule-of-thumb criterion is used for ensuring satisfactory control system performance in practical cases. Namely, if the phase margin is between 40° and 60° at the 0-dB crossover point, the system responds rapidly to step inputs, and produces only a few well-damped oscillations.

Stabilization Networks

When the fixed characteristics of a given control system have transfer functions that result in unsatisfactory performance, stabilization networks, which alter the fixed characteristics, are introduced to obtain the required performance. Three such networks (phase-lag, phase-lead, and phase-lag-lead) are reviewed in the following sections.

Phase-Lag Networks

A phase-lag network provides a convenient means of reducing the gain of a control system at higher frequencies without sacrificing low-frequency gain or system accuracy. A typical transfer function for a phase-lag network is expressed by:

$$\frac{E_o}{E_{in}} = \frac{1 + j\omega T_2}{1 + j\omega T_1} \qquad (6)$$

where $T_2 = 0.25 T_1$. As shown in Fig. 3a, the network provides no attenuation up to the break frequency $\omega = \frac{1}{T_1}$, but at this point an attenuation rate of 20 dB/decade begins. This slope continues until the upper break frequency $\omega = \frac{1}{T_2}$ is reached.

At higher frequencies, the network exhibits a constant attenuation equal to T_2/T_1, or 12 dB. The phase shift of the network is negative; i.e., the output signal *lags* the input signal, hence the name of the network. The desirable attribute of the lag network is its high-frequency attenuation, which can be used to lower the 0-dB crossover frequency of a system to the point at which the phase margin is satisfactory.

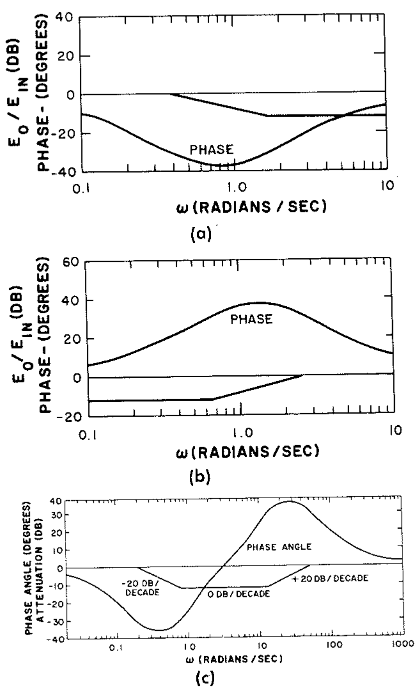
Phase-Lead Networks

The attenuation characteristic of a phase-lead network is shown in Fig. 3b. This characteristic exhibits a positive slope of 20 dB/decade with increasing frequency in the region between the lower break frequency ($\omega = \frac{1}{T_1}$) and the upper break frequency ($\omega = \frac{1}{T_2}$). A typical transfer function for a phase-lead network is expressed by:

$$\frac{E_o}{E_{in}} = \frac{T_2}{T_1} \cdot \frac{1 + j\omega T_1}{1 + j\omega T_2} \qquad (7)$$

where $T_2 = 0.25\ T_1$. At frequencies below the lower break point, the network exhibits a constant attenuation equal to T_2/T_1, or 12 dB. There is no attenuation at frequencies above the upper break point. The phase shift of this network is positive; i.e., the output signal *leads* the input signal. The desirable attribute of the network is this positive phase shift, which can be used to increase the phase margin of a system at the frequencies in the vicinity of the 0-dB crossover point. However, the inherent low-frequency attenuation of this network requires additional amplifier gain if the original loop gain is to be maintained at low frequencies.

Fig. 3—Representative attenuation and phase-angle characteristics for a) phase-lag, b) phase-lead, and c) phase-lead-lag networks.



Phase Lag-Lead Networks

The characteristics of the phase-lag and phase-lead networks may be combined in a single network. This approach overcomes the undesirable low-frequency attenuation of the phase-lead network. The general transfer function of the phase-lag-lead network is expressed by:

$$\frac{E_o}{E_{in}} = \frac{(1 + j\omega T_2)(1 + j\omega T_3)}{(1 + j\omega T_1)(1 + j\omega T_4)} \qquad (8)$$

where $T_1T_4 = T_2T_3$, and $T_1 + T_4 > T_2 + T_3$.

The attenuation characteristic of a phase-lag-lead network is shown in Fig. 3c. The frequencies at which the two upward break points occur are $\omega = \omega_2 = \frac{1}{T_2}$ and $\omega = \omega_3 = \frac{1}{T_3}$. These break frequencies can be made coincident or spaced as far apart as desired; i.e., $T_2 = T_3$ or $T_2 \gg T_3$. The frequency at which the first downward break occurs is $\omega = \omega_1 = \frac{1}{T_1}$. The ratio T_1/T_2 can be selected to obtain any required ratio ω_1/ω_2 of the first downward and upward break frequencies. The ratio T_3/T_4 then assumes the same value, as dictated by the restrictions of equation 8; i.e.,

$$\frac{T_3}{T_4} = \frac{T_1}{T_2}.$$

For the attenuation plot shown in Fig. 3c, the ratios T_1/T_2 and T_3/T_4 are equal to 4, and the ratio T_2/T_3 is equal to 16.

The only restriction on the selection of the ratio T_2/T_3 is that it be equal to or larger than 1. Proper selection of the time constants T_2 and T_3 places the undesirable lagging phase shift at frequencies far below the 0-dB crossover point of the system. The leading portion of the phase characteristic can be located to effect an increase in the system phase margin at the frequency where unity gain occurs (0-dB crossover point). Thus, the stabilizing effect of a phase-lead network can be achieved without undesirable low-frequency attenuation.

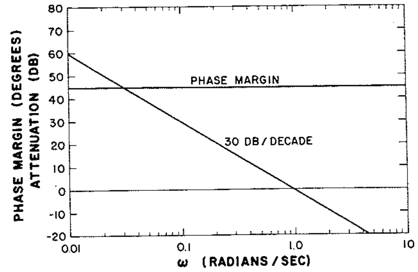


Fig. 4—Attenuation and phase-margin characteristics of hypothetical control system.

PHASE-ANGLE STABILIZATION CONCEPT

As previously stated, one of Bode's theorems relates the phase shift of a network or system to the slope of the attenuation characteristic at any desired frequency. Examination of the Bode plot in Fig. 2 reveals a phase shift of −135° at the downward break frequency of the attenuation characteristic. (By equation 5, this phase shift is equal to a phase margin of 45°.) At this frequency, the slope of the true attenuation curve (not the asymptotic approximation) has been determined to be 30 dB/decade. From the theorem, it can be seen that any attenuation plot will have this slope at the frequency where a phase margin of 45° occurs.

Analysis of a hypothetical control system having an attenuation characteristic with a constant slope of 30 dB/decade from the very low frequencies, through the 0-dB crossover, to the very high frequencies discloses several significant facts. These are as follows:

1) The phase margin of the hypothetical system would remain constant at 45° (Fig. 4).
2) The Nichols chart, used to obtain closed-loop frequency response directly from attenuation characteristics, would consist of a vertical straight line. This type of plot indicates that variations in forward gain would have no effect upon the shape of the closed-loop response curve, which would peak at + 3 dB regardless of open loop gain.
3) The bandwidth, B, of the hypothetical system would increase or decrease with corresponding changes in open-loop gain, G, by an amount determined by

$$\frac{B_2}{B_1} = \left(\frac{G_2}{G_1}\right)^{2/3}. \qquad (9)$$

Bandwidth varies directly with open-loop gain in a system that has an atten-

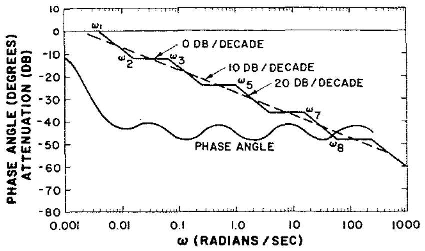


Fig. 5—Attenuation and phase-angle characteristics of network having transfer function expressed by equation 10.

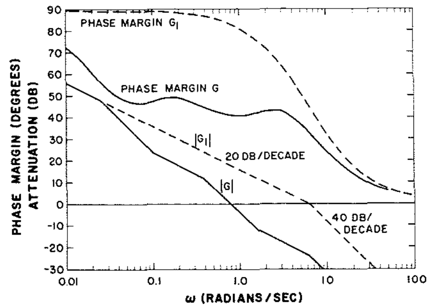


Fig. 6—Attenuation and phase-margin characteristics of simple control system before and after alteration of phase characteristic.

uation characteristic of 20 dB/decade. In the hypothetical system, changes in open-loop gain would have less effect on bandwidth.

It can be seen from the foregoing that the effects of gain variations on closed-loop response and bandwidth would be reduced if the hypothetical system were substituted for a practical system. In order to realize this improvement, the phase-angle stabilization technique can be used to establish a phase-margin characteristic which is suitably close to 45° over the range of frequencies where 0-dB crossovers are anticipated. This phase-margin characteristic would be equivalent to a system attenuation characteristic of approximately 30 dB/decade.

IMPLEMENTATION OF THE PHASE-ANGLE STABILIZATION TECHNIQUE

Effective implementation of the phase-angle stabilization technique involves an increase or decrease in the phase shift associated with an attenuation characteristic, with the aim of producing a phase margin that is equal to 45° within a specified tolerance. In order to retain the rule-of-thumb minimum phase margin of 40°, a tolerance of ±5° about the nominal value of 45° has been established as the design goal.

The feasibility of the phase-angle stabilization technique will be demonstrated by first considering an attenuation characteristic that consists of a series of straight-line segments having alternate slopes of 0 and 20 dB/decade. If the frequency range of each segment is the same, the average attenuation rate is 10 dB/decade. The general transfer function for a network having this attenuation characteristic is expressed by

$$\frac{E_o}{E_{in}} = \prod_{K=1}^{n} \frac{1 + j\omega T_{2K}}{1 + j\omega T_{2K-1}}$$

$$= \frac{1 + j\omega T_2}{1 + j\omega T_1} \cdot \frac{1 + j\omega T_4}{1 + j\omega T_3} \cdots \frac{1 + j\omega T_{2n}}{1 + j\omega T_{2n-1}} \qquad (10)$$

where $T_{2K} = rT_{2K-1}$, $T_{2K-1} = rT_{2K-2}$, n is the number of terms, and r is the ratio selected to determine the length of the straight-line segments.

For a value of ω much greater than $\frac{1}{T_1}$, the phase shift of the network varies sinusoidally above and below —45°. The magnitude of this phase variation is a function of the spacing of the network break frequencies.

The attenuation and phase-angle characteristics of a network having the transfer function expressed by equation 10 are plotted in Fig. 5. The ratio r was assigned a value of 0.25. The phase-shift curve varies between 41.8° and 48.2°, a peak variation of only 3.2° about the center value of 45°. This amount of variation is better than the established tolerance of ±5°; thus the selected value of r is recommended for use in determining the time-constant values for equation 10. The time-constant relationships become:

$$T_{2K} = 0.25\ T_{2K-1}$$
$$T_{2K-1} = 0.25\ T_{2K-2} \qquad (11)$$

Examination of equation 10 reveals that each term represents a general phase-lag stabilization network which has the transfer function expressed by equation 6. The phase-shift analysis of equation 10 was based on the use of a large number of such networks; however, it will be shown that only two or three networks are necessary for practical applications.

APPLICATION OF THE TECHNIQUE

Stabilizing the Simple System

The application of the stabilization technique will be illustrated by considering again the system shown in Fig. 1 and defined by equations 2 and 3. Assuming a time constant (T) of 0.156 second, system transfer function G_1 becomes

$$G_1 = \frac{6.4}{j\omega(1 + 0.156j\omega)} \qquad (12)$$

The attenuation and phase-margin characteristics corresponding to this transfer function are shown by the dotted lines in Fig. 6. The phase margin is 45° at the 0-dB crossover point of the attenuation characteristic. Although it is stable, this system will illustrate the improvement that can be realized by the use of the phase-angle stabilization technique.

Determining the location of the fixed break frequency, and using the time-constant relationships of equation 11, the phase-margin of the system is altered by incorporating two phase-lag networks which have initial break frequencies of 0.025 and 0.4 radians/second, respectively. The transfer function of the resulting system is

$$G = \frac{6.4(1 + 10j\omega)\,(1 + 0.625j\omega)}{j\omega(1 + 40j\omega)\,(1 + 2.5j\omega)\,(1 + 0.156j\omega)} \qquad (13)$$

The attenuation and phase-margin characteristics of the altered system are shown by the solid lines in Fig. 6. The new attenuation plot consists of a series of line segments with alternate slopes of 20 and 40 dB/decade. Each segment (including the one between the final network break and the fixed system break) covers a frequency range of two octaves. The altered phase-margin characteristic lies between 40° and 50° over the frequency range of 0.04 to 4.0 radians/second. In the original system, the phase margin of 40° to 50° extended over the much narrower range of 5.4 to 7.6 radians/second.

Stabilizing a High-gain System

If the open-loop gain of the original system is increased by 40 dB, the transfer function is changed to

$$G_1 = \frac{640}{j\omega(1 + 0.156j\omega)} \qquad (14)$$

The system would remain stable with the increase in gain, but it would tend to oscillate, since the phase margin of 5.7° at the 0-dB crossover point is significantly less than the rule-of-thumb minimum phase margin of 40°. A slight additional phase shift contributed by an extraneous high-frequency break point would place the system in a sustained oscillation mode. This tendency to become unstable can be overcome by the addition of a stabilization network having a suitable attenuation characteristic. The slope of the attenuation characteristic of the existing system is 40 dB/decade at crossover. Therefore, an average positive slope of 10 dB/decade must be added by the stabilization network to implement the phase-angle stabilization technique.

The required slope is typical of the phase-lead network; however, the low-frequency attenuation associated with this network is undesirable. This deficiency can be overcome by the use of a lag-lead network, but the effects of the lag characteristic must be evaluated. It is conceivable that 1) alteration of the system characteristic below the first break frequency may be required, or 2) if not required, it would at least be allowable. In either case, a phase-lag characteristic could be used at frequencies below the first system break point, and a phase-lead characteristic could be used at frequencies above the break point. Fortunately, there is no maximum restriction on the ratio T_2/T_3 in equation 8; therefore the necessary flexibility is ensured.

The use of the phase-lag-lead network to improve the performance of the system defined by equation 14 is illustrated in Fig. 7. The attenuation and phase-margin characteristics of the unaltered system are shown by dotted lines. In accordance with the two-octave break point relationship established in equation 11, the time constants of the lag-lead network have been selected as:

$$\begin{aligned} T_2 &= 4T = 0.625 \text{ second,} \\ T_3 &= 0.25T = 0.039 \text{ second,} \\ T_1 &= 4T_2 = 2.5 \text{ seconds, and} \\ T_4 &= 0.25T_3 = 0.0098 \text{ second.} \end{aligned} \tag{15}$$

The system transfer function thus becomes

$$G = \frac{640(1 + 0.625j\omega)(1 + 0.039j\omega)}{j\omega(1 + 2.5j\omega)(1 + 0.156j\omega)(1 + 0.0098j\omega)} \tag{16}$$

The attenuation and phase-margin characteristics of the modified system are shown by the solid lines in Fig. 7. A comparison of the original and altered characteristics discloses the following significant changes:

1) The 0-dB crossover point has been reduced only slightly from 64 to 40.6 radians/second.
2) The phase margin at the unity-gain crossover point is 43° as compared with 5.7°.
3) The phase margin remains within the design goal of 40° to 50° throughout the frequency range of 0.64 to 64 radians/second. Therefore, the shape of the closed-loop response will not differ significantly for gain increases of 4 dB or decreases of 56 dB.
4) The low-frequency gain is unchanged.

Phase-control stabilization may be extended to even higher frequencies to obtain higher loop gain at the low frequencies, or to compensate for a system transfer function that contains two downward breaks. This improvement may be achieved by introducing a second lag-lead network or, alternatively, by sacrificing some phase control at the lower frequencies to gain additional phase lead at the higher frequencies. This compromise may be accomplished by changing the value of the ratios T_1/T_2 and T_3/T_4 from 4 to 10, or, in other words, by changing T_1 and T_4 in equation 15 to

$$\begin{aligned} T_1 &= 10T_2 = 6.25 \text{ seconds, and} \\ T_4 &= 0.1T_3 = 0.0039 \text{ second.} \end{aligned} \tag{17}$$

Both approaches are used in solving the variable-gain control system problem that follows.

Stabilizing a Variable-Gain Control System

The variable-gain control system considered for improvement by application of the phase-angle stabilization technique is an actual design that was developed to provide rapid, automatic measurement of a parameter of a large quantity of transistors.[1] The gain variation of the system was 46 dB. The transfer functions for the two gain extremes of the system without stabilization are expressed by

$$\begin{aligned} G_{1H} &= \frac{22{,}000}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)} \\ G_{1L} &= \frac{110}{j\omega(1 + 0.032j\omega)(1 + 0.02j\omega)} \end{aligned} \tag{18}$$

where G_{1H} was the transfer function at high gain, and G_{1L} was the transfer function at low gain.

The attenuation and phase-margin characteristics for G_{1H} are shown by the dotted lines in Fig. 8. The system was unstable without stabilization, as indicated by the high negative value of phase margin at the 0-dB crossover point. The stabilization actually applied to the system consisted of a simple phase-lead network having the transfer function

$$\frac{E_o}{E_{in}} = \frac{0.1(1 + 0.008j\omega)}{(1 + 0.0008j\omega)} \tag{19}$$

The transfer functions of the system with stabilization, at high and low gain, are expressed by

$$G_H = \frac{2{,}200(1 + 0.008j\omega)}{j\omega(1 + 0.032j\omega)(1 + 0.002j\omega)(1 + 0.008j\omega)}, \tag{20}$$

$$\text{and } G_L = \frac{G_H}{200}$$

The attenuation and phase-margin characteristics for G_H and G_L are shown by the solid lines in Fig. 8. The phase margin of 13° at the 0-dB crossover point indicates that the system was barely stable at high gain. Also, it had not been possible to restore the attenuation introduced by the phase-lead network and still maintain stability. As a result, the response of the system was sluggish at low loop gain, and errors due to static friction became evident.

Phase-angle stabilization techniques applied to this system indicate that substantial improvements can be obtained by the introduction of two lag-lead networks. The break frequencies of the lag-lead networks must be appropriately spaced in relation to the two break frequencies of the system. Using time-constant ratios (T_1/T_2) of 0.25 and 0.1, respectively, the transfer functions of the two networks are as follows:

$$\begin{aligned} G_2 &= \frac{(1 + 0.128j\omega)(1 + 0.008j\omega)}{(1 + 0.512j\omega)(1 + 0.002j\omega)}, \text{ and} \\ G_3 &= \frac{(1 + 2.05j\omega)(1 + 0.002j\omega)}{(1 + 20.5j\omega)(1 + 0.0002j\omega)} \end{aligned} \tag{21}$$

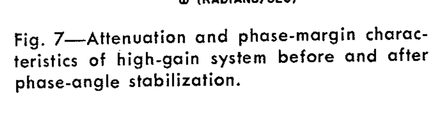


Fig. 7—Attenuation and phase-margin characteristics of high-gain system before and after phase-angle stabilization.

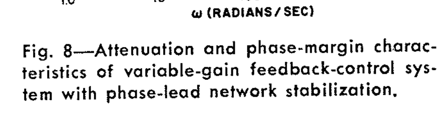


Fig. 8—Attenuation and phase-margin characteristics of variable-gain feedback-control system with phase-lead network stabilization.

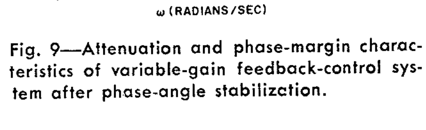


Fig. 9—Attenuation and phase-margin characteristics of variable-gain feedback-control system after phase-angle stabilization.

Due to the coincidence of a downward break of G_2 with a fixed break of the system, the second upward break of G_3 must be placed at the same frequency as the second downward break of G_2 to cancel the effects of each. The addition of the lag-lead networks to the system results in the following system transfer functions:

$$G_H = \frac{22{,}000(1+2.05j\omega)}{j\omega(1+20.5j\omega)(1+0.512j\omega)} \times \frac{(1+0.128j\omega)(1+0.008j\omega)}{(1+0.032j\omega)(1+0.002j\omega)(1+0.0002j\omega)}$$

$$\text{and } G_L = \frac{G_H}{200}. \qquad (22)$$

The attenuation and phase-margin characteristics of the phase-stabilized system are shown by the solid lines in Fig. 9. The original attenuation characteristic for G_{1H} is shown in dotted form. The phase-margin at the 0-dB crossover point is 41° and remains between 40° and 50° from 0.625 to 250 radians/second. This frequency range exceeds the frequency span between the high- and low-gain 0-dB crossover points by a considerable margin. Thus, system stability would be obtained without sacrificing any of the original low-frequency gain. The modification would eliminate the static friction errors and sluggish response at low loop gain and the oscillatory tendencies at high loop gain, which were encountered with phase-lead stabilization.

SUMMARY OF PHASE-ANGLE STABILIZATION TECHNIQUE

The methods to be used for applying the phase-angle stabilization technique to the design of feedback control systems are, in general, valid for all types of control systems. However, inherent differences in certain systems may require variations to the techniques decribed in preceding sections. The basic approach consists of altering the characteristics of the given control system to obtain a phase margin of approximately 45° over a wide range of frequencies. This phase margin is obtained by establishing an average attenuation rate of 30 dB/decade throughout the desired frequency range.

Specific rules for obtaining this attenuation rate in the design of a control system are as follows:

1) Based on the known requirements of the system, select a value for the low-frequency gain and sketch the Bode plot of the system transfer function, as derived from the fixed elements.
2) From this plot and a knowledge of the minimum bandwidth requirement of the system, determine whether the attenuation characteristic must be altered below, above, or on both sides of the fixed break point frequencies.
3) Utilizing the fixed break points to the extent possible, locate alternate downward and upward break points at two-octave intervals to provide alternate slopes of 40 and 20 dB/decade. Generally, this procedure will be used to implement one of the following steps, depending on the portion of the attenuation characteristic that requires alteration:
   a) *Below the system break frequencies:* Use one or more lag networks, as neccessary, to cover the desired frequency range.
   b) *On both sides of the system break frequencies:* Use one or more lag-lead networks as described in previous sections.
   c) *Above the system break frequencies:* Use one or more lead networks if the amplifier gain can be increased 12 dB for each network. If the gain cannot be increased conveniently, use lag-lead networks, as indicated in step *b*.
4) Sketch the attenuation and phase-margin characteristics of the stabilized system and determine the maximum open-loop gain that will still ensure a phase margin of 40°. The nominal gain will then be equal to the geometric mean of this maximum gain value and the required minimum value. For example, assume that a minimum gain (K_1) of 100 is required to meet the mimimum accuracy and response specifications for the system. After phase-angle stabilization is applied, it is found that a phase margin of 40° would still exist with a gain (K_2) of 1000. The nominal forward gain (K) of the system will be given by
   $$K = \sqrt{K_1 K_2} = 316 \qquad (23)$$
   Variations in system elements that affect open-loop gain may be allowed provided that the total combined variation is within ±10 dB of the nominal value.

These steps will apply to the three common types of control systems as follows: (Note that the type number is identical with the power of the $j\omega$ term in the denominator of the system transfer function).

1) Type 0—Characterized by no $j\omega$ term and a concomitant attenuation slope of 40 dB/decade at low frequencies. In this type, step *3a* applies, but an additional attenuation of 20 dB/decade is required from the stabilization network at frequencies where the system attenuation is 0 dB.
2) Type 1—Characterized by a single $j\omega$ term and a concomitant attenuation slope of 0 dB/decade at low frequencies. All control systems described in this work are of this type; steps *3a*, *b* and *c* apply.
3) Type 2—Characterized by a $j\omega^2$ term and a concomitant attenuation slope of 40 dB/decade at low frequencies. For this type, step *3c* applies. When lag-lead networks are used, the phase-lag characteristic must be placed well below the lowest frequency at which the 0-dB crossover is expected to occur.

Simplification of the Bode Attenuation Diagram

A convenient simplification may be used when drawing the Bode attenuation diagram in step 4. The alternate 20- and 40-dB slopes may be approximated by a single slope of 30 dB, starting one octave below the first downward break frequency and ending one octave above the last upward break frequency. This simplification is illustrated in Fig. 5, where the average slope, shown by the dotted line, is 10 dB/decade. The dotted line begins at $\omega = \omega_1°/2$ and would end at $\omega = 2\omega_8$, if ω_8 were the last break point. For break frequencies spaced two octaves apart, this approximation is nearly equal to the actual attenuation curve. The greatest error (1 dB) occurs at the begining and end points of the average-slope line; namely, at $\omega_1/2$ and $2\omega_8$ in Fig. 5. The error at the actual break points, ω_1 through ω_8, is only 0.25 dB.

However, the approximation can only be used for a portion of the frequency range when two different break-point intervals are used on the same diagram. For example, in Fig. 9, where the first pair of break points are one decade apart and the remaining breaks are two octaves apart, the approximation may be used over the frequency range of 0.25 to 1,000 radians/second, but cannot be extended to 0.01 radian/second.

CONCLUSIONS

The phase-angle stabilization technique is a valuable, practical method of stabilizing feedback control systems. It is valuable because it minimizes the trial-and-error approach by providing specific rules for selecting the break frequencies for stabilization networks. When these selections are made in the precise and methodical manner indicated, the performance of the system can be predicted over a wide range of open-loop gain. The technique is practical since it allows the basic networks, which are familiar to system designers, to be combined and used as the necessary stabilization networks. A slight disadvantage of the technique is encountered in those cases where the input of the second network may not be directly connected to the output of the first, because of impedance matching considerations. In such applications, network synthesis can be employed in the design of the stabilizing network.

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THE USE OF HF RADIO IN INTERNATIONAL COMMUNICATIONS

This paper discusses the role of high-frequency radio in international communications. The development of the CRF concept, the ARQ system, and simulated single-sideband techniques are reviewed; present operations are described; and the future of HF radio is considered.

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HIGH-FREQUENCY radio became an important means of international communications in the mid-1920's. Fading, the particular disadvantage of HF, was overcome by diversity reception, an RCA invention. Automatic (machine) keying and reception on syphon ink recorders were already established on long wave, and they became the standard mode in HF communication. The receiver of that day, and the key clicks produced by on-off keying, dictated a clear bandwidth of about 15 kHz (kc/s) for a single high-speed (50- to 100-wpm) channel. Crowding of the HF spectrum soon became a problem.

Capacity was increased by time-division multiplex, allowing four channels on a single carrier. More selective receivers improved operation and reduced the clear bandwidth necessary for reliable reception. These two advances just about matched the growth in HF activity, so that spectrum crowding remained about the same.

During World War II, the body of propagation knowledge was greatly expanded, the change from Morse to teletype and from on-off keying to frequency shift was accelerated, and the use of tape relay systems of traffic handling became more widespread. Traffic volume increased and continued to increase after the war. The expert high-speed international Morse operator faded rapidly from the increasingly mechanized scene. Many circuit peculiarities that these experts could clearly recognize were hidden from the teletype operator. Traffic handling became an all-absorbing task for traffic supervisors as radio facilities became more complicated, and the supervisors were unable to use the greatly increased store of technical knowledge available.

Final manuscript received January 25, 1966

CRF AND ARQ SYSTEMS

The Controller of Radio Facilities (CRF) concept evolved in 1948. Under this concept a single supervisor on each watch directed the use of all radio facilities at the central telegraph office (CTO). He corresponded with his counterparts at other CTO's on direct and indirect operating problems and called for engineering guidance when necessary. This system was developed at RCA Communications, Inc. in New York and was subsequently copied in whole or in part by major centers all over the world. The CRF system was established just in time to meet several changes: customer-to-customer services, reduction in fixed service frequency bands, and adverse propagation conditions.

RCA Communications, Inc. inaugurated leased-channel service in 1948 and telex service in 1950. These two services were made possible by the development of the mutilation reduction system, known as ARQ (A for automatic, RQ for request for correction). The ARQ system uses a seven-element, constant-ratio code; departures from this code (extra elements due to hits, or missing elements due to dropouts) cause a signal to be sent back to the transmitting station requesting correction. The mutilated character is then retransmitted from storage.

The rearrangement in frequency allocation worked out at the International Telecommunications Conference in 1947 removed considerable spectrum space from the international point-to-point service and allocated it to other applications. RCA Communications was especially hard hit by the loss of large frequency blocks, many in the critical 6- and 8-MHz (mc/s) bands. The 11-year sunspot cycle went into its low end, the period of greatest trial for HF radio, in the winter of 1950; it was the first such period encountered since our operations were changed from Morse to teletype.

A. W. GRAY received his BSEE degree from the University of California in 1929. He joined RCA in 1929 as a technician on transmitting and receiving equipment. Later he became supervisor of an RCAC frequency-measurement laboratory at the Pt. Reyes, Cal. receiving station. From 1941 to 1947 he served as a communications officer in the U.S. Navy. Upon returning to RCA Communications, Inc., he was named Coordinator of Radio Facilities for the N.Y. district. In 1958 he became Coordinator of Radio Facilities for RCAC. In this capacity he is responsible for the use of transmitters, antennas, and frequencies for RCAC's international communications network. He has been active for years in CCIR affairs and presently serves as a member of Study Group VIII on International Monitoring.

The centralized control of radio facilities under CRF proved invaluable in meeting all of these challenges with minimum outage.

SIMULATED SINGLE SIDEBAND

Increasing use of ARQ, coupled with four-channel, time-division multiplex, added considerably to frequency-spectrum capacity but only partially met the need for expansion. Additional carriers were required. It became apparent that, if for no other reason than to conserve frequency space, single-sideband (SSB) techniques must be applied to telegraph operations. Lacking appropriate transmitters, receivers, and channeling equipment, RCA Communications developed the *simulated* SSB system, whereby in one frequency assignment of 3-kHz bandwidth, a frequency-shift-keying (FSK) carrier was placed 900 Hz (cps) below the assigned frequency and another 900 Hz above it. The result simulated an SSB system with the carrier completely suppressed. These carriers were produced by two separate FSK transmitters; adequate separation of the carriers was maintained by separate frequency-stable control units. The reliance on these units was justified—in more than 10 years and over millions of operating hours, there are only two cases on record where such a pair of *reference frequencies* drifted enough to interfere with each other.

The widespread use of four-channel MUX/ARQ made it logical for use on actual SSB when facilities became available. This application required a center-to-center separation of 680 Hz between subcarriers. Initial systems were designed for three such subcarriers. Since SSB transmitters were available in the U.S. before SSB receivers were available abroad, a simulated SSB technique was applied. The middle subcarrier was dropped and a subcarrier added below the reduced carrier, thus providing sufficient separation to permit reception on three separate FSK receivers. This arrangement required a bandwidth of about 4 kHz, a rather unusual requirement, necessitating application for many bandwidth expansions from 3 to 4 kHz. By the time SSB receivers became available abroad, expansion often made it necessary to use three subcarriers on the upper sideband and one on the lower sideband. In some cases three subcarriers were used on each sideband, carrying a total of 24 teletype channels; this arrangement required a bandwidth of between 5 and 6 kHz.

Trials using two-channel MUX/ARQ showed that the separation between subcarriers could be reduced to 170 Hz; consequently, in a bandwidth of 3 kHz, up to 30 teletype channels could be accommodated. Additional benefits were expected because of: 1) the reduction of noise and interference from the use of narrow receiving filters, and 2) the advantages of two-channel MUX/ARQ over 4-channel MUX/ARQ, especially during adverse propagation conditions. Results have far exceeded expectations. However, a system already established on four-channel MUX/ARQ is costly to convert. Most countries using SSB also use ocean cables, and they tend to think of expansion by cable or satellite rather than by HF radio. The change to narrow-spaced, two-channel MUX/ARQ, worthwhile as it is, has therefore not advanced as rapidly as was possible.

PRESENT-DAY OPERATIONS

International record communication today is almost entirely by teletypewriter, and much of it is on MUX/ARQ systems. On the surface there is some uniformity; however, radio facilities, practices, and procedures vary from the most primitive to the most advanced, depending on the state of development of the countries involved. Even at some of the most advanced locations, expansion and ingenuity have kept in operation many facilities that would ordinarily have been retired long ago.

Control of Radio Facilities

The effect of all this is to impart a personality to each and every radio circuit. The CRF supervisor must know all these circuits, and he must estimate accurately the capabilities of each correspondent in meeting sudden departures from the routine, when such changes become necessary. Naturally, he must also know what the facilities under his control can do. He is aided by a considerable amount of data—a status board showing the current employment of all radio facilities at his center, frequency lists, transmitter lists, antenna lists, propagation data, and *talker* or telex channels close at hand for ready contact with distant points. However, these are merely aids; they do not solve problems, and most operating problems require solution immediately. Consequently, an excellent memory is a basic requirement for the CRF supervisor.

At the technical control center, needed frequencies are more readily available than they were 20 years ago. The several conserving factors mentioned earlier have, from this viewpoint, offset the growth of new frequency assignments and uses. At the transmitting station the effect of these changes is that frequency tolerances have been reduced, and regulations regarding spurious or out-of-band emissions are much more stringent. Here too, improved control equipment has kept pace. Most noticeable is the change at receiving stations, where the identification of a desired signal sandwiched between numerous close neighbors with the same type of emission has become an art.

HF Radio vs. Cables

RCA Communications, Inc. began using transatlantic coaxial channels for record communications in 1960. A single voice channel could carry 22 channels, which was about the same number that could be carried by the best HF SSB systems of that day. Freedom from ionospheric disturbances made the use of cable channels very attractive. However, cable interruptions have occurred, sometimes lasting several days, sometimes lasting weeks.

In between cable breaks, cable reliability has not been 100%. Long "tails" often going through several countries at the European end suffer outages much more frequently (though for much shorter periods) than do the ocean cables. They also produce distortion which may be difficult to locate. Cable diversification has grown. The reliability of most cable channels between cable breaks is on the order of 99% plus. This reliability figure can be equalled only on a few of the best HF radio systems. The number of cable channels has increased to the point that existing HF radio systems could not begin to carry the full load.

High-frequency radio proved invaluable as a backup during cable breaks. Most European correspondents have retained HF radio systems which are still carrying active channels, with additional capacity in emergencies, to pick up portions of the load which could not be handled by other means.

Over the past two decades or so HF radio has made great strides in reliability and capacity. Periods of total radio blackout have been reduced to about ½ of 1% of total operating time. Capacity has grown from 1 channel/frequency to 30 or more. A widespread and systematic application of RF propagation knowledge can reduce or eliminate the reliability gap between cables and HF radio to where cost and availability may be the deciding factor as to whether radio or cable channels will be used.

Cable voice channels are uniform entities: a specific bandwidth which may be subdivided into a reasonably consistent number of teletypewriter channels. Dividing total cable costs by total teletypewriter channels gives a reasonably accurate cost/channel figure. Radio systems, however, carry anywhere from one teletypewriter channel to 30 or more. Initial equipment costs for high-capacity systems are greater than for low-capacity systems; however, maintenance costs of the latter are almost always higher (because much of the equipment is older). The older systems take up much more floor space and use a good deal more power. To determine the cost of a radio channel, therefore, it is necessary first to determine the cost of the system, and then divide this by the number of channels.

Harmful Interference

Forty years ago if you heard another signal on your frequency, it did not belong there and was interference. However, increased activity and increased knowledge of propagation made it apparent that two or more agencies could use the same frequency without mutual interference. As equipment and techniques improved, the number of duplicated frequency assignments increased; today such assignments are numerous. Generally, the lower the frequency the greater the number of users, because the lower the frequency the greater the variety of uses. A good daytime frequency for a path of about 300 miles would be 7 MHz; across the Atlantic it would be one of the nighttime frequencies required.

The International Frequency Registration Board (IFRB) at Geneva endeavors to give status in the International Frequency List (IFL) only to those frequency assignments not likely to cause harmful interference to established users. These determinations are based largely on theoretical computations. If an agency receives an unfavorable finding from the IFRB, and can show 60 days of use without report of harmful interference, an entry is made to that effect; and a sort of status in limbo is established. This apparently successful use in the face of science may be due partly to the fact that many of the frequencies with which the new user should have interfered are not on the air. Some may have been unused for years; some may never have been used at all and are simply paper registrations. It is equally true, however, that propagation conditions are not constant. Conditions may favor a particular use (that is, eliminate its interference potential to another particular use) for months or years.

Inevitably, interference cases do arise, and when an identification is made, the user enjoying *priority* (the best date in the IFL) makes representations to the offender. Most cases are settled directly between users. Corrective action may be to cease using the frequency, to cease using it during certain hours, or to use it on a different antenna bearing.

Correspondence is usually by service message or by letter. Rarely is the degree of interference mentioned; that is, whether the interference causes complete stoppage, intermittant stoppage, or is merely a nuisance requiring more exact receiver tuning. The fact that the interference may be due to improper use, or use on an inferior antenna, by the complaining agency is never considered. Dates, times, and duration of the interference may not be mentioned and very often are not even required. The tendency is to take the complaint at face value. It is not possible to guess how many frequency assignments are made idle because of interference that occurs a few days a month, for a few months a year, for a few years of the 11-year cycle; but there must be many such cases.

Occasionally the IFRB asks a carrier whether, in a spirit of international cooperation, it will allow another agency to use a certain frequency for certain hours of the day. Thus, the thinking of almost all those in authority is geared to the assumption that propagation conditions are constant day in and day out, which they certainly are not.

The operations man must insist on a complete set of facts producing positive identification. An exchange of frequency measurements on one occasion showed an RCA frequency to be 2kHz removed from one "positively identified" as being the same assignment. In another similar case an interfering station, using the same SSB tones as ours and on approximately the same frequency as one of ours, was found to be a foreign station.

In those rare cases that are handled directly between competent and cooperative supervisors at the operating level, "serious and consistent" interference often is eliminated by one user or the other moving to another frequency in its complement without harmful effect to the circuit concerned. If such practices were more widespread (a more universal recognition of the fact that interference is not necessarily consistent from day to day), the usefulness of the HF spectrum might be doubled or tripled.

High-frequency complements are usually at or near the minimum required for reliable communication. This is considered good frequency management by most authorities; in fact, carriers have been urged to follow this practice as a means of conserving the HF spectrum. This often means using a frequency that is not optimum but is of usable strength. Such a frequency would certainly be optimum on some other path; thus creating an interference potential on the side lobes as well as the main beam of the antenna. The use of frequencies as close to the optimum as practicable would increase the number of frequency changes required per day and might complicate the work of frequency allocation. However, with effective coordination at operating levels that would ensure prompt removal of each frequency from the air when it is no longer required, interference potentials could be reduced, circuits would become more reliable, less transmitter power would be required, and, because each frequency would be used less by each user, increased use could be made of the spectrum.

A LOOK AT THE FUTURE

International radio carriers 15 years ago were distressingly familiar with marginal operations. Sending intelligence by telegraph messages was considered by some an antiquated method of communicating. Smart people used the telephone, or airmail. Something would have to be done if international record communications companies were to progress.

Something was done. International telex service and leased channel service, both pioneered by RCA Communications, Inc., made their appearance and grew phenomenally. Some thought these new and attractive services would practically eliminate previously established message service; but they didn't. Message traffic grew too; not spectacularly, but steadily, until today the volume is roughly twice what it was in 1948-1950.

In the long-distance communications field, new ideas are sprouting like weeds: ever-higher data speeds; 48-kHz systems switchable from cable to cable; and international TV on a regular and routine basis. In addition, telephone calls to persons overseas are becoming more frequent. Tremendous as cable and satellite capacity is, it will probably be hard put to keep up with demand.

It now appears that cables will not reach every part of the globe as was thought probable a few years ago. Satellites may, but this is not a certainty. Should a country, for example, with an immediate communications future of one message traffic channel, one telex channel, possibly one leased channel, and telephone service for two or three hours a day, set up a satellite ground station to carry this light load? It would be more convenient and less expensive to use HF radio.

Today HF radio is regarded by many in somewhat the same light as was message traffic 15 years ago. However, HF radio likewise has a place. If we apply what we know now, and do not neglect HF radio, it is quite likely that it will continue to be the most favored means for narrow-band communications. High-frequency radio, cables, and satellites are all assets—company assets and national assets. Common sense indicates we should strive to make the best use of all three.

A STUDY OF HIGHLY LINEAR, FM, VHF, SOLID-STATE OSCILLATORS

This paper describes internal modulation and heterodyning techniques that can be used to construct highly linear, wide-deviation, solid-state, frequency modulated oscillators. Such units are inexpensive and easily aligned. An analysis of FMO linearity is given, heterodyning techniques are discussed, and the test results of two solid-state FMO units are examined.

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DIRECT frequency modulation of an RF oscillator has usually been accomplished by use of a separate and distinct electrically variable reactance.[1] This technique is exemplified by the reactance-tube modulator and by the varactor-diode modulator. To obtain a large-deviation, highly linear variation of frequency with an electrical parameter by this technique requires elaborate circuits and tedious alignment procedures.

Direct frequency modulation of a transistor RF oscillator may be achieved also by varying the nonlinear capacitances associated with the transistor junctions. In this way a highly linear, frequency-modulated oscillator (FMO) may be realized with a simple circuit and a routine alignment. By properly heterodyning the output of a high-frequency FMO to a lower frequency, the deviation may be greatly extended while retaining the high linearity and other desirable characteristics of the basic oscillator.

The original analytical demonstration of linearity in an FMO was done by Mr. Leo Harwood of RCA. The essence of his analysis is given below.

ANALYSIS OF FMO LINEARITY

Within the UHF frequency range, the internal capacitances of a transistor become very influential. Thus, a Colpitts-type oscillator may be constructed readily with only one capacitor external to the transistor. In the circuit shown in Fig. 1, C_1 represents the transistor output capacitance, C_2 the emitter-to-base diffusion capacitance, and C_3 an external feedback capacitance. Since two of these capacitors are determined by the transistor itself, they may be changed by varying either voltage or current.

The variation of frequency with an electrical parameter can be made linear, as is shown by a simple analysis of the given Colpitts circuit. The frequency of oscillation is, for all essential purposes, given by

$$f_o = \frac{1}{2\pi\sqrt{LC_T}},$$

where C_T is the effective circuit capacitance given by

$$C_T = C_1 + \frac{C_2C_3}{C_2 + C_3}.$$

If higher-order terms are neglected, the relative frequency change due to an incremental change, ΔC_T, of the total capacitance, C_T, is given by the series expansion

$$\frac{\Delta f}{f_o} = -\frac{1}{2}\frac{\Delta C_T}{C_T} + \frac{3}{8}\left(\frac{\Delta C_T}{C_T}\right)^2.$$

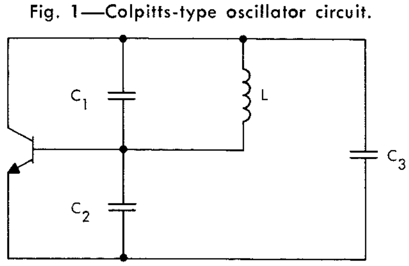
The output capacitance, C_1, is determined by the reverse-bias collector-base junction of the transistor. This capacitance is related to the applied potential, V, by the relation

$$C_1 = C_{10} + \frac{K_1}{\sqrt[3]{V}},$$

where C_{10} is the shell and lead capacitance and the contact potential is neglected. If the applied potential is changed by an incremental amount, the output capacitance is given by

$$C_1 + \Delta C_1 = C_{10} + \frac{K_1}{\sqrt[3]{V + \Delta V}}$$
$$= C_{10} + \frac{K_1}{\sqrt[3]{V}\sqrt[3]{1 + \frac{\Delta V}{V}}}$$
$$\approx C_{10} + \frac{K_1}{\sqrt[3]{V}}\left[1 - \frac{1}{3}\frac{\Delta V}{V} + \frac{4}{18}\left(\frac{\Delta V}{V}\right)^2\right]$$

Fig. 1—Colpitts-type oscillator circuit.



Final manuscript received April 14, 1966

Hence, the incremental change in output capacitance is

$$\Delta C_1 = \frac{K_1}{\sqrt[3]{V}}\left[-\frac{1}{3}\frac{\Delta V}{V} + \frac{4}{18}\left(\frac{\Delta V}{V}\right)^2\right].$$

However, because $\Delta V \sim -\Delta I$, this can be expressed as

$$\Delta C_1 = A\Delta I + B(\Delta I)^2,$$

where

$$A = \frac{K_1}{3V\sqrt[3]{V}} \quad \text{and} \quad B = \frac{4K_1}{18V^2\sqrt[3]{V}}.$$

The emitter-base diffusion capacitance, C_2, appears across the tuning inductor, L, in series with the feedback capacitance, C_3. Therefore, the effective capacitance is

$$C_2' = \frac{C_2C_3}{C_2 + C_3},$$

and

$$C_2' + \Delta C_2' = \frac{(C_2 + \Delta C_2)C_3}{C_2 + C_3 + \Delta C_2}.$$

Therefore,

$$\Delta C_2' = \frac{C_3(C_2 + \Delta C_2)}{C_2 + C_3 + \Delta C_2} - \frac{C_2C_3}{C_2 + C_3}$$
$$= \frac{C_3^2\Delta C_2}{(C_2 + C_3)^2\left(1 + \frac{\Delta C_2}{C_2 + C_3}\right)}$$
$$\approx \frac{C_3^2\Delta C_2}{(C_2 + C_3)^2}\left(1 - \frac{\Delta C_2}{C_2 + C_3}\right)$$
$$= \frac{C_3^2}{(C_2 + C_3)^2}\left[\Delta C_2 - \frac{(\Delta C_2)^2}{C_2 + C_3}\right].$$

However, C_2 is directly proportional to the emitter current and, hence, the base and collector currents. Therefore,

$$\Delta C_2 = K_2\Delta I,$$

and

$$\Delta C_2' = \frac{C_3^2}{C_2 + C_3}\left[K_2\Delta I - \frac{(K_2\Delta I)^2}{C_2 + C_3}\right]$$
$$= M\Delta I - N(\Delta I)^2,$$

where

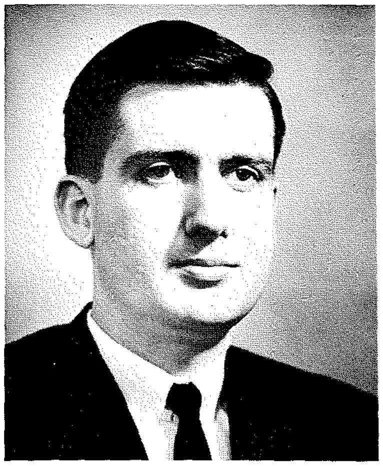
$$M = K_2\left(\frac{C_3}{C_2 + C_3}\right)^2$$

and

$$N = K_2^2\frac{C_3^2}{(C_2 + C_3)^3}.$$

The change in the total capacitance is, therefore,

$$\Delta C_T = \Delta C_1 + \Delta C_2'$$
$$= (M + A)\Delta I + (B - N)(\Delta I)^2,$$



ROBERT L. ERNST received his BEE degree from Manhattan College in 1961 and his MSEE from Polytechnic Institute of Brooklyn in 1965. From 1961 to 1963 he worked with the Radio Systems Div. of Western Union Telegraph Co. as a microwave engineer. In 1963 he joined the technical staff of the Solid-State RF Techniques Group of RCA, where he has developed interference-reduction techniques for microwave receivers; measured and analyzed the properties of resistive, varactor, and tunnel diodes; designed electronically tunable microwave bandpass filters; and analyzed ferroelectric capacitors for low-distortion microwave receivers. While with the Microwave Research Laboratory, Princeton, N.J., he evaluated a new mode of transistor operation and developed a transistor microwave power source in which a single transistor yielded watts of power at L-band frequencies. He is presently engaged in the design and development of voltage-tunable transistor microwave power sources. Mr. Ernst is a member of IEEE, PTGMTT, and Eta Kappa Nu.

TABLE I — Experimental Results

Model		Modulation Sensitivity (rms)	Modulator Linearity	NPR (dB)	BINR (dB)
Transistor mixer	A	30 mV/MHz	Less 0.6% over ± 1.5 MHz	53	53
	B	30 mV/MHz	1% over ± 3.5 MHz	57	52
Diode mixer	A	70 mV/MHz	1% over ± 1.5 MHz	50	50
	B	10 mV/MHz	Less 0.6% over ± 1.5 MHz 1% over ± 3.5 MHz	49	49

and the relative frequency change is

$$\frac{\Delta f}{f_o} = -\frac{1}{2C_T}[(M+A)\Delta I + (B-N)(\Delta I)^2] + \frac{3}{8C_T}[(M+A)\Delta I + (B-N)(\Delta I)^2]^2.$$

Assuming that higher than second-order products of ΔI can be neglected, the best linearity is obtained by making

$$\frac{1}{2C_T}(B-N) = \frac{3}{8C_T^2}(M+A)^2$$

or

$$B - N = \frac{3}{4C_T}(M+A)^2.$$

Thus, by varying the input current of a UHF transistor oscillator, it is possible to vary the frequency of oscillation in a proportional manner.

HETERODYNING TECHNIQUES

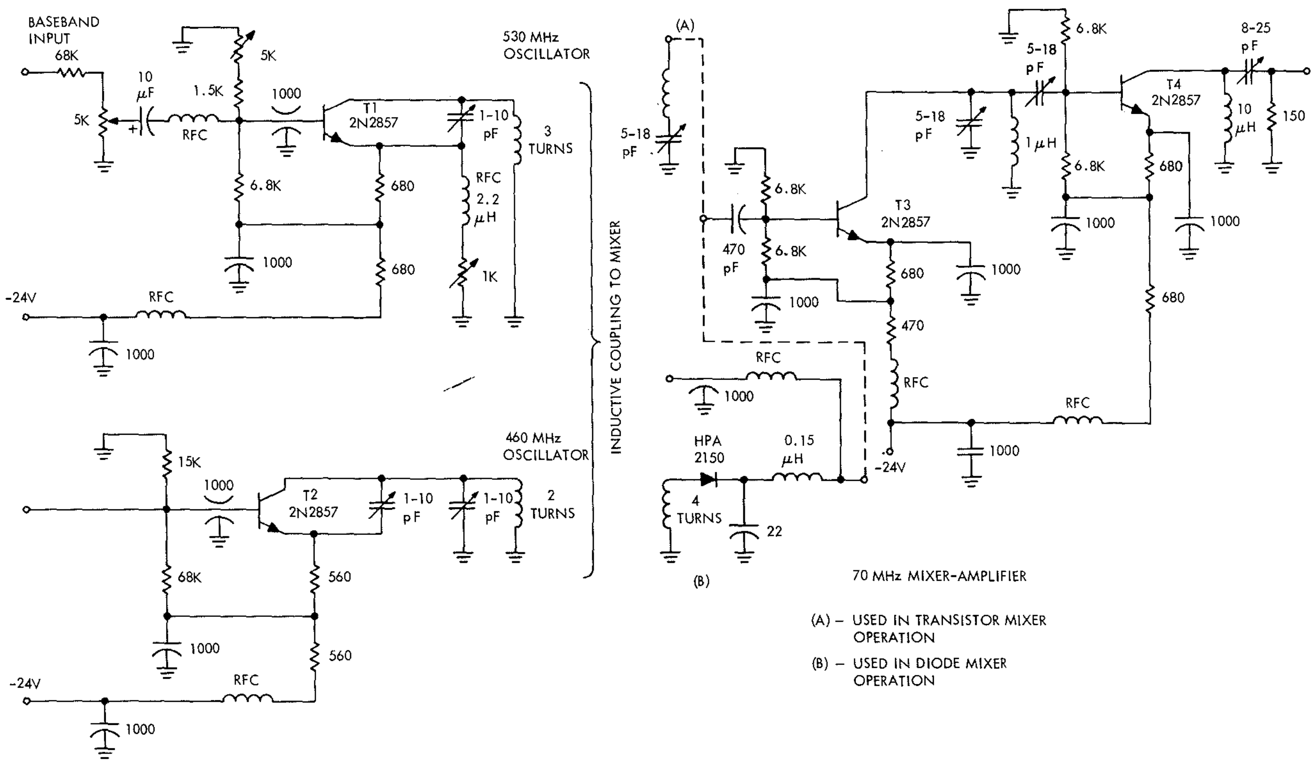
If a high-frequency FMO is heterodyned to lower frequency, the resulting unit will have a large relative deviation and a high linearity; e.g., a 530-MHz FMO may beat with a 460-MHz local oscillator (LO) to produce a unit which acts as a 70-MHz FMO.

The mixing process may be accomplished in any nonlinear device; transistor mixers or separate diode mixers are most commonly used. In the transistor mixer, the nonlinearity of the transfer characteristic is used to generate the difference frequency. Since the transistor is an active device, it is possible to design and construct a mixer which has gain. The diode mixer operates with a nonlinear resistance mechanism, and very efficient mixers have been designed using this method. The *hot-carrier* diode,[2] which can withstand large LO powers, is capable of mixing with low intermodulation distortion.[3]

LARGE-DEVIATION FM OSCILLATORS

By combining the internal modulation scheme with the heterodyning technique, a unit with both large frequency deviation and high linearity may be readily

Fig. 2—Schematic diagram of solid-state, 70-MHz frequency-modulated oscillators.



constructed. The schematic diagram of such a device, which beats a 530-MHz FMO with a 460-MHz LO to produce a 70-MHz output, is shown in Fig. 2. Both oscillators have similar aging and temperature characteristics; therefore, the output signal, being at the difference frequency, should be relatively stable. If required, automatic frequency control can be applied to the LO without affecting frequency linearity. The linearity of the FMO can be altered by the proper bias, which is experimentally determined by varying two rheostats (Fig. 2).

EXPERIMENTAL RESULTS

Two models of the solid-state FMO were tested. One model used transistor $T3$ as a mixer; the other model used a hot-carrier diode as a mixer and transistor $T3$ as a 70-MHz amplifier. The outputs of both models were examined with a Tektronix 661 sampling oscilloscope.

Because of poor shielding and high radiation from the two oscillators, the unmodulated output of the transistor mixer model consisted primarily of the linear sum of the two oscillator outputs. Although this sum has the appearance of an amplitude-modulated signal (Fig. 3a), the shape of this wave is caused by linear addition, as shown by the equation

$$\cos \omega_1 t + \cos \omega_2 t = 2 \cos \frac{\omega_1 + \omega_2}{2} t \cos \frac{\omega_1 - \omega_2}{2} t.$$

Thus, the sum of a 460-MHz signal and a 530-MHz signal (Fig. 3a) is equivalent to the product of a 35-MHz signal and a 495-MHz signal. Since the amplitude of this wave is constant, it is concluded that the 70-MHz component is very small relative to the oscillator radiated outputs.

The output of the diode-mixer model was a clean 70-MHz signal of +2-dBm magnitude (Fig. 3b). The radiation of the oscillators was restricted by shielding. By using a Tektronix type 585 high-frequency oscilloscope, which behaves as a low-pass filter, only the 70-MHz components of each unit were displayed. The output of the diode model exceeded the 70-MHz component of the transistor models by 20 dB.

The modulator linearity, noise-power ratio (NPR), and baseband-intrinsic-noise ratio (BINR) were measured using standard techniques. The variation of linearity with oscillator frequency was displayed on an oscilloscope by using an RCA delay and linearity test set. The NPR and BINR were determined directly by using a Marconi noise loading test set. Table I shows the results of these measurements. Measurements A resulted when the oscillators were set to 460 MHz and 530 MHz, respectively. When the linearity of the FMO was changed by adjusting the bias rheostats shown in Fig. 2, the overall output frequency was changed from 70 MHz. This condition was corrected by a corresponding adjustment of the frequency of the LO. However, knowledge of the actual frequencies of the FMO and the LO is not important in optimizing the overall performance of the unit. Measurements B resulted when these frequencies were changed to improve linearity while maintaining a 70-MHz difference frequency.

In earlier versions of the transistor mixer model, the NPR and BINR were both 40 dB. These earlier models did not have the isolation shown in the bias circuits of Fig. 2, and shielding plates were not used between the transistor stages.

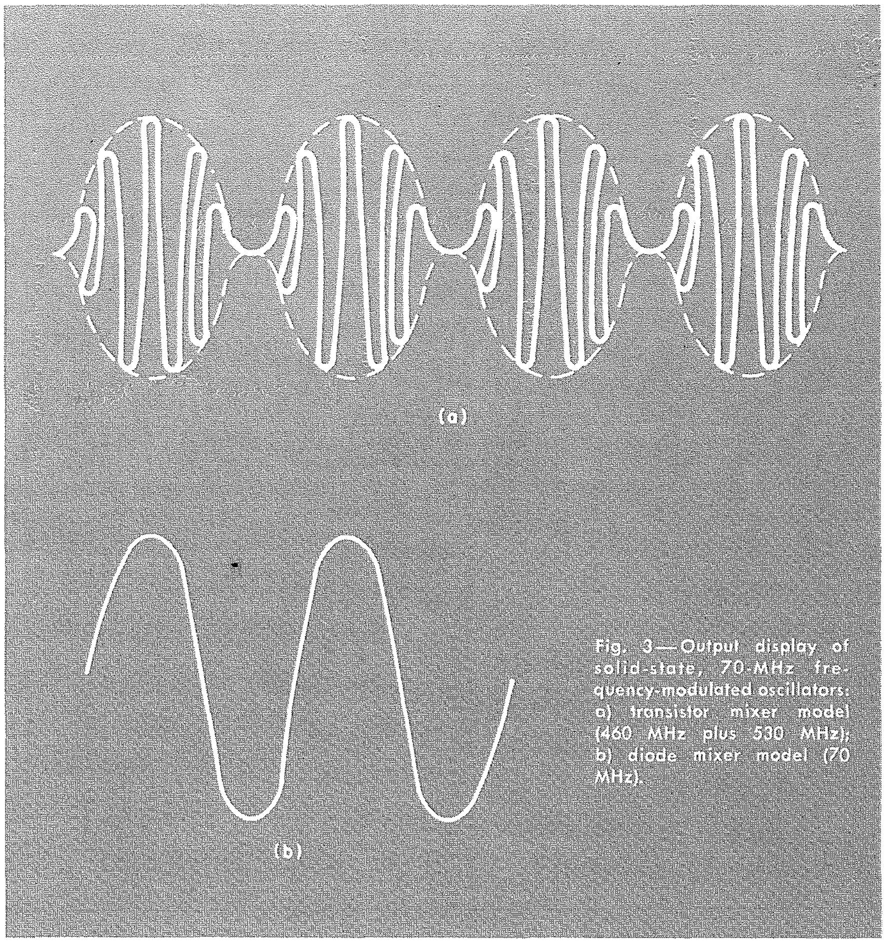


Fig. 3—Output display of solid-state, 70-MHz frequency-modulated oscillators: a) transistor mixer model (460 MHz plus 530 MHz); b) diode mixer model (70 MHz).

CONCLUSIONS

By properly using the internal modulation and heterodyning techniques described in this paper, a highly linear, wide-deviation, solid-state FMO may be readily constructed. The oscillator units are inexpensive and easily aligned.

Various discrepancies in the results of Table I indicate the need for more accurate measurements. Although the NPR would normally be expected to improve when the linearity is optimized, the device becomes noise limited and, thus, both the NPR and the BINR become slightly degraded. Furthermore, since the use of a hot-carrier diode mixer results in lower intermodulation distortion and greater power output, the NPR and BINR should show improvement over the transistor mixer model. A more reliable evaluation and comparison of the mixer stages should result by using the same transistors in the rest of the circuit. In other words, rather than compare separate units having different mixers, the mixers should be inserted in turn into the same unit, and the resulting change in performance measured. In this way, the mixer stage is the only variable, and its change in over-all performance may be determined reliably.

A detailed study of the oscillator units is required to determine the best operating conditions in terms of linearity, sensitivity, and noise performance. These conditions include operating frequency relative to the transistor cutoff frequency, selection of bias points, and circuit configuration.

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2. RCA Quarterly Report No. 4, *Interference Reduction Techniques for Receivers*, Contract No. DA 36-039-AMC-02345(E), pp. 64-67, October 31, 1964.
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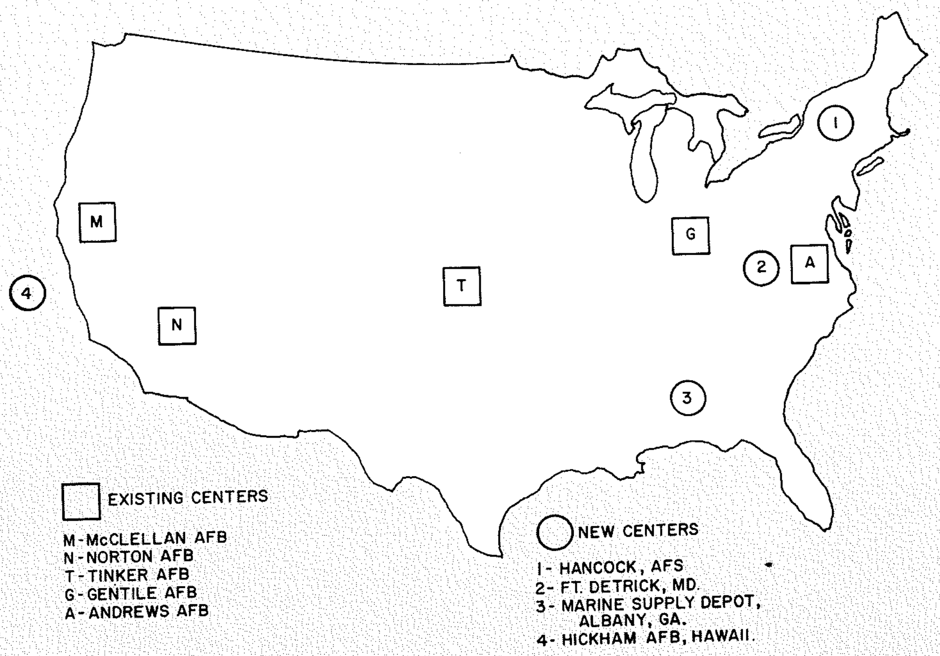
Fig. 1—Locations of AUTODIN switching centers.



EXPANSION OF DCS AUTODIN SYSTEM

This paper discusses the expansion program for the Automatic Digital Network, the data portion of the Defense Communication System. The expansion program, being performed by RCA and Western Union Telegraph Co., will provide a system with nine switching centers and a capacity of 2700 full-duplex channels. The original five-center system is described, and the configuration and capabilities of the expanded system are detailed.

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RCA is completing a contract for a five-fold expansion of AUTODIN (AUTOmatic DIgital Network), the data communication portion of the Defense Communication System. AUTODIN first became operational early in 1963 when it consisted of five switching centers, interconnecting 550 full-duplex communication channels. In March 1964 the Department of Defense requested that the system be expanded to include nine switching centers with a capacity of 2700 full-duplex channels. This paper describes the original five switching centers and the program for expansion which is now approaching completion.

The initial AUTODIN switching centers were developed by RCA on subcontract to the Western Union Telegraph Co., which was responsible to the U.S. Air Force for the entire network including lines and subscriber terminals. The contract provided for five switching centers—two on the west coast, one in the central United States, and two in the eastern part of the country (Fig. 1). Each center included a message switch and a circuit switch, which were connected to subscriber lines and trunks through the technical control (Fig. 2). Subscribers connected to the message switch were provided with store-and-forward service.

Subscribers connected to the circuit switch had either direct circuit switched service or store-and-forward service depending on the messages and on the message handling required. This system has been described in several papers, referenced at the end of this article.

The resulting network provided many service features never before available, including: automatic code, speed, and format conversion to allow intercommunication between unlike subscriber terminals; automatic error detection and correction for all data subscribers and on all trunks; automatic priority handling for six levels of priority with interrupt capability for the highest two levels; and automatic security checks on all channels, with automatic alternate routing of classified traffic to a security alternate. For the circuit-switching subscriber, it provided a direct, real-time connection or store-and-forward message switch service. The latter is often advantageous since it provides multiple address and group address capabilities in addition to traffic handling at much higher trunk loads than is possible with circuit switching service. For the communicator, the network provides completely automatic traffic handling, automatic accumulation of traffic statistics, automatic alternate routing, and intercept capabilities for out-of-service channels.

In 1964, after the Department of Defense determined that a system expansion was required, Western Union and RCA undertook the expansion program now approaching completion. Equipment for four additional switching centers has been constructed, and the existing centers have undergone considerable modification. The first new center, Hancock AFB, is now installed and operational; the second, Ft. Detrick, is installed awaiting final acceptance testing. Hardware for the remaining new centers, completed at the RCA Camden factory, will be installed as soon as facilities are completed. The existing centers have been modified and the revision program, to take advantage of the hardware modifications, will be activated after a "live" verification at Hancock AFB.

SWITCHING CENTER CAPACITY

Before expansion the network consisted of five switching centers. Each center terminated 50 full-duplex lines on the message switching unit (MSU) and 50 full-duplex lines on the circuit switching unit (CSU), with the exception of the Tinker AFB center, which terminated 100 full-duplex lines on the MSU and 50 on the CSU. These terminations are used interchangeably for: 1) subscriber or user terminations, 2) trunk terminations, and 3) MSU/CSU interchange channels.

Each MSU at the five existing sites is being expanded to 250-channel capacity, and new MSU's with 250-channel capacity are being provided at the four new sites. A new 50-line CSU is being provided at each of the four new sites.

EQUIPMENT CONFIGURATION OF PRESENT CENTERS

The equipment configuration of the present switching centers is shown in Fig. 3. Subsequent paragraphs describe the individual units from a functional standpoint and indicate the role of each in the

Final manuscript received April 18, 1966

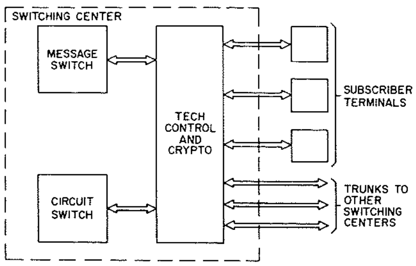

Fig. 2—Block diagram of AUTODIN system.

flow of traffic. Redundant elements ensure continued system operation during periods of scheduled maintenance or equipment outage.

Buffers

Each communication channel is terminated with a MODEM, which converts tone-modulated signals to DC pulses suitable for digital circuits. These pulses are stepped into a buffer which assembles one character of information and also serves as an output staticizer, storing a single character of information while the bits forming that character are stepped out to the communication channel. The buffer is a small unit that can be provided in a number of configurations to tailor system input characteristics to those of an individual channel. Three types of buffers are provided; these are for operation with 1) low-speed synchronous channels (up to 600 bauds), 2) high-speed synchronous tributary and trunk channels (up to 4800 bauds), and 3) teletypewriter channels.

Accumulation and Distribution Unit (ADU)

The ADU accumulates the incoming characters associated with each channel to form *chunks* of information suitable for efficient processing by the communications data processor (CDP). For outgoing channels, the ADU performs the opposite function, accepting chunks of information from the CDP and distributing them to the appropriate outgoing buffers, one character at a time.

The ADU performs error control functions for the synchronous (data) channels. Transmission over synchronous channels is in groups of 84 characters, referred to as line blocks. Each line block starts with a pair of special control characters and ends with another pair of control characters. The last character in each block is a longitudinal parity-check character which, together with the character parity bits, provides a nearly foolproof check on the accuracy of tranmission. As each line block is received and found to be accurate, the ADU acknowledges the block and the sending station proceeds to the next block. If the block is found to be in error, the ADU rejects it and sends an error signal, causing the sending station to repeat the in-error block. The ADU performs these control procedures for both incoming and outgoing traffic and mechanizes them through logic common to all its channels.

A separate core memory in the ADU, known as the procedure memory, stores the sequence for servicing channels, the locations associated with each channel, the code conversion required, and the status of channel coordination. The procedure memory can also store code conversion tables for up to four different channel codes. Channel speed or code assignments may be easily changed by simply changing the data stored in the procedure memory.

Communications Data Processor (CDP)

The central unit of the message switch, the CDP, is a stored-program digital computer that has been tailored to this application. This computer tranfers incoming data from the ADU's to an intermediate store where messages are queued, and transfers outgoing messages back to the ADU's in accordance with first-in first-out and precedence rules. In making these transfers, the CDP performs routing, code and format changing, bookkeeping, and control functions. The operation of the CDP is described in greater detail under "Computer Programming."

Drum Storage Unit (DSU)

The DSU provides storage for relatively large amounts of information, with a relatively short access time. It is used to store: 1) messages in queue, 2) ledger information for use in the event of an error or equipment failure during the succeeding program cycle, and 3) seldom-used program routines.

The DSU is used mainly for storage of messages awaiting transmission to outgoing channels. Each message is stored only once, even though the message may have to be distributed to several subscribers and trunks. Queue lists maintained in the high-speed memory may contain several entries referring to the same message in intermediate store. Tables mapping the available drum space do not show a drum area cleared until all copies of a particular message have been transmitted.

Magnetic Tape Units

Thirteen tape transports are assigned to the CDP for bulk storage of information. Two additional tape transports are assigned to the tape search unit. The following functions are provided:

1) Reference File—One transport is used to file a copy of every message processed in the center. This file is maintained in a library for several days in order that an additional copy of a message may be sent if requested.
2) Journal File—One transport files the identification of every message processed into or out of the center, the channel over which the message was transmitted, the time of day, and the location of the message in the reference file. This file contains data for tracing messages through the network and for gathering management statistics.
3) Intercept—Two transports are available to receive traffic addressed to channels unmanned at night or otherwise out of service. These tapes permit the removal of large amounts of traffic which would otherwise overload intransit storage capabilities.
4) Intercept Input—One transport allows reels of intercepted traffic to be reintroduced into the message switch.

H. P. Guerber (standing) and J. A. Kalz

HOWARD P. GUERBER received his BSEE and MSEE degrees from the University of Colorado in 1947 and 1954, respectively. He joined RCA in 1950, after two years with Westinghouse Electric Corp. His first assignment at RCA was on feasibility studies that led to the development of the RCA Bizmac computer systems. From 1951 to 1953 he served with the U.S. Navy. On returning to RCA, he participated in the development of the Bizmac system. Later he was engaged in the study and proposal effort that led to the development of the Air Force ComLogNet switching centers. From 1959 to 1963 as Leader, Systems Engineering, he directed the systems engineering efforts on the ComLogNet—AF DataCom—AUTODIN message switching centers. Mr. Guerber has co-authored five papers on automatic switching networks and holds five patents. He is a member of IEEE and ACM.

JAMES A. KALZ received his BSEE degree from the University of Minnesota in 1949. Following graduation he served as a communications officer in the U.S. Air Force. He joined RCA in 1952 as a microwave equipment design engineer in the Industrial Electronic Communications Department. For the next 7 years he was involved in the design of microwave transmitters, receivers, and associated baseband, monitoring, and automatic switchover equipments, and in the system application of these equipments. Since 1959 he has been a Systems Engineer on the ComLogNet and AUTODIN Projects, establishing requirements for, and evaluating and specifying system approaches for, hardware and software for message and circuit-switching systems.

5) Overflow Store—Three transports are available for temporary storage of messages in case the amount of traffic and its statistical distribution overload the drum storage unit.

6) Program Library—One transport holds the program tape, and provides for rapid entry of the production program and test and maintenance routines.

7) Tape Pool—The remaining transports are assigned as spares. They can be assigned to a tape pool where they will be available for automatic switching, under program control, into any of the above file functions while filled tape reels are being removed or replaced. They can also be used with the off-line CDP.

Tape Search Unit (TSU)

A small off-line processor, the TSU is used to derive statistical information from the journal file and to recover messages from the reference file. The outputs from this unit may be recorded on an output tape, punched in paper tape, or printed out. Two tape transports are used.

High-Speed Printer (HSP)

This unit provides the means for extracting reports from the processor while it is processing traffic. It is also used as a programming aid for dumping memory.

System Console

The system console contains indicators that display the status of each system unit and of each channel. It also has monitor printers to print out program alarms, and controls to implement various procedural changes, such as putting a channel *on* or *off* intercept status.

Circuit Switching Unit (CSU)

The CSU provides the crosspoint switches and common control needed to establish circuit-switching connections. In the Continental United States, AUTODIN is a combined message-switching/circuit-switching network. Message switch channels are connected directly to the message switching unit; circuit-switching channels are terminated in the CSU. The CSU provides direct-connection capabilities between circuit-switching subscribers that operate at the same speed. It allows circuit-switching subscribers to be connected into the message switching unit for the relay of messages to message-switching subscribers or to circuit-switching subscribers operating at different speeds or for processing of multiple address messages, group address messages, and messages requiring format conversion. In addition, the CSU allows the message switching unit to deliver messages to circuit-switching subscribers.

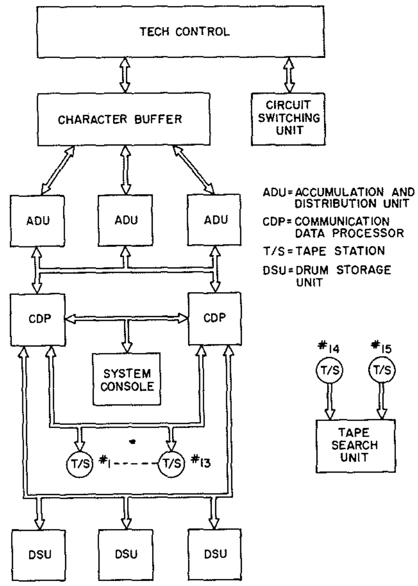

Fig. 3—Equipment configuration of existing switching centers.

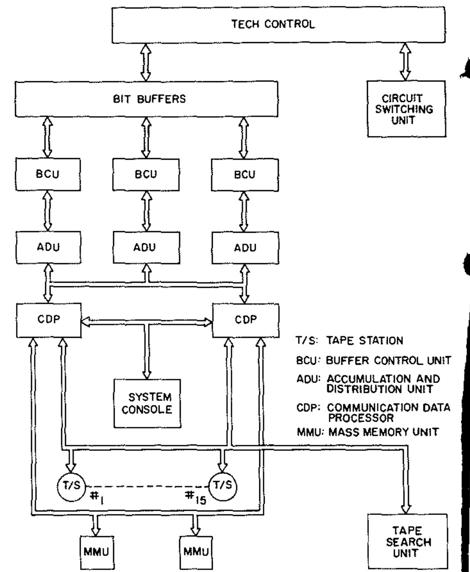

Fig. 4—Equipment configuration of expanded switching centers.

EQUIPMENT CONFIGURATION OF EXPANDED CENTERS

This section describes the design changes made to support the expansion of existing AUTODIN switching centers. The expanded configuration is shown in Fig. 4, and the characteristics of the modified units are shown in Table I.

Buffers and Buffer Control Unit (BCU)

Character buffers are used in the existing system to terminate each connected channel. These buffers consist of about 20 plug-in modules each. Expansion to 250 channels would require 5000 plug-in modules in this one area alone. To avoid such an increase in hardware, a new concept was adopted by which only a single bit of information is buffered for each incoming and each outgoing channel. The bit buffers are scanned by a buffer control unit, which assembles the bits arriving from each channel in a common core memory until a character of information is formed. This character is then transferred to the ADU through an interface similar to that of the character buffers.

Accumulation and Distribution Unit (ADU)

The ADU's in the existing centers service up to 25 full-duplex channels, which can operate at speeds from 60 words per minute teletype to 4800 bits per second data. The modified ADU will operate with up to 125 full-duplex channels, provided only that the aggregate bit rate of all channels does not exceed 127,500 bits/second (in one direction). For example, a mix of 100 low-speed lines operating at 150 bits/second and 25 high-speed lines operating at 2400 bits/second has an aggregate rate of 75,000 bits/second and is within the capacity of the modified ADU.

System Console

The system console in the present installation has separate indicator lamps for each channel which display deviations from normal character propagation. To handle 250 channels, this display has been changed to a common numerical display which will sequentially show the channel designations for channels in trouble and indicate the nature of the problem.

Mass Memory Unit (MMU)

Because of the greater number of channels to be serviced, a substantial increase in the in-transit storage capacity is required. To provide the additional capacity, a disc file, known as the mass memory unit, is being used. One MMU will operate in parallel with the drum storage units at the present sites. At the four new sites, two MMU's will provide the in-transit store.

Tape Search Unit (TSU)

At the new sites, a general-purpose computer will perform the functions of the tape search unit. This computer and its peripheral devices, known as a recovery and management system, will be used to obtain statistical reports relative to channel use and message flow, in addition to off-line recovery of message information. A system change at new and existing sites permits the TSU to access four of the 15 magnetic tapes, under control of the system console.

Magnetic Tape Units

The reference and journal files were combined into a history file. Redundant copies are maintained for message protection purposes.

COMPUTER PROGRAMMING

The computer programs for the communications data processors (CDP) have undergone substantial augmentation. These programs are an integral part of the switching-center system. Previous experience on this and on other real-time systems has shown conclusively that careful coordination of hardware and software is a vital requirement for successful system operation.

The current program at the five message-switching centers performs all functions required for the handling of message traffic. These can conveniently be divided into three areas: 1) message switching functions, 2) message processing functions, and 3) message bookkeeping and protection functions.

The message switching functions of the program are concerned with accepting messages in incoming channels and delivering them to outgoing channels. The first part of the incoming message, called the header, indicates the destination and determines the network routing in accordance with a stored routing table.

The system recognizes six levels of precedence, and transmits all messages of a specific precedence before transmitting any messages of a lower precedence. The two highest levels of precedence have a priority interrupt feature; i.e., if a message of lower precedence is being transmitted over an outgoing channel when a priority message arrives, the lower precedence message is cancelled and the priority message is sent out. The lower precedence message is retransmitted in appropriate sequence with other messages in queue.

An important message-switching program function is intercept. Stations for which traffic is to be held can be placed in an intercept status. An example of such a situation is a subscriber terminal that is manned only during office hours, and for which unattended operation is not desired. Traffic for a subscriber in intercept status is sent to an intercept magnetic tape and stored there until reentered under operator control.

The major function performed by the message processing program is message exchange. Message exchange refers to the handling of messages from unlike subscriber terminals, e.g., from a card terminal to a teletype terminal. In the case of unlike terminals, the message speed (bit rate), code, and format must be changed before the message is set to its destination.

Message protection functions are needed because the switching center is responsible for delivering every message received. All incoming messages are stored on magnetic tape, so that they can be retrieved off-line on the tape search unit if required. This *history* tape provides a basis for message recovery in the unlikely event that equipment malfunction might destroy the queue lists or in-transit store of messages. At the end of each program cycle, a *snapshot* of system status is recorded on the in-transit store. In case of failure of one of the CDP's, the standby CDP will read in the snapshot and use it as the starting point for message processing. This snapshot is called the drum ledger and the program that uses it to bring the off-line CDP into operation is called the restart program.

Each of the program functions described above is being expanded and modified to meet new requirements. The objective of the reprogramming is to expand the features provided in the switching center and at the same time operate more rapidly to keep up with the heavier traffic load. As a result, the new centers will provide the same fast service for message traffic as is presently provided at the existing centers.

TABLE I—Equipment Characteristics at Expanded Centers

Unit	Number Provided Existing Sites/New Sites	Characteristics of Each Unit
Buffer subsystem		
Bit buffers		Staticizes one bit of information on input side and one on output of full-duplex channel (any type).
Bit buffer unit (BBU)	2*/2	Provides housing and logic control for up to 128 full-duplex bit buffers.
Buffer control unit (BCU)	3/3	Provides scanning control, character framing, and character assembly for 1-bit buffer unit.
Accumulation & Distribution unit (ADU)	3/3	Controls up to 125 full-duplex channels provided that aggregate traffic does not exceed 127,500 bauds. Recognizes start and end of message. Provides up to four different code conversions. Checks character and block parity. Provides automatic repeat of blocks received in error.
Communication data processor (CDP)	2/2	Controls up to four ADU's. Contains 32,000 words of memory, 56 bits/word. Memory cycle time: 1.5 μs.
Mass memory unit (MMU)	1*/1	Storage capacity: 1,290,240 8-bit characters. Access time: 33.6 ms (average). Information transfer rate: 500,000 characters/sec.
Tape stations	*/15	Tape speed: 112½ in/sec. Information transfer rate: 46.8 or 30.4 8-bit characters/sec. Reel capacity: 2400 ft.
System console (SC)	1/1	Displays status of all system units. Combined (cycling) display of status of all channels.
Recovery & management subsystem (RMS)	1/1	General-purpose computer; 20,000-character (7-bit) memory capacity.
High-speed printer (HSP)	*/1	Printing rate: 1000 lines/min. 120 character lines. Alphabet: 64 characters.

* At the existing sites, presently installed hardware will continue to be used.

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COMPUTER-AIDED DESIGN OF WAVEGUIDE FILTERS

This paper describes a comprehensive computer program for the design of waveguide bandpass filters. The computer prints out the exact mechanical dimensions of the filter, which can be transferred directly to an engineering drawing. The printout also provides the electrical network analog, isolation-vs.-frequency responses, and passband group delay characteristics. The program has been exhaustively tested for maximally flat and Tchebychev filters containing 2 to 10 sections.

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The demand for microwave filters has grown enormously over the past few years, and the waveguide bandpass filter has emerged as the most widely used structure. Increasing use of large-index, wideband, FM systems and the consequent congestion of the frequency spectrum have often generated the need for filters that meet very stringent specifications. The program for computer-aided design of waveguide bandpass filters described in this article was started with the following objectives: 1) to provide the designer with the exact performance data of the filter, 2) to take the drudgery out of his work, and 3) to reduce the lead time between the submission of a requirement and the production of a satisfactory design.

DEVELOPMENT CYCLE

The typical development cycle of a filter, sketched in Fig. 1, can be conveniently divided into four major areas. The initial stage, at which engineering intervention is required, transforms the input requirement into a format that enables the designer to specify the basic parameters of the filter by the use of various design charts.[1,2] The second stage, which is mainly computation, synthesizes the electrical analog, i.e., the definition of the filter in terms of the iris susceptances and the electrical lengths of the cavities. The third stage of the cycle includes the preparation of sketches of the required filter and the fabrication and test of a prototype. The format of the computer printout is arranged so that the transfer of dimensions to a standardized sketch of a filter is facilitated. The last stage, at which designer intervention is really necessary, is the evaluation of the predicted and measured performance of the filter. The decision taken may be: 1) to reject the filter as unsuitable for the given requirement and restart the cycle at stage one, 2) to make slight modifications to the mechanical dimensions of the filter to improve its performance and restart at stage three, or 3) preferably, to proceed with the manufacturing drawings and production.

Final manuscript received March 29, 1966.

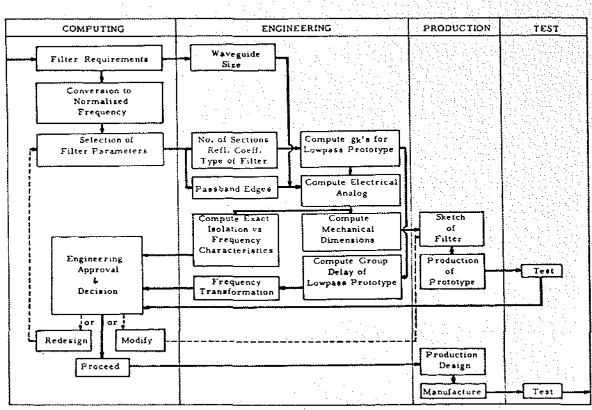


Fig. 1—Typical development cycle of a filter.

FILTER REQUIREMENTS AND SELECTION OF PARAMETERS

From the system requirements, the designer can usually extract four basic design criteria:

1) Minimum passband width
2) Maximum reflection coefficient (or amplitude ripple) in the passband
3) Maximum stop-band width
4) Minimum insertion loss at required stop-band width.

A frequency transformation is necessary to convert the bandpass filter frequencies centered on f_o to normalized low-pass prototype frequencies.[3] A multitude of graphs and monograms are available[2,4] to aid in the selection of filter parameters in terms of the normalized frequency response of low-pass prototype filters.

Since an infinity of filter designs can satisfy the four basic requirements, a further criterion has to be introduced. This could be the minimum passband loss, small group delay, or minimum number of cavities (and thus the cost).

Based on the above considerations, three parameters are selected which completely specify a low-pass prototype filter possessing a passband of 1 rad/sec.

1) Type of filter: maximally flat or equal-ripple Tchebychev
2) Number of sections: n
3) Reflection coefficient in passband: R in dB

The use of reflection coefficient R in preference to the commonly used amplitude ripple A_m for Tchebychev filters or the half-power points for the maximally flat filter has the advantage of a uniform description regardless of filter type.[2]

To convert to a waveguide bandpass filter, two more parameters are needed:

4) Waveguide size
5) Design passband width. (The design passband can be wider than the required passband, since the designer has a certain amount of freedom in specifying this parameter while still meeting the other requirements.)

The five parameters listed above provide the basic input data to the computer.

COMPUTER SUBPROGRAMS

The following paragraphs describe the various subprograms that constitute a typical computing procedure. The subprograms may be divided into three categories: 1) synthesis of an electrical analogue, 2) prediction of the filter behavior, and 3) conversion to mechanical dimensions. Wherever known techniques are used, only brief descriptions and reference to original literature are given.

Synthesis of the Electrical Analog

There are two stages in the electrical design procedure. In the initial stage, the low-pass prototype filter is synthesized from the first three inputs listed above. The low-pass prototype is then transformed to a direct-coupled waveguide bandpass filter with the desired passband. This procedure was first described by Cohn,[3] and a complete set of equations are available.[4]

Low-Pass Prototype Subprogram

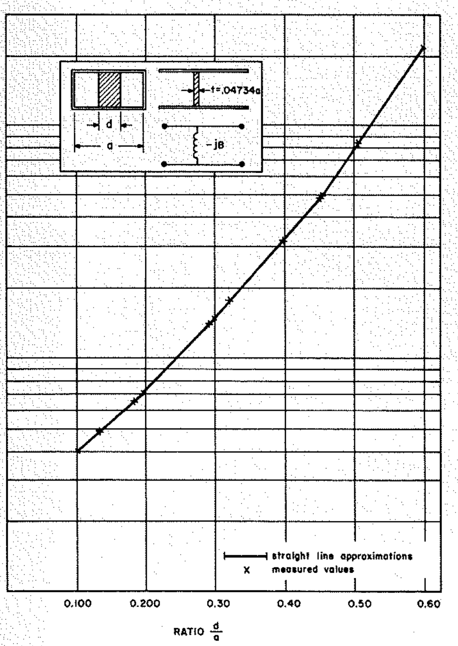
This subprogram consists of the basic equations given in Ref. 4 suitably modified to permit a uniform description of all filters in terms of their return-loss bandwidth. Although tables of low-pass prototype elements for maximally flat and Tchebychev filters are available, this subprogram was included to reduce the input data and to give the designer more flexibility in his choice of passband characteristics.

Electrical Analog Subprogram

The input data to this subprogram consists of the waveguide size, the frequencies defining the passband width, and the low-pass prototype elements calculated in the previous subprogram.

The electrical analog consists of $(n + 1)$ normalized shunt susceptances designated b_1 to b_{n+1}, and n line lengths in radians, both being evaluated at FR, the center frequency of the filter. This is defined, and computed, as the frequency at which the guide wavelength is the arithmetic mean of the guide wavelengths at the passband edges.

Fig. 2—Normalized susceptance of inductive irises in rectangular waveguide at f = 1.44 fc.



PREDICTION OF FILTER BEHAVIOR

Insertion Loss vs Frequency Response

The historical origin of this program was the prediction of insertion loss over a very wide frequency range where the standard frequency transformations[1-3] give erroneous results. This method, which consists of evaluating the total transfer matrix of the filter at each individual frequency, is possible only because of the speed and ability of modern digital computers to handle large numbers. The heart of the program is a matrix multiplication loop which sequentially multiplies individual transfer matrices of shunt-susceptances and line lengths in the proper order.

Starting with the electrical analog, where the values of the shunt susceptances and line lengths are given at FR, the center frequency, the program first computes their values at the frequency of interest. For the line lengths this involves a simple multiplication by the ratio of guide wavelength at F to that at FR. For the susceptances, however, some assumption about their frequency variation has to be made. An assumption that is frequently, but not exclusively, used in this program is that the susceptances vary linearly with the guide wavelength.[3] This assumption involves the division of each susceptance by the above ratio.

The program forms the individual transfer matrices of the susceptances and line lengths and multiplies them to get the total transfer matrix of the filter. The evaluation of the insertion loss then follows.[4]

This program is keyed to compute and print out the insertion loss between any two designated frequencies with a specified frequency interval.

Group Delay vs Frequency Response

A knowledge of the group delay contribution of microwave filters is often mandatory in applications involving high-quality satellite or earthbound communication systems. This subprogram accepts the low-pass prototype elements computed previously and computes the phase, absolute group delay, and relative group delay of the prototype using the equations given in Ref. 5. A suitable frequency transformation is employed to convert these quantities to those of the required bandpass waveguide filter.

Conversion to Mechanical Dimensions

The real success of this program has been in its ability to convert the electrical analog, which is exact within the bounds of its assumptions, to its mechanical equivalent.

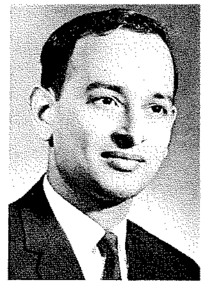
The first step is to convert the electrical line lengths to cavity lengths in inches by the use of the formula

$$l_{ij} = \theta_{ij} \cdot \frac{\lambda_{go}}{2\pi} \qquad (1)$$

where θ_{ij} is the electrical and l_{ij} is the mechanical length of the ith cavity between the centers of the shunt irises. A 2.5% shortening of the cavity lengths is introduced so that the filter tunes slightly higher in frequency and can be brought down to the required frequency by slight insertion of a capacitive tuning screw.

To convert the shunt susceptances into iris dimensions has always been a major stumbling block because the susceptance is a function of both iris dimension and frequency. The frequency parameter is eliminated by converting the required susceptances to normalized susceptance values at a standardized frequency. The curve relating the logarithm of the normalized susceptance to the normalized iris width can be approximated very closely by segments of straight lines. (The derivation of this procedure is described in subsequent paragraphs.) This empirical relationship is stored in the computer memory and the computer interpolates on the appropriate straight lines to give the normalized iris widths.

Lastly, to conform with standard drafting procedures, the computer performs a simple arithmetic operation to relate the dimension of each cavity and the location of each iris to the center of the filter. This is then printed out in a format that can be transferred to a



N. K. M. Chitre

M. V. O'Donovan

N. K. M. CHITRE received B.Sc. and M.Sc degrees in Physics from Banaras Hindu University in 1953 and 1955, respectively, and the M. Tech. degree in Electronics from the Indian Institute of Technology, Kharagpur in 1956. After a year with Van der Heem, N.V., The Hague, he studied at the Imperial College, London, where he received his diploma (D.I.C.). In 1962 he received his Ph.D. degree from the University of London. In March 1963 Dr. Chitre joined RCA Victor Co., Ltd., Montreal, where he is now assigned as a Specialist Engineer in the Antenna Engineering Department. He has worked on microwave communications systems, both overland and satellite, and has designed various microwave multiplexing networks, filters, and ferrite components.

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standardized filter sketch, which can be sent out for manufacture.

COMPUTING THE OBSTACLE DIMENSIONS

Conventional Methods

It is possible to calculate the obstacle dimensions for some configurations of inductive iris, but this method is inaccurate since a number of empirical correction factors have to be included in the theoretical formulae. Accurate formulae have been derived by Marcuvitz[6] for the case of the inductive post, but this type of obstacle is not suitable for narrow-band filters since large values of susceptance cannot be realized. Another method of attacking the problem is to measure experimentally the susceptance of a number of irises at the center frequency of the desired filter design. The design curve plotted from the measured data can then be used to determine the required iris dimensions. Irrespective of whether a theoretical or empirical approach is adopted, a number of experimental models are usually required before an acceptable design is evolved.

Derivation of an Accurate Transformation Technique

A flat metal slab, centrally located in the waveguide (Fig. 2) was chosen as the most suitable obstacle configuration. It has the merit of simplicity, and filters using this type of obstacle are less expensive to manufacture than most others.

The first stage in the derivation was empirical. Obstacle susceptances were measured experimentally in WR137 waveguide, at 10 different frequencies over a band of 500 MHz centered on 6.175 GHz.

Wherever possible more than one experimental technique was used in the measurement of each obstacle. The obstacle thickness was kept constant and the width varied to ensure a wide spread of susceptances (4 to 240). The measured susceptances of each obstacle were plotted as a function of guide wavelength, and in each case the results indicated that the points should lie in a straight line.

Theoretically, it is sufficient to know the susceptance at one frequency; the susceptance at all other frequencies can be found from the relationship

$$B = B_o \frac{\lambda_g}{\lambda_{go}} \qquad (2)$$

where λ_{go} = guide wavelength at frequency f_o

λ_g = guide wavelength at frequency f

B_o = susceptance at f_o

B = susceptance at f

The straight lines that best fit each set of experimental points may not obey that law. To find the straight line that fits each set of data, the technique of fitting a line of regression by the least-square-error criterion was adopted. It was found that the slope of each straight line derived, using the above technique, differed slightly from that of the ideal relationship of equation (2). The divergence, however, is so small that the error introduced by ignoring it is less than 2% over a large portion of the usable waveguide band.

It was decided, therefore, to use the relationship of equation (2) to transform the required susceptance to the normalized susceptance. Normalized susceptance is defined as the susceptance at 1.437 times the frequency of cutoff.

The choice of the reference frequency for normalized susceptance is governed by the fact that all measurements were carried in a band of frequencies centered on 6175 MHz in WR137. The graph relating the logarithm of the normalized susceptance to the ratio of obstacle width to waveguide width can be represented by a number of straight lines (Fig. 2). Perusal of this graph shows that its slope changes only at very large and very small values of susceptance. The maximum error introduced through approximating the curve by segments of straight lines is less than 1% for values of susceptance between 5 and 200.

EXAMPLE OF THE FILTERS DESIGNED BY THE COMPUTER PROGRAM

Two specific examples, chosen for their diversity in size and electrical specifications, are provided to demonstrate the versatility and accuracy of the program. In both cases the computer-derived dimensions were transferred directly to a standardized sketch, one example of which is shown in Fig. 4. It was not necessary to adjust the mechanical dimensions, and in neither case was the penetration of coupling or tuning screws greater than one-tenth inch. (These screws are really necessary to take up the tolerances of manufacture.)

The first example is a narrow-band filter required to pass a communications carrier in a 4-GHz high-quality microwave relay link. The second filter was designed as part of a satellite study and was required to split the common carrier band at 6 GHz into two halves, calling for an extremely wide-band filter with steep skirts. In both cases, the initial

Fig. 3—Computer printout data for narrow-band filter.

Input Data

Type of filter	Tchebychev
Number of sections, n	5
Return loss in passband, R	—34.00 dB
Cutoff freq. of waveguide, F_c	2576.86 MHz
Edges of passband, FR_1	3807.00 MHz
FR_2	3843.00 MHz
Insertion loss printout from F_1	3725.00 MHz
to F_2	3805.00 MHz
in steps of	10.00 MHz
and from F_1	3845.00 MHz
to F_2	3925.00 MHz
in steps of	10.00 MHz

Intermediate Design Data

Arithmetic center of passband, F_o	3825.00
Width of passband, delf	36.00
Design center of passband, FR	3824.81
Guide wavelength at FR, inches	4.18
Loaded Q of filter, Q	106.27
Guide width, inches	2.290
Obstacle thickness, inches	0.107

Electrical Analog			*Mechanical Equivalent*	
Susceptance at FR (B)	Norm. Susceptance at 1.437 FC (B Norm)	Electrical Length of Cavity at FR (Theta Radians)	Obstacle Width (Inches)	Cavity Length (Inches)
— 4.431	— 4.718	0.000	0.301	0.000
—30.499	—32.474	2.897	0.930	1.979
—46.701	—49.725	3.087	1.044	2.102
—46.701	—49.725	3.099	1.044	2.110
—30.499	—32.474	3.087	0.930	2.102
— 4.431	— 4.718	2.897	0.301	1.979

Dimensions for Sketch (inches)

Waveguide WR229, Flange CMR229

C1	1.055	T1	2.106	W1	1.044
C2	3.157	T2	4.147	W2	0.930
C3	5.136	T3	0.000	W3	0.301
T	0.107	A	0.834	L	13.404

Frequency Response vs. Insertion Loss

Frequency (MHz)	Insertion Loss (dB)
3725.00	66.82
3735.00	61.87
3745.00	56.34
3755.00	50.07
3765.00	42.79
3775.00	34.10
3785.00	23.20
3795.00	8.80
3805.00	0.06
3845.00	0.05
3855.00	7.94
3865.00	21.44
3875.00	31.64
3885.00	39.68
3895.00	46.32
3905.00	51.97
3915.00	56.89
3925.00	61.23

Group Delay vs. Frequency Response

Frequency (MHz)	Phase (Degrees)	Absolute Group Delay T (Nanoseconds)	Relative Group Delay T-TO (Nanoseconds)
3807.00	—150.806	28.731	7.176
3808.80	—132.921	26.618	5.063
3810.60	—116.158	25.208	3.653
3812.40	—100.165	24.204	2.649
3814.20	— 84.740	23.436	1.881
3816.00	— 69.757	22.832	1.277
3817.80	— 55.121	22.363	0.808
3819.60	— 40.749	22.015	0.460
3821.40	— 26.566	21.775	0.220
3823.20	— 12.509	21.624	0.069
3825.00	1.475	21.551	—0.004
3826.80	15.435	21.548	—0.007
3828.60	29.418	21.623	0.068
3830.40	43.477	21.786	0.231
3832.20	57.675	22.052	0.497
3834.00	72.080	22.430	0.875
3835.80	86.771	22.932	1.377
3837.60	101.832	23.583	2.028
3839.40	117.381	24.451	2.896
3841.20	133.599	25.686	4.131
3843.00	150.803	27.541	5.986

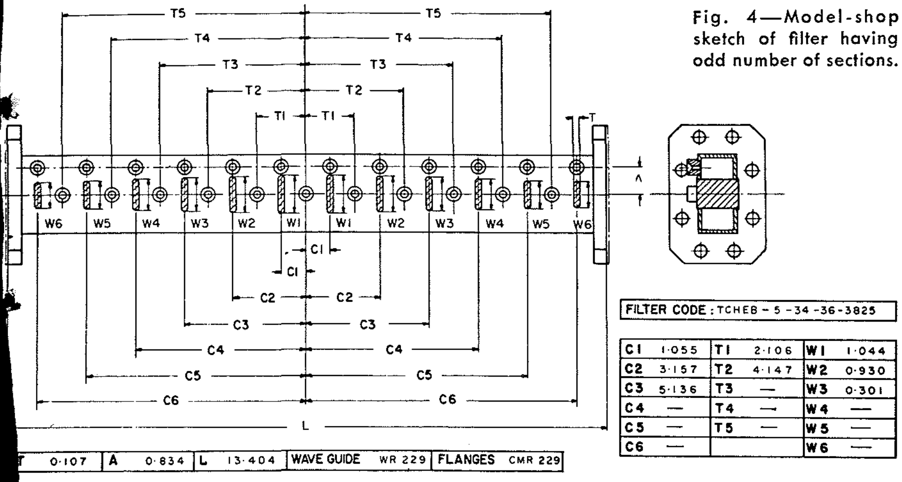

Fig. 4—Model-shop sketch of filter having odd number of sections.

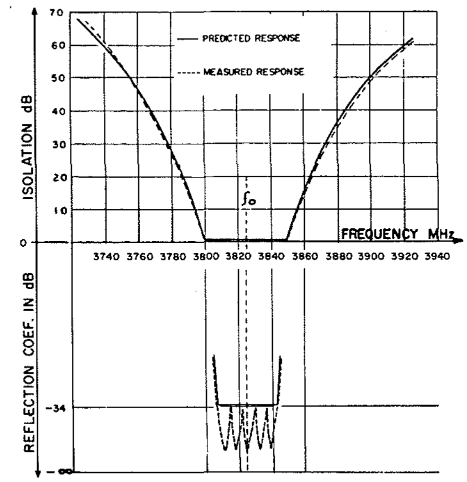

Fig. 5—Response of WR-229 five-cavity band-pass filter.

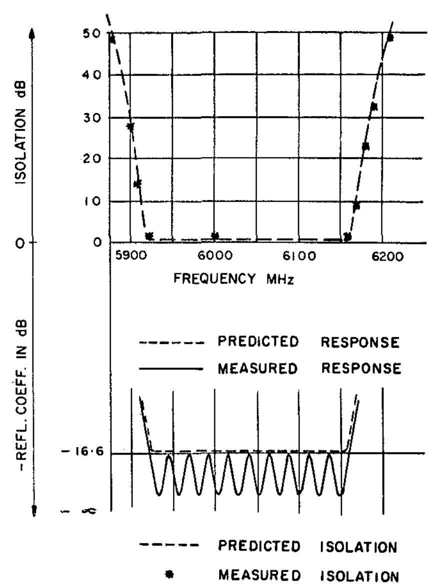

Fig. 6—Response of WR-137 ten-cavity band-pass filter.

requirements were reduced to the following inputs to the computer program.

No.	Input	4 GHz Narrow band	6 GHz Wide band
1	Type of filter	Tchebychev equal ripple	Tchebychev equal ripple
2	Number of sections	5	10
3	Reflection coeff. in passband (dB)	−34 dB	−16.6 dB
4	Cutoff freq. of waveguide	2577 MHz (WR229)	4300.9 MHz (WR137)
5	Edges of passband:		
	from	3807 MHz	5919.50 MHz
	to	3843 MHz	6160.50 MHz

The computer printout for the narrow-band filter is given in Fig. 3. The model-shop sketch shown in Fig. 4 is the standard sketch for odd numbers of sections. A second sketch is necessary for filters with an even number of sections, since Tchebychev filters of this type are not symmetrical about the center line.

Figs. 5 and 6 compare the predicted and measured characteristics of the two filters and show how closely the filters meet their design requirements. Fig. 7 shows a photograph of the 10-cavity wide-band filter that was the engineering model, the prototype, and the final design all in one.

CONCLUSION

The drudgery normally associated with the calculations of the electrical analog has been virtually eliminated. The time- and money-consuming aspects of filter design, however, have always been the internal recycling within the development cycle, leading to the fabrication and testing of a number of experimental models. The major achievement of the program has been to dispense, in most cases, with the need for more than one prototype. This is mainly due to the subprogram which transforms the electrical analog into exact mechanical dimensions. Another area of improvement is the accurate prediction of both the insertion-loss-vs-frequency and pass-band-group-delay responses. These characteristics, included in the printout, enable the designer to reject, if necessary, the proposed filter prior to fabrication and testing.

Separate subprograms were compiled for each stage of the design procedure wherever possible to ensure that the overall program and individual subprograms can be adapted and added to without difficulty. The program has been exhaustively tested in different sizes of waveguide. In every case there was close agreement between the predicted and measured characteristics.

ACKNOWLEDGEMENTS

The Authors wish to express their thanks to G. Payette for his considerable assistance in the compilation of this program. Thanks are also due to J. Hansen and K. Flood for assistance in testing the filters and preparing this paper.

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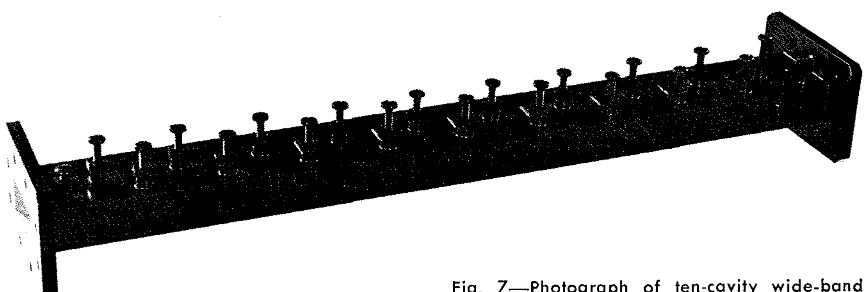
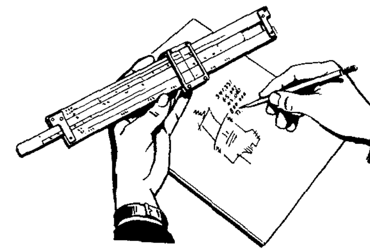


Fig. 7—Photograph of ten-cavity wide-band filter.

Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST



Protecting Solar Array Output Against Individual Cell Failures

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Final manuscript received February 8, 1966.

The effects of possible failures of individual solar cells on total array power output has been studied by the Space Power Group at AED. The predominant failure mode proved to be open cells, although the number of actual failures observed was very small (the effect of one open cell in one hundred is a power loss of over one percent). Paralleling does little to protect arrays, and the small amount of protection gained must be traded off against increases in weight, cost, and the potential loss of reliability.

In the simple network shown in Fig. 1, components are connected into several series strings as common output terminals, similar to cells in a solar array. Identical resistive components are used in Fig. 1 for subsequent illustrative purposes.

EFFECTS OF PARALLELING

To minimize effects of individual failures, components are inter-paralleled at intermediate levels so that no two components are directly in series or in parallel with each other, and the effects of either opening or shorting any one are minimized. Such a network offers protection when linear components are used, but not when such components are replaced with nonlinear components such as solar cells. Paralleling components together using this or any other method is primarily a safeguard against failures in the *open mode.*

In contrast, when a component shorts out, perturbation introduced by the short is amplified; see the network of Fig. 1 where a certain fixed resistance is maintained between terminals O-G, despite individual component failure.

1) *Network of Fig. 1, with no paralleling at "in-between" levels*
   Change in total resistance due to any one resistor "R" open .... +20%
   Change in total resistance due and any one resistor "R" shorted .... —2.3%
2) *Network of Fig. 1 with paralleling*
   Change due to any one open R .... +4.2%
   Change due to any one shorted R .... —4.2%

Considering both modes of failure equally probable, it does pay to interparallel to some extent. Two questions arise: first, what is the probability of a solar cell shorting out in the sense of placing a short circuit across cell terminals; and second, would solar cells behave as resistors?

A cell in a solar array is considered very unlikely to short out; earlier theories concerning micrometeorites causing full or partial shorts have been all but abandoned; no cells have failed in the short-circuit mode in tests at AED. The infrequent cell failures affecting circuit continuity were of the open-cell mode. Thus, one concludes that required protection should minimize the effects of open, rather than shorted cells; therefore, the more cells paralleled together, the better.

To test Nimbus modules, 33 modules of ten cells in parallel were connected in series and illuminated. One of the modules was picked at random, and cells were progressively removed from that module; the characteristic I-V curve was plotted before and after removal. Although ultimate protection was employed by paralleling at individual cell levels, the removal of each cell reduced the current output of the total circuit by roughly 10%, just as though a like number of cells were removed from each of the remaining modules. The disproportionate dropoff in output power is explained in the following way.

The plot of Fig. 2 shows the measured I-V characteristics, both 1st and 2nd quadrant, of a single 2- x 2-cm solar cell of the type used in Nimbus; a plot for 5 and 8 cells was constructed by adding the ordinates of the graph. A plot of the I-V characteristic of a circuit of 32 ten-cell modules connected in series is shown in Fig. 3.

When two cells are removed in the ten-cell module, its I-V would be as the top curve in Fig. 2; if the resultant eight-cell module were connected in series with the 32 ten-cell modules, the resultant I-V is obtained by algebraic addition of the two voltages at a fixed current over the entire current range. The result, shown in Fig. 3 as the upper dotted curve, represents the total I-V of a circuit of 33 ten-cell modules where two cells are open in any one module. The

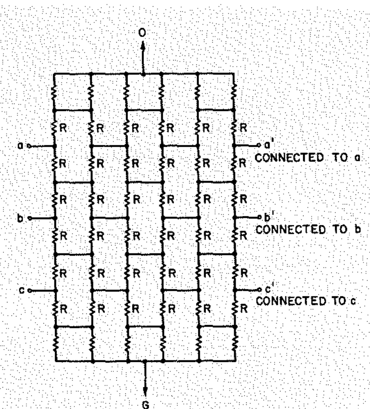


Fig. 1—Network using interparalleled resistive components.

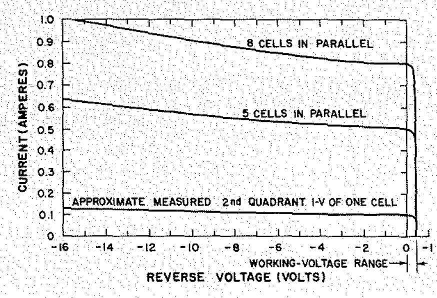


Fig. 2—First and second quadrant characteristics of NIMBUS 2- x 2-cm solar cells. (I_{sc} normalized to 0.1.)

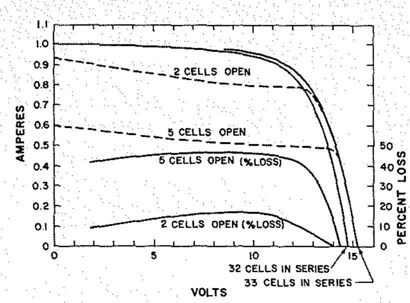


Fig. 3—Approximate characteristics of 10-cell NIMBUS modules at about 40° C. (I_{sc} normalized to 1.0.)

lower dotted curve is the total I-V where five cells are removed. The percent of current loss is also plotted in Fig. 3 as a function of circuit voltage.

Examination of Fig. 3 reveals that if the 2nd quadrant characteristics of solar cells tend to remain flat instead of slowly rising as reverse voltage across the cells is increased (Fig. 2), the percent of current loss reaches a slightly higher peak value, and continues at that value rather than decreasing as the working voltage of the cell goes lower (Fig. 3). It is possible that in outer space environment, where humidity does not exist and surface conductivity is low, such flattening would occur. Nevertheless, Fig. 3 can be used to indicate what might be gained by interparalleling; thus, the curves shown must be compared to a straight current drop at all voltages, say 20% for two open cells, 50% for five, and so on, just as though no paralleling connections were used. If the 33-module curve of Fig. 3 represented an array, in actual practice it would most likely be operated between 7 and 13 volts to achieve relatively efficient operation over the temperature range likely to be encountered.

Inability of paralleling to adequately protect arrays can be explained theoretically by considering a solar cell as a highly nonlinear resistor. Resistance of a lunar orbiter (LO) cell, for example, at 25°C, is defined approximately by the functions

$$\frac{dv}{di} = -\frac{0.06}{0.122 - i} = -1.12\, e^{-17v} \times 10^{4}$$

At maximum power, or at roughly 0.46 volt, the cell resistance is about 5 ohms. Assume this cell as part of a string of other cells paralleled in a manner similar to that of the 33-module experiment; when one cell is "open," the paralleled cells attempt to absorb the difference current. A mere 5% rise in cell current doubles the 5-ohm resistance, tending to reduce the cell voltage by one-half. By contrast, if cells were linear resistors, the change in voltage drop would be essentially negligible. In practice, LO cells are operated at about 0.3 volt; at this voltage, the +25°C cell has a resistance of 70 ohms and would more than double with a current rise of less than one-half percent.

Cells in parallel with an open cell generally pass far less added current than the gross amount lost due to one "open," and in so doing reduce the current flow of an entire string. Improvement of paralleling over that of straight series operation is slight, except when a very large number of cells are paralled together; in this case, the per-cell share of added current would be very small when one cell is open, and only when the cell is operated near maximum power. A solar cell is a relatively fixed-current generator and, unlike a resistor, will not allow passage of any substantial amount of additional current through itself without a disproportionately large voltage drop.

CONCLUSIONS

The removal of one, two, or more cells in the 33-module circuit has the approximate effect of removing a like number of cells in each of the modules placed in the series circuit. This suggests that if more than one open cell occurred at random, the effect of a second open cell occurring in another module would be negligible, provided that paralleling connections were used. The limited test data available indicates that the probability of occurrence of more than one open cell in a series string is small, even if the string involves a significant fraction of all the cells in the array. However, the loss due to the first open cell would still not be adequately covered.

Paralleling all cells together (possible only in oriented arrays) would make the added per-cell current small (assuming that the array is very large), and would greatly reduce the effect of all subsequent random "opens." But if any intercell connections or wiring shorted to the substrate for any reason, the effect would be disastrous.

The problem of large voltage drop across an open cell can be solved by placing diodes in parallel with each module, either externally or as an integral part of the package. Although this approach creates other problems, the diodes will hold the voltage drop to a reasonable value and will provide continuity. Solar-cell circuits constructed of such modules would function much like linear ones, and losses due to open cells would be greatly minimized.

ACKNOWLEDGMENT

The author wishes to acknowledge the contribution of Vernon Landon, Manager, Technical Advisory Staff, AED in the inception of this paper.

Computation of Shaped-Beam Antenna Reflector Surfaces

C. B. Davis R. W. Klopfenstein O. M. Woodward

C. B. Davis and R. W. Klopfenstein, *RCA Laboratories, Princeton, N. J., and* O. M. Woodward, *M&SR, Moorestown, N. J.*

Final manuscript received March 1, 1966.

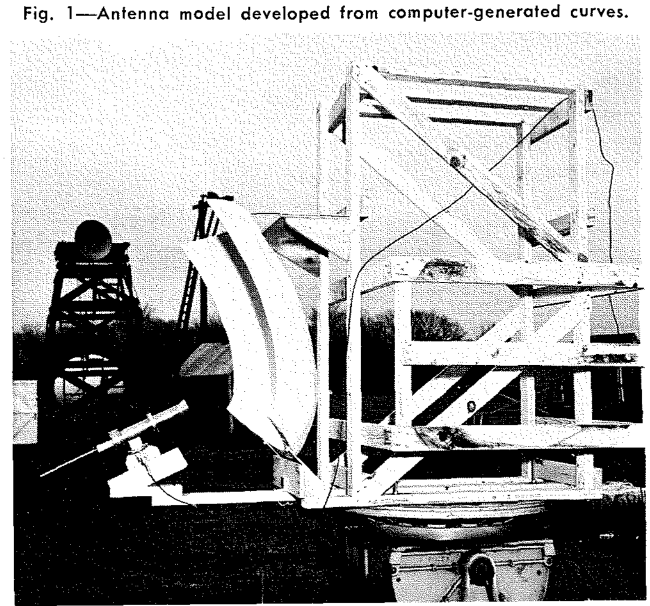
For many applications of directional microwave antennas, the beam pattern in the vertical plane must have a specified shape. Such patterns can be achieved by a suitably shaped reflector fed by a horn. However, the specification of a surface to give a desired pattern is often difficult. Since the problem frequently does not lend itself to a straightforward analytical solution, the practice has been to determine the surface configuration on a scaled-down model by semiempirical or cut-and-try methods. Such methods are both time consuming and expensive.

Significantly, the Applied Mathematics Group at the David Sarnoff Research Center has developed a computer program for the RCA 601 by means of which the contours of a complex antenna surface can be generated and its radiation pattern calculated. This program, developed to assist an M&SR group at Moorestown in the design of a radar antenna for the Air Force, consists of two parts. The first part is a system for approximating a surface that will come close to giving the desired radiation pattern. The second part enables the accurate calculation of virtually all operating characteristics of an antenna having the surface contours generated in part one. These characteristics include not only the radiation pattern, but also such important parameters as the gain of the antenna, amplitude of cross-polarized components of radiation, and contours of constant current density on the reflector surface. When the last-named characteristic is known, it may be possible to reduce the reflector size by eliminating regions contributing little to the total pattern.

The beam of the Air Force antenna was to have a cosecant-squared pattern in the vertical plane. A series of curves specifying the antenna contours in vertical cross section were generated by the computer. Calculations showed that this antenna should meet all performance requirements of the Air Force. Using the computer-generated curves, a scaled-down model of the antenna was constructed at Moorestown (Fig. 1). Experimental measurements of the characteristics of the antenna showed excellent agreement with the calculated values. For example, the measured gain (30 dB) was within about ½ dB of the calculated value.

Significant savings in time and manpower were achieved by this cooperative effort. Furthermore, since the area of the final antenna will be considerably less than that thought necessary to achieve the gain specified by the Air Force, the cost and complexity of manufacture will be reduced, and transportation and wind-loading problems will be alleviated. The programs developed in designing this antenna will be useful in the design of similar antennas.

Fig. 1—Antenna model developed from computer-generated curves.



Automatic Phase-Lock Tracking Oscillator

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Final manuscript received April 27, 1966.

This engineering note describes an oscillator whose frequency and phase are determined by a reference signal (Fig. 1).

When no reference signal is applied to the input of the phase discriminator, its output is such as to maintain the *npn* transistor, Q_1, nonconductive. With Q_1 nonconductive, capacitor C_1 charges at a rate determined by resistors R_1 and R_2. The voltage across capacitor C_1 is applied to the emitter of the double-base diode (unijunction transistor), Q_2; when the voltage becomes high enough, Q_2 becomes conductive and rapidly discharges C_1. The process is repetitive and results in a saw-toothed voltage appearing across capacitor C_1. This voltage is applied as a reverse bias to voltage variable capacitance diodes, CR_1 and CR_2, which are a part of the oscillator tuning circuit, and results in the oscillator frequency sweep.

When a reference signal is applied to the input of the phase discriminator, at a certain value of the sweeping voltage the oscillator

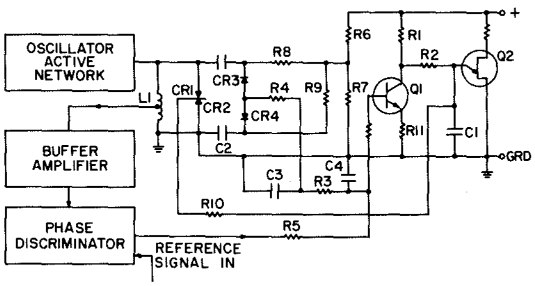

Fig. 1—Circuit diagram of oscillator.

and the reference signals will be in such a phase relationship to each other that a positive voltage output will be produced by the phase discriminator. This will a) render Q_1 conductive, lowering its collector voltage below the breakdown point of Q_2 and thus effectively stopping the sweep, and b) maintain a phase-lock condition via CR_3, CR_4, R_3, R_4, R_5, C_3 and C_4 feedback loop.

In summary, the oscillator is swept in frequency by the sweep voltage produced by the charging and discharging of capacitor C_1 when no reference signal is applied to the discriminator. When a reference signal is applied to the phase discriminator, the sweep voltage is stopped and the oscillator is locked in at the same frequency as the reference signal and at a predetermined phase relation. The oscillator then tracks the frequency and phase of the reference signal within the tuning range of voltage variable capacitance diodes CR_1 and CR_2 for a given sweep excursion across capacitor C_1.

New Tools for Space Hardware

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Final manuscript received April 29, 1966.

The subminiature, multipin connector is the most frequently used type of connector in the spacecraft industry. It has been in use for almost two decades, and for almost two decades there has been the problem of extracting a connector from its mate without damage to the connector, adjacent harnessing, or hardware.

Although functionally excellent (being sound, light in weight, and occupying little space), the subminiature, multipin connector is subject to manhandling during insertion and removal; this is especially true of the 37- and 50-pin connectors. The standard connector in a typical spacecraft communications system must be engaged and disengaged for testing numerous times and must remain reliable. One damaged contact pin can result in intermittent operation, resulting in hours of testing and repair.

The disengaging of connectors becomes particularly difficult when they are nested among several *black boxes* and access is difficult. This situation tempts the technician to disengage the connector by pulling on the connector cable or by prying with a screwdriver, inevitably leading to damage of the equipment. Damage to the connector is not entirely the fault of the test engineer or technician; the difficulty of separating the connector is the problem. The need to remedy the problem resulted in a development program that supplied the spacecraft industry with long-needed tools.

Three distinct types of disconnect tools were developed for use with rectangular miniature connectors. These tools were mass-produced and used, with excellent results, at the Astro-Electronics Division on several space programs, including TIROS, Ranger, and Relay. Although these tools have been used mainly for space equipment, there are many other types of equipment in which multipin connectors are used in almost inaccessible locations. Some of the advantages of these tools are:

1) A quick, clean separation of mating connectors
2) Elimination of the need for a rocking motion to extract connectors (often a cause of bending of connector pins)
3) A substantial reduction of the force required for extraction of the connectors
4) Elimination of the need to pry connector mating flanges with screwdrivers
5) Elimination of the need to pull on connector harnesses.

The method of separation is essentially the same for each of the three tools discusssed: the tool is applied between the flanges of the mating connectors, which are separated quickly and cleanly by a suitable motion. The three types of tools are: single push-pull (Fig. 1), plier (Fig. 2), and push-pull (Fig. 3). All these tools perform the same function; the application depends upon the accessibility of the connector and the location of the adjacent parts.

The single push-pull, the first tool developed, is useful in disengaging relatively inaccessible connectors. These tools are used in pairs (Fig. 1); the ears of the tools are placed between the flanges of the mated connectors and a simple squeezing motion applies a linear force to separate the connectors. These tools were extremely useful on the Ranger and Relay spacecraft programs, where complex structures made it difficult to reach the connectors. Use of the single push-pull tools increased system reliability by avoiding damage due to mishandling during integration and test.

The plier-type tool permits the removal of a connector with one hand tool. Where space permits its use, this tool will remove connectors quicker than the single push-pull tool. Shaped like a pair of pliers (Fig. 2), it has a wedge-shaped molded-nylon anvil on each jaw. These anvils, retained by a screw and a spring, are self-aligning. When the anvils are wedged between the flanges of mating connectors, a force sufficient to crack a walnut separates the connectors. This technique was discovered when it was noted that a metal rod pressed against the mating connector flanges caused the connectors to separate; nylon is used for the anvils because it is softer than metal and provides a smoother wedging action. A minor disadvantage of the plier is that it can produce a slight cocking of the connectors during separation; this is not detrimental, although it may be objectionable to some users.

The push-pull tool (Fig. 3) is used to extract a connector in an easily accessible location where the hand and tool will readily fit. An ideal application for this tool is in a rack where connectors are stacked, or in a spacecraft, such as TIROS, where connectors are in a horizontal plane. An advantage of this tool is that with one motion it can be easily adjusted for the width of the connector. The ears of the tool are placed between the flanges of the mated connectors (as with the single push-pull tool), and a retaining spring holds the ears against the connector. This tool applies an equal extraction force on each side of the connector, thus preventing cocking of the connector during removal.

Proper placement of connectors during design will permit the use of the appropriate tool for connector removal and replacement, resulting in less rework, greater reliability, and cost savings.

Fig. 1—Single push-pull tool.

Fig. 2—Plier-type tool.

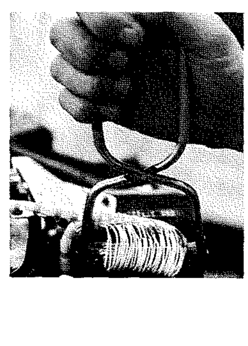
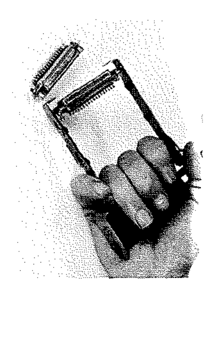


Fig. 3—Push-pull to



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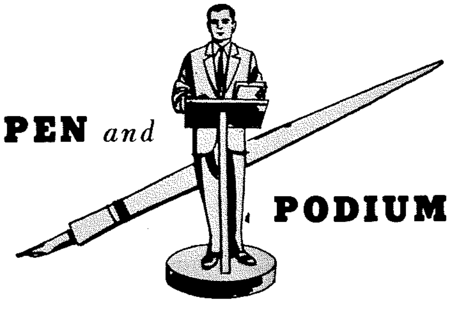

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Keohane, E. L. space communication
Lowe, M. H. space navigation
Macko, S. radar
Patton, W. T. communications components
Stribling, S. radar
Wylde, D. V. space navigation

RCA VICTOR COMPANY, LTD.

Bachynski, M. P. electromagnetic waves
Carswell, A. I. laboratory equipment
Davies, D. E. properties, surface
Gibbs, B. W. electromagnetic waves
Green, R. M. laboratory equipment
Shkarofsky, I. P. electromagnetic waves
Shkarofsky, I. P. plasma physics
Tilley, B. J. circuits, integrated
Walker, A. communications components
Webb, P. P. properties, surface
Webb, P. P. laboratory equipment

RCA VICTOR HOME INSTRUMENTS

Andrews, D. L. recording

RCA COMMUNICATIONS, INC.

Becken, E. D. communications systems

BROADCAST AND COMMUNICATIONS PRODUCTS DIVISION

Coleman, Dr. J. W. laboratory equipment
Gihring, H. E. antennas
Horner, J. A. properties, molecular
Kozanowski, Dr. H. N. television broadcasting
Siukola, M. S. antennas

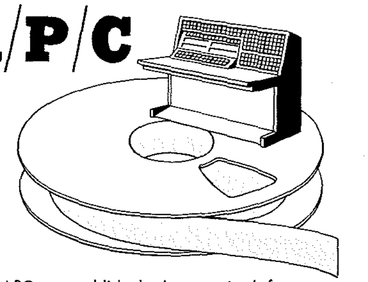
GRAPHIC SYSTEMS DIVISION

Barnett, Dr. M. P. mathematics
Barnett, Dr. M. P. computer applications
Barnett, Dr. M. P. computer applications
Barnett, Dr. M. P. computer applications
Greenberg, J. S. graphic arts
Korman, Dr. N. I. computer applications
Korman, Dr. N. I. computer applications
Korman, Dr. N. I. computer applications
Korman, Dr. N. I. computer applications
Lavine, Dr. L. R. computer applications

RCA LABORATORIES

Anderson, C. H. properties, magnetic
Anderson, C. H. properties, magnetic
Anderson, C. H. properties, atomic
Anderson, C. H. masers
Annavedder, E. K. properties, atomic
Aubrey, B. B. properties, atomic
Binggeli, B. properties, molecular
Bosenberg, W. S. solid-state devices
Burns, L. L. computer storage
Cardona, M. properties, surface
Cheng, K. L. laboratory equipment
Duncan, R. C. laboratory equipment
Duncan, R. C. laboratory equipment
Evans, R. J. properties, molecular
Fatuzzo, R. properties, molecular
Fischer, G. properties, surface
Fitske, E. V. energy conversion
Fox, E. C. communications components
Friedman, L. properties, electrical
Gerritsen, H. J. lasers
Goedertier, P. V. lasers
Goedertier, P. V. lasers
Goldstein, B. properties, atomic
Goldstein, Y. superconductivity
Gorog, I. management
Goydish, B. I. laboratory equipment
Hammer, J. M. properties, atomic
Hattori, T. properties, molecular
Heilmeier, G. H. properties, molecular
Heilmeier, G. properties, molecular
Hernqvist, K. G. tube components
Herzfeld, F. properties, atomic
Hirota, R. eletromagnetic waves
Hirota, R. eletromagnetic waves
Kiess, H. properties, molecular
Klein, R. properties, surface
Kudman, I. properties, atomic
Lechner, B. J. displays
Levine, J. D. tube components
Madaras, R. J. properties, magnetic
Martinelli, R. U. lasers
McEvoy, J. P. properties, surface
Nagle, E. M. computer storage
Pankove, J. I. properties, atomic
Pearl, J. properties, surface
Pearl, J. electromagnets
Perkins, D. energy conversion
Pinch, H. L. properties, magnetic
Pressley, R. J. lasers
Rajchman, J. A. computer storage
Revesz, A. G. properties, molecular
Rose, A. properties, atomic
Rosenblum, B. properties, surface
Rosi, F. D. energy conversion
Sabisky, E. S. properties, atomic
Sabisky, E. S. masers
Sabisky, E. S. properties, magnetic
Sabisky, E. S. properties, molecular
Sass, A. R. computer storage
Schilling, R. B. properties, electrical
Smith, C. P. circuits, integrated
Steele, M. C. electromagnetic waves
Steigmeier, E. F. properties, atomic
Struck, C. W. properties, atomic
Suzuki, K. electromagnetic waves
Suzuki, K. electromagnetic waves
Toda, M. plasma physics
Toda, M. properties, atomic
Vural, B. interference
Williams, R. properties, molecular
Wittke, J. P. properties, molecular
Wojtowicz, P. J. properties, magnetic
Yim, W. M. energy conversion
Zaininger, K. H. properties, molecular
Zotter, B. interference
Zworykin, V. K. medical electronics

S/C/A/P/C



Scientific
Computer
Applications
Program
Catalog

Data sheets added to SCAPC are published when received from Dr. J. Kurshan, RCA Labs., who coordinates SCAPC. Data sheets contain an abstract describing the program and its status. The following engineers maintain SCAPC data sheets for reference.

AEDH	R. Goerss, AED, Prin., N.J.
ASDB	J. L. Richmond, ASD, Burl., Mass.
BCDM	F. M. Brock, Broadcast Microwave Eng., Cam., N.J.
CSDC	H. Jacobowitz, CSD, Cam., N.J.
DEPA	R. D. Smith, Appl. Res., Cam., N.J.
EDPP	S. Heiss, EDP, W. Palm Beach, Fla.
EDPS	L. Stuart, EDP, Cher. Hill, N.J.
LABS	R. W. Klopfenstein, Prin., N.J.
M&SR	R. Faust, M&SR Div., Mrstn., N.J.
VICM	G. Payette, RCA Victor Co., Ltd., Montreal, Can.
WCDV	A. E. Cressey, West Coast Div., Van Nuys, Calif.

SCAPC INDEX: Entries below consist of: the **key words** identifying the application (boldface type), **program title** (quoted italics), **computer language**, name(s) of program **contributor(s)**, and SCAPC **program number** (including location symbol from above list).

ANTENNA DESIGN: *"Doubly Curved Reflector Synthesis and Analysis"*—Fortran II; C. B. Davis, R. W. Klopfenstein, LABS-0016

CONVERGENCE ACCELERATION: *"Euler Transformation of Alternating Series"*—Fortran II; H. E. Kulsrud, LABS-0012

CURVE FITTING: *"POLFIT and POLVAL—Least Squares Polynomial Fit and Evaluation"*—601 Assembly Language; H. E. Kulsrud, LABS-0011

RATIONAL APPROXIMATION (& Curve Fitting, & Function Evaluation): *"Minimax Rational Approximation"*—601 Fortran II; R. L. Crane, A. Pelios, LABS-0008

FILTERS (& Denormaliziing, & Scaling): *"Low Pass to Band Pass Filter Transformation"*—301 Fortran II; F. M. Brock, BCDM-0005

FUNCTIONS, ERROR: *"ERFC(X̄) and EXERFC(X) Function Subprogram for Evaluation of Unscaled and Scaled Complementary Error Functions"*—Fortran II; C. B. Davis, LABS-0013

FUNCTIONS, NONLINEAR: *"ZLOC—A Subroutine for Finding Zeroes of Real Non-Linear Functions"*—Fortran II; A. Pelios, LABS-0020

GRAPH PLOTTING: *"PLOT—FORTRAN Subroutines Generating Single-Page Point or Bar Graphs and Long Plots"*—601 Assembly Language for use with Fortran; J. A. Goodman, LABS-0010

HARMONIC ANALYSIS (& Trigonometric FOURIER ANALYSIS (& Trigonometric Series): *"Fourier Analysis (FOUVAL) Routine"*—601 Assembly Language; J. R. Golden, R. L. Crane, LABS-0009

INTEGRALS, TRIGONOMETRIC: *"SCINT(X, SI, CIN)—Subroutine Subprogram for Evaluation of Sine and Cosine Integrals"*—Fortran II; C. B. Davis, LABS-0014

DIFFERENTIAL EQUATIONS, ORDINARY (& Integration, & Predictor-corrector): *"ADAMS—A Subroutine for the Numerical Solution of Ordinary Differential Equations"*—Fortran II; R. L. Crane, LABS-0006

DIFFERENTIAL EQUATIONS, ORDINARY (& Integration, & Predictor-correct): *"NODE—An RCA 601 Numerical Ordinary Diifferential Equations Subroutine"*—601 Assembly Language; L. J. Berton, R. L. Crane, R. W. Klopfenstein, LABS-0007

NETWORK ANALYSIS (& Iterative Analysis, & Bashkow Method): *"Ladder Network Analysis"*—301 Fortran II; F. M. Brock, BCDM-0004

NETWORK ANALYSIS (& Ladder Networks): *"CHARAC—A Subroutine for Evaluation of Amplitude, Phase, and Delay Characteristics of Ladder Networks"*—Fortran II; C. B. Davis, LABS-0015

SORTING (& Parameter Matching): *"Transistor Sorting Program"*—Fortran II; J. L. Richmond, R. McNaughton, A. Burwell, ASDB-0004

POLYNOMIAL ZEROES: *"POLZER—A Subroutine for Finding Zeroes of Polynomials with Real Coefficients"*—601 Assembly Language; A. Pelios, LABS-0018

POLYNOMIAL ZEROES: *"POLZIM—A Subroutine for Finding Zeroes of Polynomials with Complex Coefficients"*—Fortran II; A. Pelios, LABS-0019

RESISTIVITY MEASUREMENTS (& Partial Differential Equations): *"Program for Calculation of Correction Factor for Four-Point Semiconductor Resistivity Measurement"*—Fortran II; C. B. Davis, LABS-0017

SIMULTANEOUS EQUATIONS (& Matrix Inversion): *"LINEQ—A Subroutine to Solve Simultaneous Linear Equations and Matrix Inversion"*—601 Assembly Language; A. H. Simon, LABS-0021

VARIANCE ANALYSIS: *"One-Way Analysis of Variance"*—Fortran II; H. R. Heidler, EDPS-0001

DOUBLE PRECISION: *"72-Bit Double Precision FORTRAN Package"*—In 601 Basic for 601 Fortran; A. H. Simon, LABS-0022

Patents Granted
TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

RCA VICTOR HOME INSTRUMENTS

UHF Adaptor for VHF Television Receivers—D. J. Carlson, J. B. Schultz (HI, Indpls) U.S. Pat. 3,242,433, March 22, 1966

Phonograph Pickup with Resiliently Loaded Stylus Beam—D. E. Laux (HI, Indpls) U.S. Pat. 3,243,524, March 29, 1966

Electronic Switching Circuit Employing an Insulated Gate Field-Effect Transistor Having Rectifier Means Connected Between Its Gate and Source or Drain Electrodes—J. O. Schroeder (HI, Indpls) U.S. Pat. 3,246,177, April 12, 1966

Past-Deflection Color Purity Correcting Magnet System for a Color TV Cathode Ray Tube—J. K. Kratz (HI, Indpls) U.S. Pat. 3,247,411, April 19, 1966

DEFENSE ELECTRONIC PRODUCTS

Command Feed Mechanism—F. W. Pfleger, Yow-Jiun Hu (MS, Mrstn) U.S. Pat. 3,245,-682, April 12, 1966

Coupling of Logic Neurons—T. B. Martin, J. E. Saultz (AppRes, Cam) U.S. Pat, 3,246,-302, April 12, 1966

DME With Fast Search—I. A. Sofen, R. P. Crow (WCD, Van Nuys) U.S. Pat. 3,246,-325, April 12, 1966

Magnetic Structure for a Loudspeaker—D. H. Cunningham (CSD, Cam) U.S. Pat. 3,247,-331, April 19, 1966

Triggerable Tunnel Diode—M. Cooperman (AppRes, Cam) U.S. Pat. 3,247,398, April 19, 1966

Optical Fiber Analog-Digital Converter—D. J. Coyle (MSR, Mrstn) U.S. Pat. 3,247,505, April 19, 1966

Optical Fiber Analog Digital Converter—E. D. Grim, Jr. (CSD, Cam) U.S. Pat. 3,247,506, April 19, 1966

Corner Reflectors—L. E. Matson, Jr. (ASD, Burl) U.S. Pat. 2,702,900, Feb. 22, 1955 (assigned to U.S. Gov't.)

Information Processing Apparatus—E. P. McGrogan, Jr. (CSD, Cam) U.S. Pat. 3,245,050, April 5, 1966

BROADCAST AND COMMUNICATIONS PRODUCTS DIVISION

Device for Automatically Stopping a Film—B. F. Floden (BCD, Cam) U.S. Pat. 3,246,817, April 19, 1966

Microwave Cavity Having Plural Capacitance Probes which Act as a Mode Separator—R. H. Fricke, J. F. McSparran (BCD, Cam) U.S. Pat. 3,209,276, Sept. 28, 1965 (assigned to U.S. Gov't.)

Magnetic Recording and Reproducing Apparatus—J. D. Bick, D. C. Pastore (BCD, Cam) U.S. Pat. 3,244,818, April 5, 1966

RCA VICTOR COMPANY, LTD.

Audio Amplifier Including Volume Compression Means—W. B. Morrison (Ltd, Montreal) U.S. Pat. 3,247,464, April 19, 1966

Meetings

JUNE 20-25, 1966; **3rd Congress of the Int'l Federation of Automatic Control** (IFAC), London, England. **Prog. Info.:** Prof. Gerald Weiss, Polytechnic Institute of Brooklyn, 333 Jay St., Brooklyn, N.Y. 11201.

JUNE 21-23, 1966: **Conf. on Precision Electromagnetic Measurements**, IEEE, G-Im NBS, NBS Standards Lab., Boulder, Colo. **Prog. Info.:** Dr. Kiyo Tomiyasu, Genl. Electric Co., Schenectady, N.Y.

JULY 4-8, 1966: **Rarefied Gas Dynamics Mtg.**, Amer. Phys. Soc., Oxford, England. **Prog. Info.:** C. L. Brundin, Dept. of Eng. Science, Univ. of Oxford, Parks Rd., Oxford, England.

JULY 11-13, 1966: **Electromagnetic Compatibility Symp.**, IEEE, G-EMC, San Francisco Hilton Hotel, San Francisco, Calif. **Prog. Info.:** A. Fong, Hewlett Packard Co., 1501 Page Mill Rd., Palo Alto.

JULY 11-15, 1966: **1966 Aerospace Systems Conf.**, IEEE, G-AES, Olympic Hotel, Seattle, Wash. **Prog. Info.:** T. J. Martin, 3811 E. Howell St., Seattle, Wash. 98122.

JULY 12-14, 1966: **William Hunt Eisenman Conf. on Failure Analysis**—Amer. Soc. for Metals at the Waldorf-Astoria Hotel, N.Y.C. **Prog. Info.:** Ronald J. Seman, News Bureau Mgr., Amer. Soc. for Metals, Metals Park, Ohio.

JULY 18-22, 1966: **Nuclear and Space Radiation Effects Conf.**, IEEE, G-NS, Stanford Univ., Stanford, Calif. **Prog. Info.:** Dr. Victor vanLint, Gen'l Atomic P.O. Box 608, San Diego, Calif.

JULY 25-27, 1966: **Rochester Conf. on Data Acquisition & Processing in Biology & Medicine**, IEEE, G-EMB, Univ. of Rochester, Rochester, N.Y. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

AUGUST 1-5, 1966: **3rd ISA Research Conf. on Instrumentation Science** (Attendance by application only), William Smith College, Geneva, N.Y. **Prog. Info.:** K. B. Schnelle, ISA Headquarters, 530 William Penn Place, Pittsburgh, Pa. 15219

AUGUST 17-19, 1966: **7th Annual Joint Automatic Control Conf.** (JACC), ISA, AIAA, Univ. of Washington, Seattle, Wash. **Prog. Info.:** A. E. Bryson, Jr., Prog. Chairman, AIAA Headquarters, 1290 Sixth Ave., N.Y., N.Y. 10019.

AUGUST 23-26, 1966: **WESCON (Western Electronic Show & Convention)**, IEEE, WEMA, Sports Arena, Los Angeles. **Prog. Info.:** IEEE LA Office, 3600 Wilshire Blvd., Los Angeles, Calif.

AUGUST 29-31, 1966: **2nd Int'l Congress on Instrum. in Aeros.** Simulation Facilities, Stanford Univ., Stanford, Calif. **Prog. Info.:** R. K. Hallett, Jr., NASA Ames Res. Ctr., Moffett Field, Calif.

AUGUST 30-SEPT. 1, 1966: **21st Nat'l Conf., Assoc. for Computing Machinery**, IEEE, ACM, Ambassador Hotel, Los Angeles, Calif. **Prog. Info.:** B. R. Parker, Tech. Prog. Chairman, 21st Nat'l Conf., P.O. Box 4233, Panorama City, Calif.

SEPT. 5-9, 1966: **Int'l. Organization for Pure and Applied Biophysics Mtg.**, Amer. Phys. Soc., Vienna, Austria. **Prog. Info.:** E. Weidenahus, Viennese Medical Academy, Alserstr 4, Vienna 9, Austria.

P R O F E S S I O N A L M E E T I N G S

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.

SEPT. 22-24, 1966: **16th IEEE Broadcast Symp.**, IEEE, G-B, Mayflower Hotel, Wash., D.C. For **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

SEPT. 23-24, 1966: **14th Annual Cedar Rapids Communication Symp.**, Cedar Rapids, Iowa. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

SEPT. 25-28, 1966: **1st Nat'l. Conf. on Non-Conventional Energy Conversion Applications**, ASME, AIAA, AIChE, IEEE, International Hotel, Los Angeles, Calif. **Prog. Info.:** R. E. Henderson, The Allison Co., Indpls., Ind.

OCT. 3-5, 1966: **Nat'l. Electronics Conf.**, IEEE, et al., McCormick Place, Chicago, Ill. **Prog. Info.:** Nat'l Elec. Conf., 228 N. LaSalle St., Chicago 1, Ill.

OCT. 3-5, 1966: **Aerospace & Electronic Systems Conv.**, IEEE, G-AES, Sheraton Park Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

OCT. 3-5, 1966: **3rd Symp. on Consumer Electronics**, IEEE, G-CT, Conference Center, Univ. of Ill., Monticello, Ill. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

OCT. 5-7, 1966: **Allerton Conf. on Circuits & System Theory**, IEEE, G-CT, Univ. of Ill., Conf. Center Univ. of Illinois, Monticello, Ill. **Prog. Info.:** Prof. W. R. Perkins, Dept. of EE, Univ. of Ill., Urbana, Ill.

OCT. 9-11, 1966: **Intl. Conf. on Automatic Operation & Control of Broadcast Equipment**, IEEE, et. al.; London, England. **Prog. Info.:** J. L. Regan, IEE, Savoy Pl., London, W.C. 2, England.

OCT. 12-15, 1966: **Ultrasonic Symp.**, IEEE, G-SU; **For Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

OCT. 13-14, 1966: **4th Canadian Symp. on Communications**, IEEE, Region 7; Queen Elizabeth Hotel, Montreal, Canada. **Prog. Info.:** Prof. G. W. Farnell, McGill Univ., 805 Sherbrooke St., W. Montreal, Canada.

OCT. 13-14, 1966: **Stat. Theory of Signal Detection in Communication & Control Systems**, IEEE Section & Nechr, Techn. Gesellschaft: Darmstadt, F.R. Germany. **Prog. Info.:** H. H. Burghoff, 6 Frankfort 70, Stresemann Allee 21 VDE Haus, F.R. Germany.

OCT. 17-18, 1966: **Systems Science & Cybernetics Conf.**, IEEE, G-SSC; Intl. Inn, Wash., D.C. **Prog. Info.:** M. D. Rubin, The Mitre Corp., P.O. Box 208, Bedford, Mass.

OCT. 19-21, 1966: **13th Nuclear Science Symp.**, IEEE, G-NS; Statler Hilton, Boston, Mass. **Prog. Info.:** J. E. Coleman, U.S. Natl. Bureau of Standards, Wash., D.C.

OCT. 26-28, 1966: **Electron Devices Mtg.**, IEEE, G-ED; Sheraton Park Hotel, Wash., D.C. **For Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

Oct. 26-28, 1966: **7th Symp. on Switching & Automata Theory**, IEEE, Computer Group, Univ. of Calif.; Univ. of Calif., Berkeley, Calif. **Prog. Info.:** D. E. Muller, Math Dept., Univ. of Ill., Urbana, Ill.

Calls for Papers

OCT. 19-21, 1966: **13th Nuclear Science Symp.**, IEEE, G-NS; Statler Hilton, Boston, Mass. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

OCT. 20-22, 1966: **Electron Devices Mtg.**, IEEE, G-ED. Sheraton Park Hotel, Wash., D.C. **Deadline:** Abstracts, approx. **8/1/66.** FOR INFO.: IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

OCT. 24-27, 1966: **21st Ann. ISA Conf. & Exhibit;** Hotel New Yorker & Statler Hilton Hotel, Coliseum, N.Y., N.Y. **Deadline:** Abstracts, approx. **6/15/66.** TO: Conf. Prog. Coordinator, c/o ISA Headquarters, 530 William Penn Place, Pittsburgh, Pa.

NOV. 2-4; 1966: **N.E. Research & Eng. Mtg.** (NEREM), IEEE, Region 1; Boston, Mass. **Deadline:** Abstracts, approx. **7/1/66.** FOR INFO.: IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

NOV. 8-10, 1966: **Fall Joint Computer Conf.**, IEEE, AFIPS (IEE-ACM); Brooks Hall, Civic Center, San Francisco, Calif. **For Deadline Info.:** AFIPS Headquarters, 211 E. 43rd St., N.Y., N.Y.

NOV. 15-17, 1966: **Electric Welding Conf.**, IEEE, G-IGA, Rackham Bldg., Eng. Society of Detroit, Detroit, Mich. **For Deadline Info.:** M. Zucker, Myron Zucker Eng. Co., 708 W. Long Lake Rd., Bloomfield Hills, Mich.

NOV. 15-18, 1966: **12th Conf. on Magnet & Mag. Matls.**, IEEE-G-MAG et. al.; Sheraton Park Hotel, Wash., D.C. **Deadline:** Abstracts, approx. **8/19/66.** FOR INFO.: IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

DEC. 1-2, 1966: **Vehicular Comm. Conf.**, IEEE, G-VC; Montreal, Canada. **For Deadline Info.:** H. Stewart, Dept. of Transport, Hunter Bldg., Ottawa, Ontario, Canada.

DEC. 5-7, 1966: **Intl. Antennas & Propagation Symp.**, IEEE-G-AP; Palo Alto, Calif. **For Deadline Info.:** R. L. Leadabrand, Stanford Res. Inst., Menlo Park, Calif.

DEC. 7-9, 1966: **Fall URSI-IEEE Mtg.**, IEEE, URSI-IEEE; Palo Alto, Calif. **For Deadline Info.:** Miss J. Hannaum, Natl. Academy of Sciences, 2101 Constitution Ave., Wash., D.C.

JAN. 10-12, 1967: **13th Symposium on Reliability**, IEEE, G-R, ASQC et al, Sheraton Park Hotel, Wash., D.C. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

JAN. 29-FEB. 3, 1967: **IEEE Winter Power Mtg.**, IEEE, G-P, Statler-Hilton Hotel, N.Y. **Prog. Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N.Y.

Engineering NEWS *and* HIGHLIGHTS

SALES AND EARNINGS FOR FIRST FOUR MONTHS OF 1966 ARE THE BEST IN COMPANY'S HISTORY

RCA achieved new sales and earnings records in April to make the first four months of the year the best for any comparable period in the company's history, Elmer W. Engstrom, Chairman of the Executive Committee, told more than 2000 RCA shareholders at their Annual Meeting.

"We are now well into our sixth year of sustained growth," Dr. Engstrom said. "If the economy maintains its present vigor, we confidently believe that new records will again be reported at the end of this calendar year."

Dr. Engstrom, President Robert W. Sarnoff, and key RCA operating executives outlined various growth trends in the principal areas of the company's business. RCA Chairman David Sarnoff presided at the meeting.

President Sarnoff, in an overall review of the company's prospects, reported on the rise of color from a $100 million annual business little more than 5 years ago to a multibillion-dollar enterprise today, and he pointed out that "this explosive growth is still in its initial stage and will be overshadowed in the years ahead."

The shareholders were briefed on achievements and prospects in their respective areas of responsibility by Group Executive Vice Presidents W. Walter Watts, Arthur L. Malcarney, and Charles M. Odorizzi, and Walter D. Scott, Chairman of the Board of NBC. These highlights were noted:

—Home instrument sales are off to the best start ever, with factory dollar sales during the first quarter running 36% ahead of the same period in 1965.

—RCA Victor records has established clear leadership in Stereo 8 cartridges, introduced last year with the opening of a new market for recorded music in automobiles.

—Industry acceptance of RCA's new four-tube color TV cameras has exceeded all expectations; during 1966, RCA expects to deliver more than 650 color cameras of all types valued at more than $45 million.

—NBC sales are expected to exceed a half billion dollars for the first time, and profits also are expected to reach an all-time record.

—RCA sales volume in space and defense electronics increased in 1965 and is expected to rise again in 1966.

—More than 1,100 RCA computer systems are now installed or on order, and deliveries of the new Spectra 70 family are on or ahead of schedule.

—First quarter sales and profits of the RCA Service Co., RCA Communications, RCA Victor Records, Broadcast and Communications Products, and RCA's foreign subsidiaries rose over those of the same period last year.

In his review of RCA activities and prospects, Dr. Engstrom paid tribute to General Sarnoff, who is observing this year the 60th anniversary of his career in communications and electronics.

23 ENGINEERS RECEIVE ECD ACHIEVEMENT AWARDS

Electronic Components and Devices has presented its annual Engineering Achievement Awards to 23 engineers in recognition of their work during the past year. Those honored include:

Television Picture Tube Div.—**F. G. Bushey,** Marion, Ind., for unique phosphor for color tubes; **R. C. Demmy, G. R. Fadner, D. L. Roberts, T. M. Shrader,** and **M. Van Renssen**, Lancaster, Pa., for color tube mechanical design.

Industrial Tube and Semiconductor Div.—**H. R. Meisel, J. H. Sondermeyer, R. L. Wilson,** and **J. E. Wright,** Somerville, N. J. and **H. W. Menzel** and **W. B. Planey,** Mountaintop, Pa. for work with hometaxial transistors. **R. A. Duclos** and **P. L. McGeough,** Somerville, N. J., for high-performance transistors for community TV systems.

Commercial Receiving Tube and Semiconductor Div.—**W. H. O'Neill** and **R. W. Young,** Woodbridge, N. J., for receiving tube glass technology. **P. Dejager,** Cincinnati, Ohio, for color TV receiving tubes.

Distributor Products—**G. G. Carne,** Los Angeles, Calif., for application of TV camera tubes.

General Sales—**M. Bernstein, S. Dobrowlski,** and **R. J. Walsh,** Harrison, N. J., for establishing a line of replacement transistors.

Special Electronic Components Div.—**J. A. Schramm** and **W. L. Varettoni,** Somerville, N. J., for integrated circuits for consumer products.

GRAPHIC SYSTEMS DIVISION MOVES TO NEW QUARTERS

The Graphic Systems Division, initially housed in the RCA Laboratories at the David Sarnoff Research Center, Princeton, N. J., has moved to a new location on Route 1, about 3 miles north of the Laboratories. The new site, formerly occupied by the Princeton Carton Co., has been completely refurbished to provide office, lab, and model shop facilities. The building is on a tract of 27 acres, with ample space for parking and further expansion of facilities.—*H. N. Crooks*

HOME INSTRUMENTS ENGINEERS TRAINED IN COMPUTER LANGUAGE

Approximately 50 engineers of the RCA Victor Home Instruments Division have completed training in the use of the FORTRAN IV computer language. Facilities have been made available through the RCA/Purdue TEAM Advanced Development Center and by teletype/telephone line connections to several time-share computing centers. The FORTRAN training will be available to all Home Instruments engineers.—*K. A. Chittick*

DR. G. H. BROWN ADDRESSES 1966 IEEE CONVENTION

Dr. George H. Brown, Executive Vice President, Research and Engineering, was one of the principal speakers at the session on International Color TV Systems at the 1966 IEEE International Convention held in New York City in March.

Speaking on "The Case for NTSC Color Television," Dr. Brown said that "the color TV system used in the U.S. was adopted as the result of the deliberations of the National Television System Committee (NTSC), a group of about 150 experts from the television industry, universities, and Government agencies, which recommended a system to the Federal Communications Commission after extensive nationwide testing."

Dr. Brown noted that in the last three years the sale of color TV sets reached a total of five million and that today's sets are almost as trouble-free as monochrome sets. He said that the old problems of differential phase and differential gain have largely disappeared.

In summarizing the case for NTSC color TV, Dr. Brown said that "it is to be preferred over other systems, such as the French SECAM and German PAL systems, because it has 12 years of continuous broadcasting experience, its quality and dependability are reflected in the inability of color receiver manufacturers to keep up with demand, its receivers cost less, and a single world standard should not exclude a potential of 10 million American viewers."

E. W. HEROLD APPOINTED MANAGER, GRAPHIC SYSTEMS A.R. LABORATORY

The appointment of **Dr. Edward W. Herold,** Staff Engineer, Research and Engineering, to the recently established position of Manager, Graphic Systems Applied Research Laboratory was announced in March by **Dr. George H. Brown,** Executive Vice President, Research and Engineering. In this additional capacity Mr. Herold will report to the Vice President, RCA Laboratories.

Mr. Herold received his BS degree from the University of Virginia in 1930 and an MS in Physics in 1942 and a D.Sc in 1961 from Polytechnic Institute of Brooklyn. Mr. Herold joined RCA Radiotron Co. in 1930 as a development engineer. When RCA Laboratories was established in 1942, he transferred to Princeton. He was named Director, Radio Tube Laboratory in 1951, and Director, Electronic Research Laboratory in 1954. In 1957 he headed the RCA group working on the C-Stellarator project. From 1959 to 1965 he was Vice President, Research, with Varian Associates, Inc.

E. I. ANDERSON ELECTED V-P, VALUE ASSURANCE, RCA SALES

The election of **Earl I. Anderson** to the position of Vice President, Value Assurance. RCA Sales Corporation was announced in March by **Raymond W. Saxon,** Vice Chairman. Mr. Anderson was previously Manager, Operations for the RCA Victor Home Instruments Division. He will report to Mr. Saxon, who is also Vice President and General Manager of the Home Instruments Division.

Mr. Anderson joined RCA in 1937 as an engineer. From 1937 to 1958 he was engineer in charge of the former RCA Industry Service Laboratory in New York. He was Chief Engineer for the Home Instruments Division for four years until his appointment as Manager, Operations.

A Fellow of the IEEE, Mr. Anderson holds 30 patents in the radio-TV field. He is a former member of the Editorial Advisory Board of the RCA ENGINEER.

W. A. ROSE RECEIVES SEER TECHNICAL EXCELLENCE AWARD

Systems Engineering, Evaluation, and Research (SEER), Moorestown, N. J., has presented its first Technical Excellence Award to **W. A. Rose.** Mr. Rose was cited for his work on electro-optic systems.

TECHNICAL EXCELLENCE AWARD WINNERS NAMED BY ASD

Technical Excellence Awards for the first quarter of 1966 have been announced by the Aerospace Systems Division, Burlington, Mass. They are: **R. J. Bosselaers,** for work in the design, fabrication, and testing of a broad-band amplifier for the DIMATE Product Improvement Program; **A. P. Arntson,** for work on an ultralightweight power supply; **W. B. Locke,** for design work on automatic production test equipment; Team Award—**R. Blanchard, D. Wellinger, R. Weiner, G. Gessler,** and **R. Tetrev** for redesign of the servo assembly for an RCA video tape recorder; Team Award—**E. Wyant, F. Hassett, W. B. Locke, H. Silverman, N. Amdur, A. Muzi,** and **S. Polednak** for work on automatic picture-tube test equipment for the ECD Marion, Ind. plant. —*D. B. Dobson*

V. J. DUKE RETIRES AT NBC

Vernon J. Duke, NBC Engineering Development Group, retired in March after 37 years with the National Broadcasting System. He joined NBC at KOA, Denver in 1929. He had been with the Engineering Development Group since 1937.

Mr. Duke's work involved all forms of TV camera tubes and optical systems, and he designed and supervised the fabrication and installation of an experimental 3V color film chain. He did extensive work in studio live camera and kinescope film equipment.

Mr. Duke holds 15 U.S. patents on TV and film equipment circuitry. He received his BSEE from the University of Colorado. He is a member of the IEEE and SMPTE. His paper, "New Transistorized AGC and Gamma Control Amplifiers for TV Broadcast," appeared in Vol. 11, No. 2 of the RCA ENGINEER.—*W. A. Howard*

RCA LABORATORIES ANNOUNCES 1966-1967 DOCTORAL STUDY AWARDS

Eight men of the RCA Laboratories have received doctoral study awards for 1966-1967. They are:

R. C. Blosser, Systems Research Lab., for doctoral studies in electrical engineering at Princeton University.

T. O. Farinre, Systems Research Lab., for doctoral studies in electrical engineering.

E. P. Helpert, Electronic Research Lab., for doctoral studies in applied mathematics at New York University.

R. S. Hopkins, Jr., Systems Research Lab., for doctoral studies in electrical engineering at Rutgers University.

E. C. Ross, Computer Research Labs., for doctoral studies in solid-state electronics at Princeton University.

D. L. Staebler, Electronic Research Lab., for doctoral studies at Princeton University.

W. P. Stollar, Materials Research Lab., for doctoral studies in ceramic engineering at Rutgers University.

R. A. Sunshine, Electronics Research Lab., for doctoral studies in electrical engineering at Princeton University.—*C. W. Sall*

22-INCH RECTANGULAR COLOR TUBE TO BE INTRODUCED IN LATE 1966

A new 22-inch (tube diagonal measurement), 90°, rectangular color TV picture tube will be introduced by RCA during the last quarter of 1966. **H. R. Seelen, Division Vice President,** RCA Television Picture Tube Div., said: "Although bulbs for the 22-inch rectangular color tube are not yet available from the glass supplier, RCA has completed the preliminary design work on this new tube."

Tentative technical data on the 22-inch picture tube has been sent to color TV receiver manufacturers to give them maximum lead time for their set design work. The short, overall length of the new tube (19.2 inches) will permit new styling innovations for compact cabinets.

The 22-inch tube will be produced in a laminated-etched version with a safety window treated to reduce reflections (RCA 22JP22) and a nonlaminated type (RCA 22KP22). Developmental samples are expected to be available in limited quantities during June.

RCA LABORATORIES—ECD ENGINEERING CONFERENCE

Electronic Components and Devices and the RCA Laboratories, Princeton, recently held an engineering conference to discuss technical programs of mutual interest and to promote close liaison between engineering and research activities. This conference was held in late April.

The technical presentations embraced television and radio, data processing, communications, power and control devices, instrumentation and direct energy conversion.—*D. H. Wamsley*

PROFESSIONAL ACTIVITIES

ASD, Burlington, Mass.: **W. Gray** served as a session moderator at the 1966 IEEE Reliability Spring Seminar, Hanscom Field, Bedford, Mass. on April 14.—*D. B. Dobson*

CSD, Camden, N. J.: **C. W. Fields,** Administrator, Tech. Publications, was elected to the National Administrative Committee of the IEEE Group on Engineering Writing and Speech to serve until June 1967. He also has been appointed editor of *Standards Engineering,* the journal of the Standards Engineers Society, Inc.

ECD, Somerville, N. J.: **H. M. Hyman,** Sr. Eng., Integrated Circuits Design, was awarded a gold watch in recognition of 10 years of service as an assistant editor of the *Journal of Applied Spectroscopy.* The presentation was made by the Society of Applied Spectroscopy at the 5th National Meeting in Chicago in June.—*I. Kalish*

ECD, Lancaster, Pa.: **R. F. Dourte** and **W. K. Peifer** attended the Cineradiology Symposium in Rochester, N. Y. in March. **R. M. Matheson, F. A. Helvy,** and **D. E. Persyk** participated in the Scintillation and Semiconductor Counter Symposium held in Washington, D.C. in March.—*R. L. Kauffman*

RCA Victor Home Instruments, Indianapolis, Ind.: **G. C. Hermeling,** Mgr., Tuner and Remote Control Engineering, is chairman of the Broadcast and TV Professional Group of the IEEE, Central Indiana Section.—*K. A. Chittick*

M&SR, Moorestown, N. J.: **A. Gold** worked with the Paper Selection Committee of AMRAC (Anti-Missile Research Advisory Council), reviewing papers submitted for presentation at the 1966 Spring AMRAC Meeting.—*T. G. Greene*

CSD recently honored its authors for 1965 with an authors' reception and dinner. Some of the 42 attending from Camden are shown at the registration desk. Handling the registration is Vivian Surplus, secretary to Chief Engineer. Left to right are: D. P. Campbell, C. W. Fields (CSD Ed. Rep.), C. Alexoff, E. J. Sass, H. E. Hawlk, P. J. Anzalone. CSD published 122 papers in 1965.

STAFF ANNOUNCEMENTS

Electronic Components and Devices, Harrison, N. J. The organization of the staff of Electronic Components and Devices, reporting to **J. B. Farese,** Division Vice President, is announced as follows: **H. F. Bersche,** Div. Vice President, Distributor Products; **G. C. Brewster,** Mgr., Operations Planning and Support; **C. E. Burnett,** Div. Vice President and General Mgr., Industrial Tube and Semiconductor Div.; **J. T. Cimorelli,** Mgr. Technical Aid and License Adm.; **D. O. Corvey,** Purchasing Agent; **L. R. Day,** General Mgr., Special Electronic Components Div.; **A. M. Glover,** Div. Vice President, Technical Programs; **L. A. Kameen,** Mgr., Personnel; **J. Koppelman,** Controller, Finance; **W. H. Painter,** Div. Vice President and General Mgr., Commercial Receiving Tube and Semiconductor Div.; and **H. R. Seelen,** Div. Vice President and General Mgr., TV Picture Tube Div.

A. M. Glover has announced the following organization of Technical Programs; **K. G. Bucklin,** Mgr., Commercial Engineering; **E. O. Johnson,** Mgr., Engineering; **R. L. Kelly,** Adm., Product Assurance; **A. M. Glover,** Acting Mgr., New Business Development.

ECD, Special Electronic Components Div., Somerville, N. J. The announced organization of the Integrated Circuit Operations Dept., reporting to **R. L. Klem,** Mgr., includes: **A. L. Gorman,** Mgr., Plant Engineering, Somerville; **J. W. Ritcey,** Mgr., Integrated Circuit Engineering; **R. P. Tittel,** Mgr., Mfg. Standards; **E. M. Troy,** Mgr., Integrated Circuit Products Mfg.; and **R. A. Wissolik,** Administrator, Operations Planning.

ECD, Commercial Receiving Tube and Semiconductor Div., Lewiston, Me. **R. M. Cohen,** Mgr., Engineering announces the appointment of **R. V. Fournier** as Resident Engineer. **H. A. DeMooy,** General Plant Mgr., announces the appointment of **G. A. Hiatt** as Plant Mgr. and **F. L. Wildes** as Mgr., Production Engineering.

ECD, Commercial Receiving Tube and Semiconductor Operations, Cincinnati, O. **J. P. Sasso,** Mgr., Tube Mfg., announces the appointment of **R. E. Ward** as Mgr., Production Engineering. Reporting to Mr. Ward are **J. A. Dierkers, R. J. Hackmeister,** and **J. J. Hanners,** Production Engineering Managers of Miniature Tubes.

ECD, Industrial Semiconductor Operations Dept., Mountaintop, Pa. The organization of Manufacturing and Production Engineering—Germanium Devices, Rectifier Stack Assembly, and Wafer Manufacturing, reporting to **L. H. Urdang,** Mgr., is announced as follows: **R. J. Miller,** Supt., Mfg.; **D. A. Pahls,** Engineering Ldr., Germanium Devices; and **A. M. Splinter,** Engineering Ldr., Photo Cells.

RCA Victor Home Instruments Div. The announced organization reporting to **R. W. Saxon,** Vice President and General Manager, includes **L. R. Kirkwood,** Chief Engineer, Engineering Department.

Announced organization reporting to **W. E. Albright,** Mgr., Mfg. Dept., includes **K. D. Lawson,** General Plant Engineer. The organization announced by **W. L. Bledsoe,** Plant Mgr., for the Rockville Plant includes **W. R. Turner,** Mgr., Mfg. Engineering. The organization of the Indianapolis Components Plant, reporting to **E. A. Swihart,** Plant Mgr., includes **J. B. Thomas,** Mgr., Mfg. Engineering and **J. C. Wood,** Mgr., Plant Engineering. The organization of the Memphis Plant, reporting to **T. F. Whitten,** Plant Mgr., includes **J. W. Good,** Mgr., Mfg. Engineering and **H. L. Slusher,** Mgr., Plant Engineering.

Broadcast and Communications Products Div., Camden, N. J. **C. H. Colledge,** Div. Vice President and General Mgr., has announced the appointment of **A. M. Miller** as Div. Vice President, Instructional and Scientific Electronics Dept.

Corporate Staff, New York, N. Y. **H. L. Letts,** Executive Vice President and Controller, has announced the appointment of **L. M. Isaacs** as Staff Vice President, Management Information Systems. The organization reporting to Mr. Isaacs is announced as follows: **B. G. Curry,** Mgr., Management Information Systems Programs; **M. S. Demurjian,** Adm., Systems Engineering Projects; **B. W. Wheeler, Jr.,** Mgr., Management Systems Studies; **A. M. Trifiletti,** Systems Engineer; **H. F. Boylan,** Systems Engineer; and **W. P. Alexander,** Mgr., Procedures and Records, Management Programs.

Corporate Staff, Camden, N. J. **F. Sleeter,** Vice President, Manufacturing Services, has announced the following appointments: **R. V. Miraldi,** Director, Industrial Engineering; **E. H. Panczner,** Director, Machine Development Projects; **B. V. Dale,** Mgr., Automatic Test and Measurement Systems.

Aerospace Systems Div., Burlington, Mass. **J. S. Furnstahl,** Mgr., Engineering Controls and Support, Engineering Dept., has announced the appointment of **J. C. Mayer** as Administrator, Value Engineering.

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months: Location and new supervisor appear in parentheses.

DEP West Coast Division

M. J. McDaniel: from Sr. Member, D&D Engrg. Staff to *Ldr., D&D Engrg. Staff* (R. Richards, Van Nuys)

DEP Communications Systems Division

A. I. Krell: from AA Engineer to *Ldr. Des. & Dev. Engineers* (E. L. Schlain, Camden)

W. Gesek: from A Engineer to *Ldr. Des. & Dev. Technical* (E. L. Schlain, Camden)

J. T. Swaim: from A Engineer to *Ldr. Des. & Dev.* (S. Tucker, Camden)

L. A. VanLingen: from A Engineer to *Ldr. Engineering Projects* (L. A. Valaranie, Camden)

DEP Aerospace Systems Division

P. A. Johnston: from Checker to *Ldr., Design Drafting* (R. C. Middleton, Burl.)

A. T. Farrell: from Ldr., Design Drafting to *Mgr., Design Drafting* (R. Rodriguez, Burl.)

R. J. Gildea: Sr. Proj. Member, Tech. Staff to *Ldr., Tech. Staff* (R. B. Merrill, Burl.)

A. J. Lynch: from Sr. Member, Tech. Staff to *Ldr., Tech. Staff* (R. E. Davis, Burl.)

R. E. Hartwell: from Sr. Proj. Member, Tech. Staff to *Ldr., Tech. Staff* (D. J. Cushing, Burl.)

W. H. Pownell: from Engineering Scientist to *Ldr., Tech. Staff* (A. L. Warren, Burl.)

Electronic Components and Devices

Harlan T. Hodder: from Production Eng. A to *Ldr., Tech. Staff* (L. B. Smith, Needham)

Peter D. Lawrence: from Sr. Member, Tech. Staff to *Ldr., Tech. Staff* (G. D. Meimaris, Needham)

A. F. McDonie: from Eng., Product Dev. to *Mgr. Production Engrg.,* Conversion Tube (M. Petrisek, Lanc.)

E. J. Vresilovic: from Mgr., Production Engrg. Conversion Tube to *Mgr., Product Engrg.* (M. Petrisek, Lanc.)

W. H. Rivard: from Eng., Manufacturing to *Mgr., Cost Reduction* (W. O. Watts, Hr.)

R. K. Schneider: from Eng., Product Dev. to *Engrg. Ldr.,* Product Development (C. T. Lattimer, Marion)

Electronic Data Processing

L. Thompson: Mbr., Engrg. Staff to *Ldr., Tech. Staff* (J. R. Hammond, Florida)

J. Williamson: from Sr. Mbr., Engrg. Staff to *Ldr., Tech. Staff* (H. N. Morris, Florida)

D. Wright: from Sr. Membr., Engrg. Staff to *Ldr., Tech. Staff* (H. N. Morris, Florida)

F. Vargo: from Sr. Member., Engrg. Staff to *Ldr., Tech. Staff* (H. N. Morris, Florida)

RCA Service Company

H. D. Masch: from Eng. to *Ldr., Engs.* (C. L. Sharp, Florida)

J. E. Smith: from Ship Instru. Eng. to *Mgr., Apollo Navigation & Data Handling* (W. J. Tubell, Florida)

A. J. Gagnon: from Eng. to *Mgr., Minuteman Support Project* (F. G. Atlee, Cherry Hill)

A. R. Miles: from Systems Service Eng. to *Mgr., Electronics Systems* (E. Sears, Florida)

E. J. Rainwater: Ldr., Engineers to *Coord., Project Operations* (B. E. Keiser, Florida)

H. F. Ramm: from Install. & Mod. Engr. to *Ldr., Systems Service Engs.* (C. M. Fisher, Alexandria, Va.)

H. C. Rollandani: from Install. & Mod. Engr. to *Ldr., Systems Service Engs.* (C. M. Fisher, Alexandria, Va.)

R. J. Johnson: from Eng. to *Ldr., Engs.* (B. E. Keiser, Florida)

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