OUR COVER

. . . an artist's conception of the SERT capsule in space. The heavily instrumented SERT capsule carried two ion engines (shown extended at sides of capsule) into space so that they could be tested in their intended operational environment for the first time. The six photographs show various sensors designed for space application by the Astro-Electronics Division—top row: left, SERT hot-wire anemometer probe to measure ion beam intensity; center, NIMBUS Advanced Vidicon Camera System (AVCS); right, APOLLO television camera—bottom row: left, RANGER partial-scan camera; center, TIGRIS, an extremely sensitive astronomical camera; right, TIROS automatic picture transmission (APT) camera. (Cover art direction, J. Parvin. Photos and sketch courtesy Astro-Electronics Division.)

Space Equipment—A Design Challenge

Professional success is never achieved without heartbreaking setbacks and, on attained, is easily lost to one's competitors. Some of the articles in this issue the RCA ENGINEER describe typical equipment which has helped RCA achie success in the national space program. To uphold our successful position must, of course, continue to use the techniques which have enabled us to produ reliable—work-every-time—designs; *but this is far from enough.* We must mo forward, learn about new techniques, understand the application of new devices; mo succinctly, we must continue to be *up-to-date* professional engineers and scientis

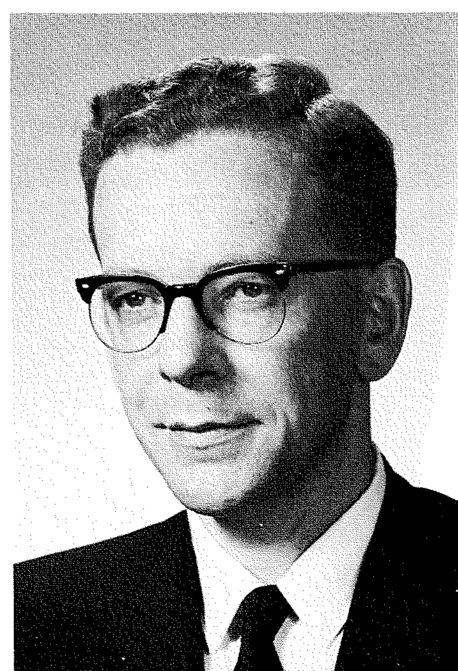
The staff of the RCA ENGINEER and the contributing authors are playing th part by making information readily available. You belong to professional societi and through your libraries you have ready access to the technical papers of t world. Have *you* faced the challenge to keep up to date in your chosen area skill so that you can help maintain RCA as a leading engineering company?

If you are a circuit-design engineer, do you know what techniques are used horizon-sensor amplifiers, how to apply integrated-circuit techniques to spa cameras, how to design efficient DC-to-DC converters and at the same time minimi the interference generated by them? If your skill is in another area, perhaps y should know how to select adhesives and insulating materials which will withsta the radiation fields in space; perhaps you need to understand the problems ass ciated with outgassing. *Whatever it is—are you keeping up to date?*

RCA engineers have been in the forefront of space activities from the beginni To stay there we must meet the technical challenge of creating state-of-the-a designs which achieve long life, and we must deliver equipment on the requir date, at a price the customer can afford. The solution to this challenge is *not* be found in ultra-conservatism, since our competitors have enterprising engineeri teams also very determined to become the best in the business. Rather, all of must produce something extra, from a personal dedication to the job at han As we succeed, we can take our place in the proud ranks of the other RCA eng neers who have maintained the fame and integrity of the RCA name througho the world.

J. Vaughan

J. Vaughan
Chief Engineer
Astro-Electronics Division
Radio Corporation of America



RCA ENGINEER

VOL. 10, NO. 5
FEB.-MAR. 1965

CONTENTS

PAPERS

NOTES

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.

An index to RCA ENGINEER articles appears annually in the April-May issue.

IN today's defense and space business, a *Project Definition Phase* (PDP) contract is an intensive advance study of all of the concepts of "value" which will affect a major government project—from the basic system concepts, through the specification, development, design, production, and operational use of hardware. The PDP considers not only actual dollar costs, but also "total value" in terms of what the system is to do, and the most effective technical and managerial means to achieve this.

In practice, PDP contracts are funded and parallel development efforts assigned to two or more contractors. Each contractor then:

The Engineer and the Corporation

TOTAL-VALUE CONCEPTS IN THE PROJECT DEFINITION PHASE

S. ROBINSON, Administrator
Value Engineering
Missile and Surface Radar Division
DEP, Moorestown, N. J.

1) Sets up preliminary engineering and management plans.
2) Establishes firm and realistic system specifications.
3) Defines interfaces and breakdowns of project responsibilities.
4) Identifies high-risk areas.
5) Establishes the "best" technical approaches.
6) Develops realistic schedules and cost estimates, leading to fixed price or incentive contracts.

By so doing, the PDP assures that the military requirements are valid and adequately defined, the proposed system is technically and tactically feasible, and state-of-the-art technology is applied wherever possible. Furthermore, major alternatives and trade-offs between them have been considered and the planned system can then be developed based on an appropriately realistic balance of performance, cost, and schedule. Finally, both the customer and the potential contractors are equipped with realistic management plans, systems, schedules, and costs prior to actual selection of a contractor and embarking on the project.

SYSTEM TRADE-OFFS

One of the most significant aspects of PDP is the concept of system trade-offs among cost, performance, and schedule. In the past, military projects were often oriented toward maximizing performance—with only secondary regard to cost. While today's defense procurement is very economy-oriented, it can be disastrous from the standpoint of system performance to swing too far in the other direction—to minimize cost irrespective of the technological consequences.

A more realistic and practical approach is to maximize capability for a *specified cost*, or to minimize cost for a *specified capability*. That is, choose a design which provides the most benefits for a fixed budget of X dollars. Or, start with the requirement that these same benefits be obtained at minimum cost, probably resulting in the same design at the same cost of X dollars.

The ratio of function to cost may also be used for comparing alternatives developed in trade-off studies, *providing the ratios hold true at different magnitudes* of function or cost. This is not always the case, however, but ratios do become progressively more realistic as constraints are placed on either the function or cost, preferably to the point where one or the other is fixed. This returns us to the more desirable approach of maximizing capability for a given cost or minimizing cost for a given capability.

TOTAL VALUE CONCEPTS

Today, RCA's total-value concepts for defense systems relate function to cost all the way from concept through use. Cost is a major design parameter, and the cost of both producing *and using* what is being designed has to be rigorously examined. Similarly, the PDP puts special emphasis on achieving balanced characteristics in the early design stages which will prevent unnecessary costs in the future. Designs are, therefore, evaluated with respect to the total cost of an equipment for its service life.

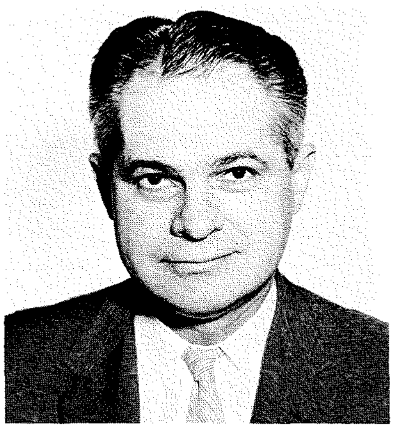
Total cost is the sum of 1) research, development, test, and evaluation (RDT&E) cost; 2) production, 3) installation, and 4) operational cost, the latter including support equipment, maintenance manpower and facilities, overhaul, and supply.

The term *service life* can be somewhat nebulous. The important factor is how well the equipment functions while in service. It is sometimes specified by the number of operating hours with "normal" maintenance, which can be valid for wear-out failure modes. But, this does not account for the unavailability of the equipment due to outages and the resources required to keep it going. A more precise measurement is operational readiness for a given number of years as defined by the four factors in the following example:

1) *Mean time between failures* = (*Total operating hours*) ÷ (*Number of system failures in same interval*) = 100 hours. From this, the probability P_s of successfully completing a 24-hour mission is: $P_s = \exp(-\lambda t) = \exp[-(1/MTBF) \times 24] = \exp[-(1/100 \times 24] = 78\%$
2) *Preventive maintenance downtime* per 1,000 hours = 10 hours.
3) *Corrective maintenance downtime* per 1,000 hours = 20 hours.
4) *Maximum allowable single downtime for corrective maintenance* = 2 hours. This is the longest tolerable downtime for corrective maintenance without compromise of the mission. This can be used to guide preventive maintenance which could be scheduled when repair or replacement of a part requires more than two hours.

System availability is the probability that the system will be operative at any given time. The above system is operable only

Final manuscript received December 15, 1964



S. ROBINSON, as Administrator of Value Engineering at the RCA Missile and Surface Radar Division, Moorestown, is responsible for the direction of the Value Engineering programs at this division. Prior to this assignment, he was engaged in Value Engineering on BMEWS, and has been continuously engaged in value engineering work at RCA since December 1958. Before joining RCA in 1958, Mr. Robinson was employed in the telemetering field for a total of seven years as Chief Design Engineer with the Applied Science Corporation of Princeton, N.J.; and with Teledynamics, Inc., Phila., Pa. Prior to this he was engaged in research, electronic engineering and production of nucleonic instrumentation for the University of Chicago Manhattan Project, U.S. Atomic Energy Commission, and Nucleonic Corp. of America for a total of five years. Mr. Robinson was also engaged in the design of airborne gun sight and fire control computing systems at Fairchild Camera Instrument Co. and in related aircraft technical fields for over four years. Mr. Robinson majored in Physics at the City College of New York, class of 1939. He is Secretary of the Delaware Valley Chapter of the Society of American Value Engineers, and a member of the EIA Committee on Value Engineering, and of the IEEE.

970 hours of each 1,000 hour period and its availability is 970/1,000 = 97%.

CONFIGURATION, COST, AND CONCENTRATION

Configuration and cost are the significant milestones established early in the PDP; they delineate the hardware items, quantities, and arrangements considered technically feasible, and their estimated costs. This information provides the basis for concentration of value improvement effort on *value-sensitive* items—those with high potential for value improvement.

The cost spectrum used by RCA embodies total value concepts and establishes target cost goals. Fig. 1 shows a cost analysis form arranged so that the cognizant design activities are provided with RDT&E, production, and operational cost goals pertinent to each "black box" they are to design. When alternates or changes are considered, they must therefore be evaluated over the same cost spectrum. Continuity of the total value concept is maintained in the value comparison form (Fig. 2), which relates function to RDT&E, production, and operational costs.

Knowledge of the total cost pattern is essential for realistic value judgments. For example, one RCA study showed that the direct cost of maintaining a typical military communication system designed to *MIL-E-4158* is $40,000 per 1,000 parts per year. The prevention of unnecessary operational costs at the design stage presents significant *value potential,* perhaps even at the expense of higher development and/or production costs. Fig. 3 illustrates an assumed system of 500,000 parts whose acquisition cost is $100 million. Using $40,000 per 1,000 parts per year, the yearly operational cost is $20 million (line *A′*). If the rate is reduced to $35,000, the yearly operational cost is $17.5 million (line *B′*). The origin of line *B′* is

				Subsystem A			Subsystem B			Subsystem C			Totals		
	Equipment	Resp	Dept	RDT&E	Prod	Oper	RDT&E	Prod	Oper	RDT&E	Prod	Oper	RDT&E	Prod	Oper
Transmitter	Amplifier		Eng. Mfg.												
	Antenna		Eng. Mfg.												
	Sub Total		Eng. Mfg.												
Receiver	Preamp		Eng. Mfg.												
	Display		Eng. Mfg.												
	Sub Total		Eng. Mfg.												
	Total														

Fig. 1—Cost analysis form for design activities.

COMPARATIVE VALUE STUDY

ITEM		PART NO.	QUAN.
USED ON			

		INITIAL CONCEPT		PROPOSED ALTERNATE				
FUNCTIONAL COMPARISON								
ESTIMATED COSTS IN $	PHASE	UNIT	TOTAL	UNIT	TOTAL	GROSS SAVING	VE COST	NET SAVING
	RDT&E							
	PROD.							
	TOTAL							
	OPERATION ____ YRS.							
STATUS								

Fig. 2—Value comparison form relating function to costs.

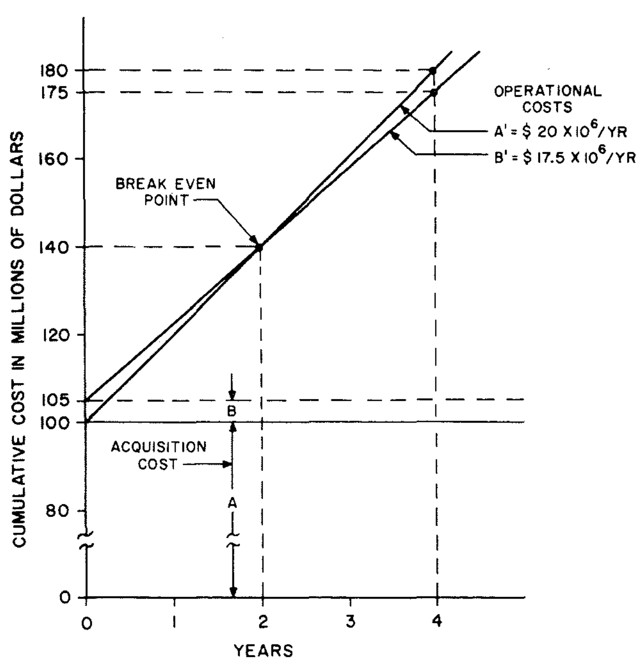


Fig. 3—Acquisition and operational cost trade-offs.

Characteristic	Weighting Factor W	System A V	System A W x V	System B V	System B W x V	System C V	System C W x V
Cost	.25	.30	.07	.50	.12	.60	.15
Range	.35	.80	.28	.70	.24	.40	.14
Weight	.10	.20	.02	.40	.04	.60	.06
Availability	.30	.80	.24	.85	.25	.90	.27
Totals	1.0		.61		.65		.62

Fig. 4—Evaluating relative worth of alternate designs for hypothetical Systems A, B, and C. As an example here, comparison is between cost, range, weight, and availability as characteristics. Each characteristic is assigned a weighting factor, W. The sum of the weighting factors must be unity. In this case, total value for each system is $(W_c V_c) + (W_r V_r) + (W_w V_w) + (W_a V_a)$.

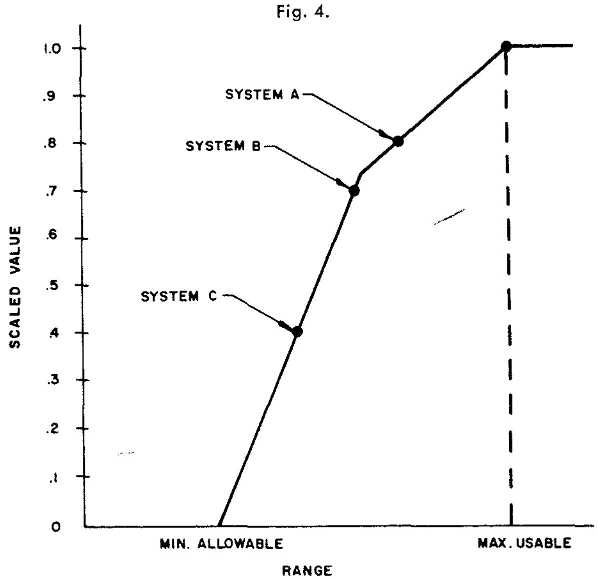
placed at $A + B$ to show that as much as \$5 million additional (5% of the original acquisition cost) could be budgeted to achieve this goal and still break even in two years. (In four years there would be a net saving of \$5 million.)

Frequently, value improvement may both lower cost and improve reliability by reducing complexity. Similarly, value improvement may reduce direct operating costs and lower the number of system parts as well. This would tend to increase the savings shown in Fig. 3, since fewer parts would decrease the slope of line *B*.

In general, a relatively few system elements account for a high percentage of system cost. Generally, proportionate value improvement effort should be devoted to these items. A ranking of item costs, according to their percentage of the total cost, will provide a quick initial guide for the concentration of value improvement effort. However, this ranking may not necessarily correspond with the items having the highest *value sensitivity*—that is, potential return for effort expended. Some additional criteria to consider are as follows:

1) *High Quality Repetitive Items*—These are frequently of low or medium cost. The quantity factor exerts high "leverage" in terms of overall savings for efforts expended. For example, a recent change by RCA in one resistor for a missile program has resulted in savings of over \$7.7 million.

Fig. 5—A hypothetical normalization curve for range in the example of Fig. 4.



2) *Standard vs. Special Items*—Standard and special designs should be evaluated to determine if total value will benefit from an exchange of roles. Standard parts tend to seem less value-sensitive because they have the protection of status. A nonstandard part must demonstrate at least equivalent function and reliability, and savings which will more than compensate for changes in the logistic system. Putting it another way, a nonstandard part has to reach "escape velocity" to get into the "orbital swim." On the other hand, the problem can be oversimplified and misstated as: "The maximum use of authorized parts, materials, and processes." This approach is essential only up to the point where "standard" items continue to provide superior *total value*.

3) *Technical Uncertainties*—The scientist and engineer inherently generate value by making it possible to perform a function that did not exist before. During the PDP, value engineering techniques assist the inventive process and guide it to the least complex and least costly innovative solutions. In this regard, high-cost areas of technical uncertainty are carefully investigated, particularly where the possible alternatives differ widely in cost.

4) *State of the Art*—A "design from scratch" is potentially more time-consuming, more costly, and less sure of reliability than an established approach. Its value improvement potential is, therefore, higher than that of a mature design. Conversely, areas in which technology is conventional and equipment design is relatively mature (such as power supply, storage, and conversion) may offer less potential. This is not necessarily because the mature design represents the best approach, but because the new design must justify the extra effort—much as described above in considering standard vs. non standard parts.

During the PDP, value studies are conducted by all program activities on system and hardware design, procurement, manufacturing, personnel, data, and management operations. In performance studies, for example, key performance parameters are varied, holding the rest of the system in conformance with specification requirements. In each case, the elements concerned with the function being varied are studied for design and cost ramifications, and new approaches are considered to minimize cost. In addition, other studies are made in which the proposed system is compared with other existing military systems. This is done by examining measures of functional effectiveness vs. cost for each system with respect to the required capability.

MEASURES OF SYSTEM VALUE

There has been much discussion regarding the need for establishing measures of system value. Such parameters might be used in the PDP and subsequent phases to define the relative importance of performance, cost, and delivery. For example, reliability groups have a parameter they call system availability:

$$\textit{System Availability} = \frac{MTBF}{MTTR + MTBF}$$

Where: $MTBF$ = mean time between failures, and $MTTR$ = Mean time to repair. The total system availability is the net result of the individual contributions of its subsidiary parts and their network relationship in the reliability model. In any

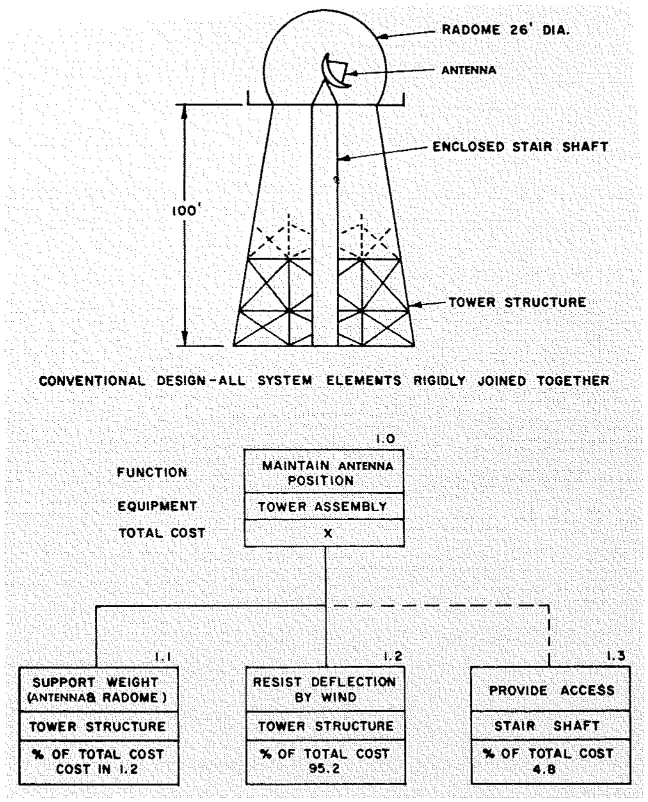


Fig. 6—Case study: original design approach to a radar antenna tower before value analysis. Function-cost charts like this (and Fig. 7) help in analyzing alternatives by focussing attention on disproportionate parameters.

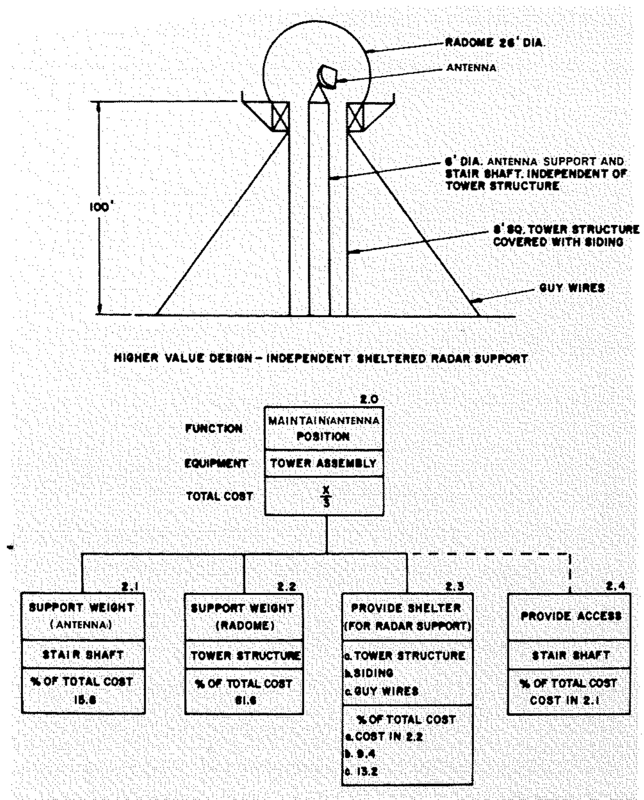


Fig. 7—Case study: higher-value design resulting from coordinated value study by RCA and the customer. Here, required functions are provided at a third the originally anticipated cost for the approach in Fig. 6.

one system, many different combinations of reliability characteristics could achieve the same overall system availability.

Similarly, it is conceivable that a measure of *total system value*, or *system worth*, might be established, although such an all inclusive concept has sometimes been compared to the "universal solvent."

RCA has been using a technique for evaluating the *relative worth* of alternative designs which is a step in this direction. This is illustrated in Fig. 4, wherein cost, range, weight, and availability are compared for Systems *A*, *B*, and *C*. (The numbers shown are for illustrative purposes only.) The characteristics are assigned weighting factors between 0 and 1 whose total equals unity. Each system is rated on a normalization curve for each characteristic. The normalization curve for range is shown in Fig. 5. The total value is the sum of the products of the individual weights and normalized values:

$$\text{Total Value} = W_cV_c + W_rV_r + W_wV_w + W_aV_a$$

Where: W_cV_c = (*Weighting factor for cost*) × (*normalized value for* W_rV_r) = (*Weighting factor for range*) × (*normalized value for range*); W_wV_w = (*Weighting factor for weight*) × (*normalized value for weight*); and W_aV_a = (*Weighting factor for availability*) × (*normalized value for availability*).

This approach enables comparison of a number of characteristics having different dimensions. It is, of course, *critically dependent on the weights and normalization curves which are established.*

DEVELOPING TRADE-OFFS: THE "CONCEPT REVIEW"

Normally, value engineering task force operations, in the classical sense, reach a peak during the early stages of the RDT&E effort. At this time, *established* design concepts and costs provide a base for evaluating the payoffs for further value improvement. However, the PDP is, in itself, a system-wide value study at an earlier level of flux and technical uncertainty. In present-day RCA defense projects, this has led to the use of value-engineering "Concept Reviews," which are tailored to this early stage. These reviews consider various subsystem approaches and configurations for value-sensitive portions of the system, rather than of all the detailed hardware elements. The purpose of these reviews is to:

1) Provide communication among specialists whose disciplines are involved in the concept study of each major subsystem.

2) Stimulate interdisciplinary contributions to overall cost effectiveness with particular reference to producibility.

3) Study the initial design concept and initiate interdisciplinary efforts in search of higher value alternatives.

The items to be reviewed are selected and scheduled by a Value Engineering group, as soon as a coherent presentation of the initial design concept can be made in terms of sketches, models, or reports. A task group representing a cross section of program disciplines is designated by Value Engineering for each review. (Typically represented are engineering, manufacturing, purchasing, and reliability personnel, with other pertinent specialists as required.)

The agenda consists of a presentation by the design activity describing the required function, the proposed concept, the factors influencing its choice with respect to other alternatives, and the cost factors. The concept is evaluated with respect to the interacting needs of the various disciplines and modifications or entirely new approaches are recommended to improve total value. Subsequent studies are triggered to investigate promising alternatives. Minutes of the review are issued.

The flexibility for change at this stage of the program permits radical changes in approach with relatively few inhibitions. For example, in one review a subsystem configuration revealed poor interdisciplinary trade-offs. A superior alternative configuration was devised and the cognizant manager directed a subsequent detailed study leading to its implementation—all during the course of a two-hour session. Cost estimates indicated production savings in excess of $1 million.

CASE STUDY—A RADAR ANTENNA TOWER

Functional and cost models of the chart type are being used in all phases of value engineering effort, but are particularly apropos during the PDP. They concentrate attention on disproportionate functional and cost parameters and assist in the analysis of alternatives. They are developed in top-down breakdown form for any desired level of system study.

Figs. 6 and 7 illustrate functional charts of alternative designs for a radar antenna tower. All functions essential to the basic function are joined to it by a solid line. Secondary functions are joined to the basic function by a dashed line.

The conventional "brute force" design originally contemplated by the specification is shown schematically in Fig. 6. For electrical reasons, a free-standing tower was thought necessary, which required a broad-based, costly structure and foundation. This was further aggravated by the need to withstand winds up to 130 mph and to minimize wind-induced motion of the antenna. In a conventional design, as shown in Fig. 6, the basic functions of weight support and resistance to deflection are borne by the tower structure. The stairshaft fulfills the secondary function of access via an internal spiral staircase. All elements of the system are rigidly joined together. (Note that the tower structure accounts for *95% of the total cost.*) The radome is not included in the functional chart because it represents a constant element, for purposes of this discussion. The functional diagram is deceptively simple in that the tower structure performs all of the basic functions, and most of the total cost is expended for basic rather than secondary function. The tower cost, however, was disproportionately high compared to other towers and to the radar itself, which performed the primary system function.

During the proposal and early contract stages, the RCA design group carried out an intensive value study of the specification and design concept in close conjunction with customer personnel. A key element in this process was the value technique of *evaluation by comparison.* A cost comparison showed that a typical guyed tower could perform the same function at approximately one-third the cost of the free-standing tower. A further study of electrical requirements revealed that this approach would be acceptable. To eliminate the effect of excessive tower deflection on the antenna, a solution was found by working with nature instead of fighting it.

The design shown in Fig. 7 achieves *higher* value by combining functions, separating other functions, and changing the character of the required functions as follows:

1) Two functions are combined in the stairshaft; that is, support the radar (*2.1*) and provide access (*2.4*). It is designed as an independent free-standing tube with no attachments to the rest of the structure.

2) To shield the antenna and its support from wind effects, the tower structure surrounds it and is covered with a siding. The tower structure still combines two functions, but they have changed their character. It supports weight, but only that of the radome (*2.2*). Instead of resisting wind deflection (as in *1.2*), it now provides shelter (*2.3*). It may deflect within limits as constrained by the guy wires without impairing radar function. This eliminates the need for the previous massive structure and provides the largest cost reduction. Note that the support of the two major weights, antenna and radome, is now accomplished by the stairshaft and tower structure, respectively, which are independent of each other.

This new design provides the functions required at one-third of the anticipated cost. This is an example of sound, value-conscious engineering applied in a coordinated effort by RCA and the customer. The specification changes required for its implementation have been approved as a value engineering change proposal and the savings will be shared by the government and RCA.

CONCLUSION

The inherent value-orientation of the PDP has stimulated the projection of value studies into the earlier stages of program development. It has also had the effect of extending the application of value concepts throughout all other program disciplines.

The PDP system has effected a significant breakthrough in the application of value concepts. It has helped to break through the "performance-orientation barrier" and put value analysis into official government contracting policy. In effect, it requires that we ask—*realistically*—of each project: *What is it? What does it do? What does it cost? What else will do the job? What will that cost? What is the "best choice"?*

This might be called cost effectiveness, or value engineering, or systems engineering, or operational analysis, or just plain, good, old-fashioned *engineering*. But it is not just one or the other of these; *it is all of them*, and more.

The most significant aspect of the PDP process is that it requires the application of *total value* concepts throughout the entire spectrum of management and engineering operations at the earliest possible stage. Each project activity must value-engineer its contribution. As a result, the effectiveness of all disciplines has been broadened.

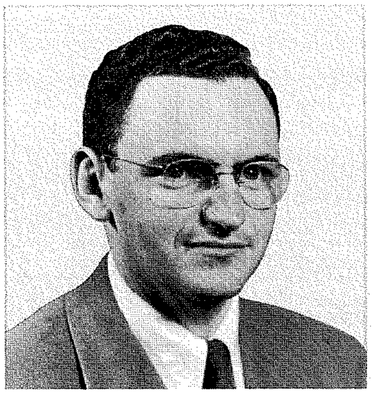
BIBLIOGRAPHY

1. E. Leshner, "Relationship of Value Engineering and Cost Effectiveness," Annual Mtg. Soc. of American Value Engineers, Los Angeles, Calif., Apr. 23, 1964.
2. A. S. Wall, "Value Engineering vs. Quality Control: Whose Turn in the Ivory Tower?", Nat'l. Convention Soc. of American Value Engr., Los Angeles, April 24, 1964.
3. C. Fallon, "Quantitative Measures for Comparison of Value," Nat'l. Convention Soc. of American Value Engrs., Los Angeles, Apr. 24, 1964.
4. S. Malasky, "Bringing an Established Program Up-to-Date," Nat'l. Mtg. of the Soc. of American Value Engrs., Los Angeles, Apr. 23, 1964.
5. S. Robinson, "Value Engineering in Project Definition Phase Contracts," 1964 Nat'l. Convention, Soc. of American Value Engrs., Los Angeles, Apr. 24, 1964.

DR. JACQUES I. PANKOVE

. . . for contributions to electrical and optical semiconductor research and development.

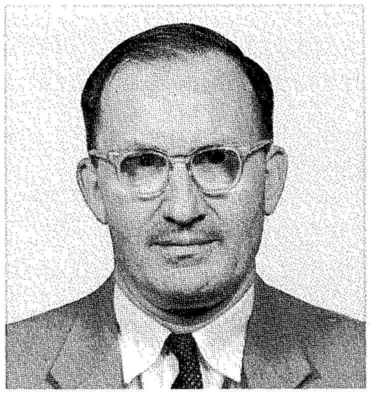
DR. JACQUES I. PANKOVE, who has made many contributions to semiconductor devices, including large-area photocells and transistors, received his BS in 1944 and his MS in 1948, from the University of California. Since 1948, he has been a Member of the Technical Staff of RCA Laboratories, Princeton. He was awarded a David Sarnoff Scholarship (1956-57) to study solid-state physics at the University of Paris under Prof. Pierre Aigrain. In 1960, he received his doctorate for his thesis on infrared radiation in germanium. Since his return, he has done research in superconductivity and on silicon carbide and germanium. He is currently studying injection luminescence and laser action in gallium arsenide and other compounds. Dr. Pankove has authored over 30 articles and has over 40 patents. He has received three "RCA Laboratories Achievement Awards." In addition to IEEE, he is a Member of APS, AAAS, and Sigma Xi.



STANLEY V. FORGUE

. . . for contributions to the development of television pickup tubes and infrared imaging devices.

STANLEY V. FORGUE, who has made major contributions to TV camera tubes and infrared imaging devices, received his BS in Physics in 1939 and his BEE and his MS in Physics in 1940 from Ohio State University. During 1940-42, he was a Graduate Assistant in Physics and a Research Fellow. Since 1942, he has been a Member of the Technical Staff of RCA Laboratories, Princeton. In January 1961, he became a Research Project Engineer in the Conversion Devices Laboratory. His primary field has been TV orthicons, image orthicons, and vidicons. He developed the photoconductive surface basic to the standard commercial vidicons and also has patents and publications in the fields of storage tubes, photoconductive cells and surfaces, color pickup tubes, color kinescopes, and infrared. For his work, he has received five "RCA Laboratories Achievement Awards." In addition to IEEE, he is a Member of APS, AAAS, Sigma Xi, Tau Beta Pi, Pi Mu Epsilon, and Sigma Pi Sigma, and is a Registered Professional Engineer (Ohio).



DR. RICHARD GUENTHER

. . . for contributions to advanced communication systems.

DR. RICHARD GUENTHER received his MSEE from Institute of Technology, Danzig in 1934 and the PhD (EE) from Institute of Technology, Danzig in 1937. From 1937 to 1945 he worked at the Siemens-Halske Company in Berlin on telephone multiplex equipment, and supervised radio communications development. In 1947 he joined the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey and did consulting work in radio relay systems, propagation, test equipment, and antennas. In 1952 he joined the Bell Telephone Laboratories, doing systems studies. Dr. Guenther joined the RCA Surface Communications Division in 1956 to establish a major system engineering capability. This led to the establishment of the Surface Communications Systems Laboratories in New York City and Tucson, Ariz. In 1963 he was made Chief Scientist responsible for the applied research and technical planning of the RCA Communication Systems Division (successor to SurfCom). In addition to IEEE, he is a member of the AAAS.

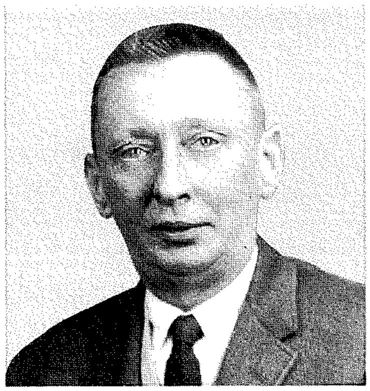
SIX RCA MEN ELECTED IEEE FELLOWS

These six RCA men have been honored by being elected Fellows of the Institute of Electrical and Electronics Engineers, an honor bestowed each year for outstanding professional contributions to the field.

WARREN R. ISOM

. . . for contributions to electromechanics and wideband magnetic recording.

WARREN R. ISOM pioneered the use of air bearings, air suspensions, and air floated heads for video recording and radar data processing. His most recent work has been precision high-velocity large-capacity magnetic-recording systems using tape, drums, and disks. The first commercially available television film projector and a mechanism which solved the mechanical probem of kinescope recording were among his early accomplishments. He has been in the mainstream of developments in thermal energy control and conversion, electro-optical composing machines, mass memories, electronic storage for documents, continuous solar simulation, and satellite mechanisms. He has 18 patents. Mr. Isom has been with RCA since 1944. He graduated in 1931 "magna cum laude" from Butler University and holds an MS from both The George Washington University and Harvard. In addition to IEEE, he is a Member of Phi Kappa Phi and a Fellow of the SMPTE.



WAYNE MASON

. . . for contributions to international agreements on maritime radio communications and safety.

WAYNE MASON has served as a shipboard radio operator, a teacher, a broadcast engineer, and an FCC official. From the University of Florida, he received his EE degree in 1951. During undergraduate work, he supervised a project on the relationship between atmospherics and tropical storms which later became the basis for the military "sferics" project of World War II. He was a member of the FCC in Washington, D.C., from 1937 to 1943. During World War II, he served in the U.S. Coast Guard in the office of the Chief Communications Officer. He also was Chairman of the Air-Sea Rescue Committee of the Joint Chiefs of Staff. Since 1945, he has been with the RCA Frequency Bureau in New York City, first as Assistant Manager and since 1946 as Manager. He has been a member of the U.S. delegation to several international telecommunications conferences, and in 1951, at the request of the Department of State, served as the Telecommunications Attaché in Geneva. In 1956 he received a special RCA Award for his outstanding contributions at the CCIR Plenary Assembly in Warsaw.

HARRY R. SEELEN

. . . for contributions to the design and development of electronic receiving tubes, cathode-ray tubes and color kinescopes.

HARRY R. SEELEN, who has been associated with many of the major tube developments at RCA during the past 35 years, received his BS from Providence College, Providence, Rhode Island, in 1929 and thereupon joined RCA in Harrison, N.J. In 1929-42, he held engineering and supervisory posts in Harrison, and in 1942 moved to RCA Lancaster, where he set up the Engineering Laboratory. In 1949, he was named Manager of Engineering at Lancaster, and in 1954 became Operations Manager, Color Picture Tubes, in Harrison. Presently, he is Manager, TV Picture Tube Operations Dept. His many technical and managerial contributions have involved acorn tubes, miniature tubes, metal receiving tubes, metal and large-size kinescopes, camera tubes, phototubes, VHF and UHF transmitting tubes, and color kinescopes. In 1955, he received the "RCA Award of Merit" for his work in development of the color picture tube. He has written papers on tubes and holds patents in the field. In addition to IEEE, he is a Member of AAAS and Sigma Pi Sigma.

THE SERT CAPSULE

Testing Ion Engines in Space

On July 20, 1964, for the first time in history an electric propulsion engine was successfully operated in space. Two complete ion (or electrostatic) engine systems were carried aboard the SERT I capsule launched from Wallops Island, Virginia by a four-stage SCOUT booster. The flight provided a zero-g time of approximately 48 minutes at an apogee of 2,500 nautical miles. A total of 24 minutes of successful ion propulsion was achieved at a thrust level of about 5 millipounds. The RCA Astro-Electronics Division, under NASA contract, developed the capsule structure, communications, command capability, power distribution, and stabilization. (NASA had developed, under separate contracts, the ion engine subsystems, the programmer, and the batteries.) RCA-AED assembled the complete spacecraft, performed tests and calibrations, and assisted NASA in final simulation testing and launch.

L. E. GOLDEN, Mgr.
RCA SERT Project
Astro-Electronics Division
DEP, Princeton, N. J.

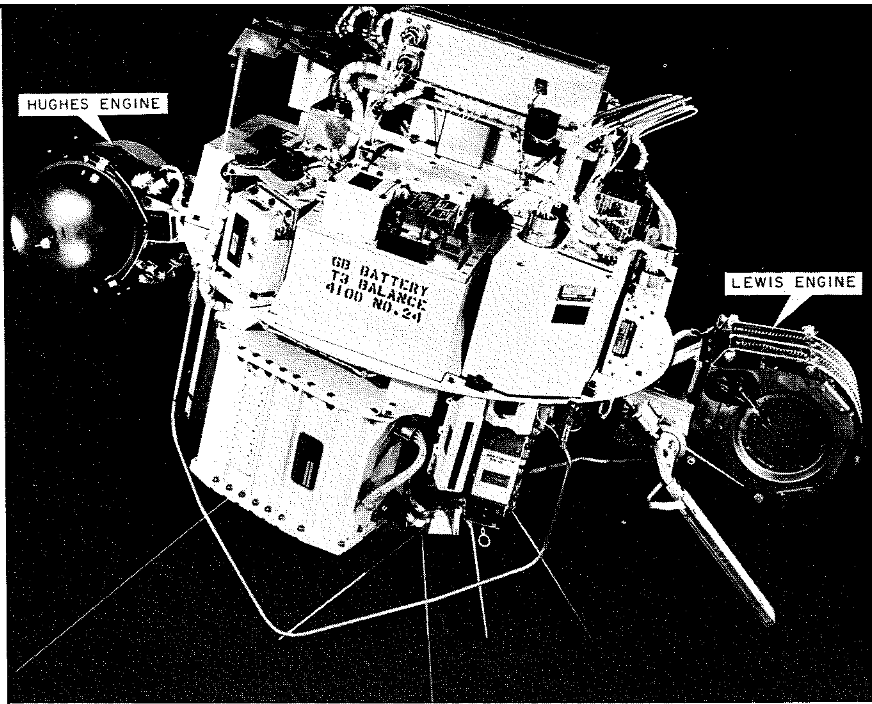


Fig. 1—The SERT I spacecraft (engines extended).

LAWRENCE E. GOLDEN received his SB and SM degree from MIT in 1953 after a major course of study in aircraft automatic control and instrumentation. At the Kaman Aircraft Company in 1953, he worked as a systems engineer. After two years as an Air Force project officer working on nuclear weapons delivery systems, Mr. Golden joined Allied Research Associates, Inc., in 1956. He became assistant project engineer on the WINDSONDE program and a directional control system for glider aircraft. Mr. Golden joined the RCA Astro-Electronics Division in early 1959 and initially participated in the development work on the TIROS precession damper. As a specialist in attitude stabilization of spinning vehicles, he later became involved in the development of the spin-stabilized "wheel" concept and its corollary—the magnetic attitude control system and data sensing techniques used therein. In 1960, he became Project Engineer for a system design study and development program on a Navy Tactical Meteorological Satellite System. In August 1961, he was appointed to his present position as Project Manager for the SERT I program. Mr. Golden is a member of the AIAA, Tau Beta Pi, Sigma Xi, and Alpha Gamma Rho.

The SERT I program was initiated during 1961 at the Marshall Space Flight Center of NASA and in 1962 was transferred to the Lewis Research Center, Cleveland, Ohio. The purpose of the SERT (Space Electric Rocket Test) program was to develop a spacecraft to carry an ion propulsion engine into space for its first test in its *native* environment.[1,2] (Ion engines can only operate in vacuum, and, although they may be tested in earth-bound vacuum chambers, their application is limited to space flight.)

The primary objective of the flight test was to study the behavior of ion beam neutralization, without which thrust is unobtainable. While vacuum-chamber tests of ion engines seemed to indicate the effectiveness of neutralization, the presence of certain limitations such as wall effects and an incomplete vacuum gave rise to a need to study, through a space test, the importance of these chamber effects.

The SERT I capsule (Fig. 1) carried the two complete ion engine subsystems, each with their ancillary power conversion equipment. In addition, the capsule contained all communications, control, and sensory equipment necessary to in-flight operation of the ion engine subsystems and retrieval of flight data. A simplified system block diagram is shown in Fig. 2.

The primary output of the spacecraft during flight was telemetered flight data, consisting of ion engine system electrical performance measurements, spacecraft operational parameters, and spacecraft spin rate. The latter information provided a measure of the thrust of the ion engines, which were mounted such as to change the spin rate during thrusting. The spacecraft was spin stabilized at approximately 100 rpm by the SCOUT fourth stage.

The 48-minute flight time was to be shared by operation of the Hughes and Lewis engines, with the Hughes engine to be operated first. Flight sequencing was to be directed by an on-board programmer, with the option of ground-commanded operations; the program consisted primarily of steady-state engine operation with some time also devoted to special studies of neutralization requirements and beam mapping. Both telemetry and command capabilities were centralized at Wallops Island using the TIROS communications facilities. Down-range tracking and telemetry receiving facilities at Bermuda and possibly several additional sites were planned.

Special design considerations for the SERT capsule evolved because of the high voltages and high power needed for ion engine operation. High voltage breakdown could not be tolerated, of course, and, to this end, outgassing was to be

Final manuscript received November 4, 1964

minimized so as to avoid the generation of breakdown paths from exposed high voltage terminals. The use of special insulation was also required. The high power requirement, and consequent power handling loss, necessitated special consideration of the thermal design problem. Further discussions of these special areas are presented below.

THE ION ENGINE

The principle of operation of an ion engine is akin to that of a vacuum tube: both involve the movement of charged particles under the influence of electrostatic fields (Fig. 3). The principle of operation involves the ionization of the fuel and the acceleration to extremely high velocities under the action of the electrostatic potential existing on the accelerator. Particle exhaust velocities on the order of 100 km/sec are readily achievable. Thrust is created by the reaction of the ions to the electrostatic fields, or, expressed differently, by the transfer of momentum to the ions in the high-velocity exhaust beyond the accelerator.

One further step is necessary to achieve, at least theoretically, successful operation of the ion engine. It is obvious that the ion exhaust will be positively charged and that, left unaltered, the ion particles would return to the body of the engine under the action of the potential difference existing. To prevent this, the beam is neutralized through the addition of electrons. One simple type of neutralizer employs a heated tantalum filament, placed directly in the exhaust, which boils off neutralizing electrons.

The two engines flown on SERT are shown in Fig. 1. The NASA Lewis Research Center engine ionizes its mercury fuel by electron bombardment; the Hughes Research Laboratories engine achieves ionization of cesium fuel through contact with hot tungsten.

ION ENGINE SUBSYSTEMS

The ancillary power conversion and control equipment for the Hughes engine was separated into four component boxes. These served to convert the 28- and 56-volt dc available from the capsule batteries into the various AC and DC voltages needed for engine operation. The maximum potential developed was approximately 4500 volts. Solid-state static inversion techniques were used throughout with voltage ratioing through specially insulated transformers. The equipment was developed for NASA by the Hughes Research Laboratories and Aircraft Company and provided to AED for capsule integration.

The power conversion equipment for the Lewis engine was contained in two boxes mounted on the underside of the baseplate. Electrical design of the equipment also employed solid-state static inversion and transformer techniques. As the Hughes equipment, the Lewis power supplies were delivered to AED for integration. An auxiliary component of this subsystem provided control of the potential of the neutralizer filament. Effect of variation of this potential was studied during one part of the mission.

Two major problems plagued both subsystems during their development. The first, solved through the use of high-response sensing circuits and current limiting, involved damage to the equipment by transients induced during high-voltage arcing of the ion engines. Early designs were proof-tested for protection against output shorting; however, this protection proved insufficient against the high current transient rates induced by engine breakdown, in vacuum, through the plasma created during engine start and operation. Although the initial approach was to improve starting performance so to eliminate arcing, it became evident quite early that such arcing would have to be considered a design condition if the program was to succeed. The second major problem was high-voltage breakdown within the power conversion equipment caused by the partial pressure conditions existing subsequent to vacuum immersion. Hughes solved this problem by encapsulating all high-voltage terminals, whereas Lewis pressurized its component boxes. Both solutions appeared to be adequate.

Expected thrusts were 6 millipounds and 1.2 millipounds for the Lewis and Hughes engines, respectively. Total electrical power requirements were, respectively, 1,400 and 610 watts.

CAPSULE STRUCTURE

The SERT capsule was notable for an extremely high payload-to-structural weight ratio, with 375 pounds of equipment packaged in a configuration which, at a diameter of 30 inches and height of 28 inches, would fit within the 34-inch diameter SCOUT heat-shield. The ion engines were mounted on hinged arms such that during launch they are folded below the baseplate and extended after separation to positions well beyond the heat shield limitation. This extension of the engines was required to: 1) minimize interference between the engine exhaust and the spacecraft; 2) reduce thermal radiation from the hot engines to the spacecraft; and 3) increase the torquing moment arm of the engines. Fig. 1 shows the SERT capsule with the engines in the extended position.

The most interesting aspect of the SERT structure is the use of a machined magnesium forging rather than the classic sheet-and-rivet construction for the 30-inch diameter ribbed baseplate. This approach provided not only excellent strength-to-weight and vibration damping characteristics but also the capability for mounting components on the baseplate underside as well as the topside. As a result of its advantages, this structural approach has been utilized on a number of other AED spacecraft programs. An open structural box, located at the top-side center of the baseplate, served to contain additional components, support the main routing of the harness, and act as an anchor for top-side component vibration bracing. The total assembly is mounted atop a hollow, machined column which provides additional component space within and which also provides clearance between the components mounted below the baseplate and the rocket fourth stage.

The high spin rate of the capsule required the provision of some means of removing kinetic energy during extension of the engines to prevent damage. The space limitations and the requirement for minimization of outgassing eliminated the use of conventional hydraulic dampers. Accordingly, a special sealed hydraulic system, employing diaphragms rather than piston-cylinder seals, was developed.

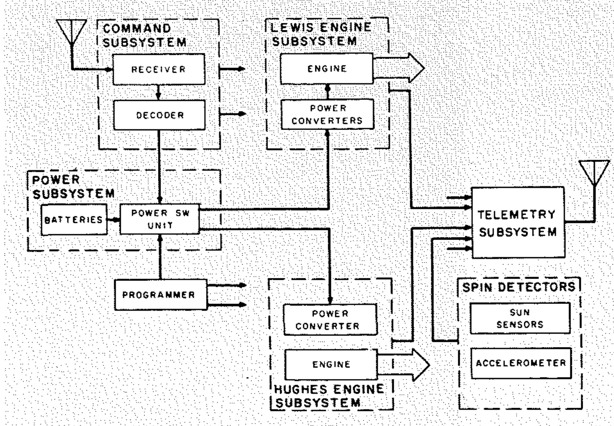


Fig. 2—SERT system.

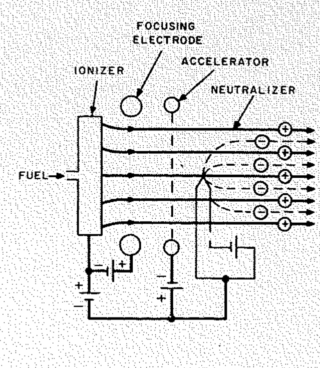


Fig. 3—Ion engine.

THERMAL DESIGN

The thermal design problem encountered with SERT differed from that representative for orbiting spacecraft in two respects: the amount of heat energy to be handled was very large for the size of the spacecraft, and the mission time was sufficiently short that the thermal behavior was transient rather than steady state. Indeed, the heat power was so large (600 watts) that much of the equipment could not have operated under the high steady-state temperatures but would have overheated shortly after completion of a 1-hour flight. Design considerations dictated that all exposed components be painted with a high emissivity, low absorption paint (white epoxy "tilecote") and that provisions be made to cool the Hughes subsystem power inverter during its prelaunch operation. Preference in assignment of outboard locations was given to high-temperature components, and special precautions were taken in the design of mounting provisions, etc., to assure sufficient heat-conducting area.

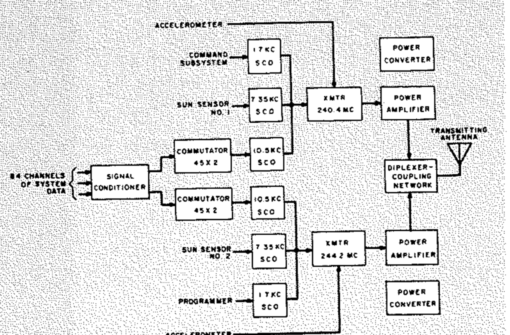
The adequacy of the thermal design was verified in vacuum chamber tests. No problems of note were encountered in this area.

POWER SUBSYSTEM

Spacecraft power was provided by silver-zinc primary batteries, selected because of their high power-to-weight ratio. The 56 volts at 30 amperes required for ion engine operation was supplied by two 28-pound batteries, while a smaller battery powered the separate communications and control circuits. In addition, two special fibreglas-cased batteries provided isolated power sources for the Lewis engine subsystem.

Switching of power throughout the system was accomplished through the use of a relay-operated power switching unit. Because of the size and weight restrictions on high-current switching devices, the main current (25 amperes) to the ion engine power converters was switched within the inverter circuits of these subsystems, with low-current control through the power switching unit.

Fig. 4—Telemetry subsystem.



During the early stages of the program, high current switching was performed within the power switching unit using silicon controlled rectifiers. After a short time, however, these rectifiers were removed from the system because of difficulties involving impedance matching and concern over the probability of inadvertent switching from ion engine subsystem noise.

Cabling presented interesting early development problems because of the high voltage, high current, low outgassing, and low thermal dissipation requirements. After study, teflon was selected as the insulating material since it combined low outgassing with good high-voltage insulating properties and could be extruded onto the wire to minimize entrapped air. Wire was sized—not by conventional means—but in accordance with the results of a thermal-balance study of the special insulated wiring in a space vacuum environment.

The high-voltage mechanical interface problem proved to be one of the more difficult encountered in the program. Early in the development, the decision was reached by all involved to utilize special connectors at most high voltage interfaces. These connectors, adapted from conventional models, employed pin-to-shell and pin-to-pin spacings sufficiently large to prevent breakdown under normal operating conditions. While these were utilized successfully in some instances, difficulties were recognized later in the program after other problems, which previously had clouded the behavior of the connectors, were solved. Since the design of the high voltage equipments already employed connectors, it became necessary to evolve corrective measures if the delays associated with a complete change of approach were to be avoided. After a short but intensive test program, it was decided to permanently bond the cabling to the connector receptacles on the equipment with potting compound excluding entrapped air which, during the rapid transition from sea level pressure to space vacuum, could provide a partial pressure breakdown path for high voltages. Great difficulties were experienced in the development of the technique, and, even though it appears to have been successfully employed, it was felt by program personnel that the practical use of high voltages in space would require intensive evaluation of the interface problem.

COMMUNICATIONS AND TELEMETRY SUBSYSTEM

The telemetry subsystem used on SERT was conventional in nature. As shown in Fig. 4, ion engine performance data and spacecraft "house-keeping" data were treated in a signal conditioner prior to being commutated. Redundant paths were then employed, each consisting of a commutator, subcarrier oscillator, solid-state 2-watt transmitter, and 10-watt power amplifier. Additional subcarriers were provided on each transmitter for spin rate, programmer, and command subsystem data. Outputs of the two power amplifiers were diplexed prior to feeding the antennas. A 15-watt load resistor was provided at the balun of the antenna coupling network to absorb reflected RF power during high VSWR launch conditions.

Of special interest is the antenna ground plane, located at the base of the column and indentifiable in Fig. 1 as the radial array of wires joined at their tips with a circumferential strand. This ground plane was folded within a slot at the base of the column and extended after payload separation. The ground plane served to remove large nulls or asymmetries in the antenna patterns which would result from the rather irregular exterior of the spacecraft. It also directed the pattern to the hemisphere beneath the baseplate; this hemisphere contains the communications vector during the complete flight. Serving a similar purpose were a pair of metal loops or "detuning wings" extending from the baseplate at diametrically opposite locations 90° from the ion engine support arms.

The antenna system consisted of two sets of 4 dipoles each located at the base of the spacecraft column. One set provided transmitting capability, and the other fed the command receiver. The complete antenna subsystem was developed, designed, and tested by the Antenna Skill Center of the RCA Missile and Surface Radar Division, Moorestown, N. J.

The final design of the telemetry subsystem was also influenced by the ion engine subsystems. During system-evaluation testing under vacuum conditions, it was found that ion engine arcing was inducing signal transients of sufficient magnitude to exceed the 300% safety margin on the input of the then solid-state commutators. As a result, it became necessary to replace these with mechanical counterparts and to provide a measure of overvoltage protection elsewhere in the telemetry subsystem and, wherever possible, in the ion engine subsystems.

COMMAND SUBSYSTEM

Major sequencing of flight events was provided through the spacecraft programmer. In view of the possibility of malfunction of the programmer or of either of the two ion propulsion experiments, the decision was reached early in the development cycle to add a limited ground command capability. The command subsystem, designed to provide this capability, possesses high noise immunity in order to obviate the possibility of inadvertent operation either by system noise or spurious transmissions. With regard to the former, analytical work, experience with ionized fields, and a small amount of ion engine data indicated the possibility of the generation of considerable RF noise by the ion beam. Through the use of a two-tone, programmed sequence code, in addition to heavy filtering, the system had the capability of command discrimination in the presence of 45 db of random noise. Excellent results with the system in spacecraft vacuum-chamber tests led to the expansion of its application to include complete ground control of the mission.

SENSORY SUBSYSTEMS

Two independent techniques were provided for measurement of spacecraft spin rate. The first utilized sun sensors, developed under the TIROS program, to detect, through a narrow vertical slit, the presence of the sun on each rotation. The pulses thus generated were then telemetered to earth where period measurements were recorded on special ground equipment. The second technique involved a high-accuracy Accelerometer aligned to sense centripetal acceleration; its sensing element, a vibrating string, provided a frequency (or digital output) proportional to acceleration. The output of this instrument directly modulated the RF carrier. Elaborate ground equipment converted the output to direct reading of spacecraft spin rate. Additional spin rate data of much lower resolution was obtainable from ground receiver AGC response.

A hot-wire anemometer probe, driven by a special mechanism, was also carried to map the energy profile of the Lewis engine exhaust beam. An associated signal conditioner was necessary to isolate the probe wires from ground and to amplify the low level signals.

VEHICLE STABILIZATION

SERT was inertially stabilized in space by the spin of approximately 100 rpm imparted to the rocket fourth stage prior to spacecraft separation. Nutational motion resulting from separation torques and engine extension was reduced to tenths of a degree by a pair of precession dampers similar to those developed under the TIROS program. Disturbing torques created by the earth's magnetic field or from other natural sources were determined analytically to have negligible effect on the mission.

FLIGHT RESULTS

Spacecraft operation, through engine deployment, was as programmed. However, upon turn-on of the high voltage to the Hughes engine, apparent breakdown was encountered. Although the protective circuits operated properly, repeated breakdowns occurred. After 9 minutes of attempted operation, the decision was made by NASA to advance the programmer, using ground command, to Lewis engine operation. Positive beam current was indicated and a real change in spin rate was evidenced following several minutes of warm-up. Neutralizer potential and beam probe studies were successfully performed after 14 minutes of steady-state operation. After an unsuccessful attempt to operate the Hughes subsystem, the Lewis engine was again activated and positive thrust developed. Ground commands were widely employed throughout the flight.

Preliminary analysis of flight test data provided the following conclusions:

1) beam neutralization could successfully be achieved in space;
2) neither thrust nor beam current could be obtained without the neutralizer operating; and
3) ion-beam current and thrust were in good agreement with theory throughout the operation. A final thrust of about 0.005 pounds was obtained.

The plot of spacecraft spin rate versus time from launch is presented in Fig. 5 as a summary of engine performance. Failure of the Hughes subsystem was clearly related to an equipment malfunction rather than to any operating principle. NASA felt that test objectives were met since successful operation of the Lewis subsystem and good correlation with vacuum chamber test results were achieved.

FUTURE OF ION PROPULSION

The particular attractiveness of ion propulsion lies in its high specific impulse (3000 to 10,000 sec) in comparison with chemical engines. However, because of the great weight penalty which must be paid in power generating and conversion equipment, ion propulsion becomes advantageous only for long-term space flight. Interplanetary manned or unmanned missions and long-life orbital missions are classic examples. The reader is urged to consult *Ion Propulsion for Space Flight* by Ernst Stuhlinger for a learned discussion of ion propulsion and its applications.[2] A comparison drawn from this source for a Mars satellite mission is presented in Fig. 6.

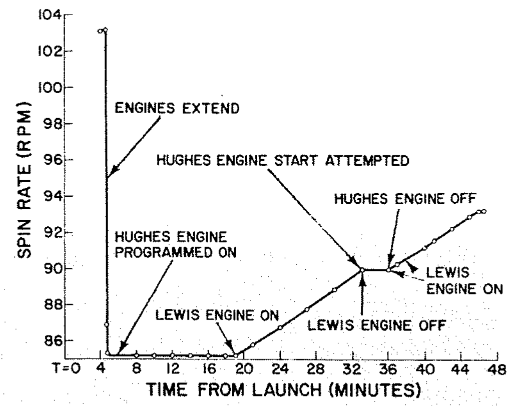


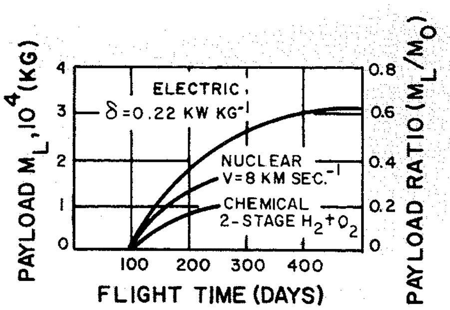
Fig. 5—SERT I flight behavior.

The application of ion propulsion to interplanetary missions will be dependent upon the development of the high-capacity power sources, ranging tens of thousands of kilowatts, necessary to the system. At present, lightweight nuclear reactors are seen to offer the the best promise, with solar power supplies also in consideration. The present rate of development, as well as the nature of the mission, make it likely that a decade will pass before serious mission applications of ion propulsion are seen. Much also remains to be accomplished in the area of the ion thrustor. Because of the good correlation between SERT I flight results and vacuum-chamber operation, it is probable that most future testing of the engines will take place in earth-bound chambers.

The future of this unique technology is deeply involved with the progress and direction of the space program.

BIBLIOGRAPHY

1. H. Gold, R. Rulos, et. al., *Description and Operation of Spacecraft in SERT I Ion Thrustor Flight Test*, NASA TM-X52050, Washington, D.C.; 1964.
2. Ernst Stuhlinger, *Ion Propulsion for Space Flight*, McGraw-Hill Book Company, New York, 1964.



* SPECIFIC POWER = POWER PER UNIT MASS, OF POWER GENERATING SYSTEM.

Fig. 6—Mars mission system comparison.

A PROPOSED STEREOSCOPIC TV OBSERVATION SYSTEM FOR A LUNAR ORBITER

This camera system has been proposed by AED for use on the SURVEYOR orbiter spacecraft. To provide information concerning the topography of the lunar surface, the camera system provides stereoscopic pairs of images. Methods of achieving stereoscopy at the desired resolution of 10 meters of lunar surface are discussed. The relation between orbital parameters, and the extent of lunar surface surveyed is considered in relation to available sensor resolution. The optical system requirements are described in terms of aperture and focal length necessary to perform the mission under the conditions of illumination, lunar albedo, resolution, and signal-to-noise ratio.

F. J. BINGLEY, Ldr.

Developmental Cameras

Astro-Electronics Division, DEP, Princeton, N. J.

A suitable balance between several interdependent parameters must be achieved in the design of a camera system for a lunar orbiter. The major purpose of such a camera system is to produce images of the lunar surfaces with more resolution than can be provided by direct terrestrial observation by telescope. The geographical coverage provided must be contiguous; i.e., it should contain no gaps except those which occur because of lack of primary interest. At the same time, total coverage of the lunar surface will not necessarily be a requirement, since a prime interest exists in the area bounded by $\pm$ 20° lunar latitude (referred to the lunar equator) and $\pm$ 50° lunar longitude (referred to the meridian through the mean libration point).

The dimension of the resolvable element on the lunar surface is a parameter of interest. For the purpose of the system under discussion, an element of 10 meters in linear dimension has been selected. This dimension is inter-related with several other important system parameters, including sensor resolution, orbital altitude, and orbital inclination.

Limitation on the rate of transmission of information is set by the available bandwidth of the communication channel. In considering the system design, cognizance was taken of the limit to be imposed by a typical communication channel which might be used in a lunar mission. It was considered that a video baseband of 350 kc would be practical.

To provide the maximum possible information regarding the lunar topology, the camera system is designed to provide stereoscope pairs of images. The stereoscopic feature is so arranged that failure of either of the two camera subsystems each of which provides one of the stereoscopic pairs of images, will not affect the monoscopic performance of the other. This feature provides a measure of redundancy. To obtain adequate stereoscopic accuracy, the base-to-height ratio of the system is unity; this is provided in a manner to be discussed later.

LUNAR ORBIT CONSIDERATIONS

Because of the performance of the camera system is constrained by the physical laws governing orbital motion, it is appropriate to consider what these constraints are. For a circular orbit:

$$v^2 = \frac{G_m}{r} \qquad (1)$$

Where: G_m is the lunar gravitational constant, r is the radius of orbit (km), and v is the orbital velocity (km/sec).

Substituting $r = R + h$ (where R is the lunar radius and h is the orbital altitude), rearranging and solving for v:

$$v = \left(\frac{G_m}{R}\right)^{1/2} \left(1 + \frac{h}{R}\right)^{-1/2} \qquad (2)$$

Recognizing that h/R will in general be small, Eq. 2 can be expanded, and powers of h/R above the first can be neglected. This gives v (in km/sec) approximately as:

$$v = \left(\frac{G_m}{R}\right)^{1/2} \left(1 - \frac{1}{2} \cdot \frac{h}{R}\right) \qquad (3)$$

The orbital period, T (in seconds) is defined by:

$$T = \frac{2\pi r}{v} = 2\pi(R + h) \left(\frac{1 + \frac{h}{R}}{G_m R}\right)^{1/2} \qquad (4)$$

$$T \approx 2\pi G_m^{-1/2} R^{3/2} \left(1 + \frac{3}{2} \cdot \frac{h}{R}\right) \qquad (5)$$

The angular separation of the ascending nodes at the lunar equator is obtained by taking the ratio of the orbital period to the period of a lunar month (2.36×10^6 seconds). This fraction of 2π radians will give the angular rotation of the moon during one orbit of the satellite. This angle multiplied by the moon radius will give the desired value for the separation S_o. We then have:

$$S_o = 2\pi \left[\frac{2\pi G_m^{-1/2} R^{3/2} \left(1 + \frac{h}{R}\right)^{3/2}}{2.36 \times 10^6}\right] R = 1.67 \times 10^{-5} G_m^{-1/2} R^{5/2} \left(1 + \frac{h}{R}\right)^{3/2} \qquad (6)$$

In Eqs. 2, 3, 4, 5, and 6, values of R = 1,738 km, and G_m = 4,900 km^3–sec^{-2} may be substituted to obtain:

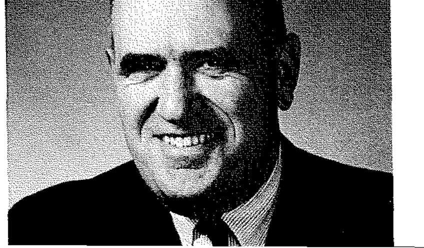
$$v = 1.69 \left(1 + \frac{h}{R}\right)^{-1/2} \qquad (7)$$

$$v \approx 1.69 \left(1 - \frac{1}{2} \cdot \frac{h}{R}\right) \text{ km/sec} \qquad (8)$$

Final manuscript received August 19, 1964

This paper was presented at the SMPTE Technical Conference in New York City, September 28, 1964.

F. J. BINGLEY received his B.Sc. in Mathematics in 1926 and B.Sc. in Physics in 1927 from the University of London. In 1927 he worked for the Baird Television Corporation in London, England, and New York, on development of early mechanical television systems. He later joined the Philco Corporation, in the development of television systems, receivers, transmitters, tube, and studio equipment. He was then promoted to Chief TV Engineer. On a leave of absence from the Philco Corporation, he was employed by the Bamberger Broadcasting Co., where he was responsible for building TV stations in both New York City and Washington, D.C. He rejoined Philco and was named Manager of the Video Products section, in charge of industrial and special-purpose television equipment, including development of transistorized TV cameras and monitors, high resolution 1000-line TV systems employing various forms of image enhancement, direct television display of stereoscopic radiographic images, and a special high-sensitivity image-orthicon system for in-flight data recording. He received the "Zworykin Television Award" of the IRE in 1956 for his contributions in the application of colorimetric science to television. He has 29 patents, all in the television field. Mr. Bingley joined the RCA Astro-Electronics Division in 1962, and has been engaged in developmental work on a special photodielectric tape camera system. Mr. Bingley is a Fellow of the IEEE and a member of the SMPTE and the Franklin Institute.



$$T = 6.4 \times 10^3 \left(1 + \frac{h}{R}\right)^{3/2} \quad (9)$$

$$T \approx 6.4 \times 10^3 \left(1 + \frac{3}{2} \cdot \frac{h}{R}\right) \text{ seconds} \quad (10)$$

$$S_o = 30.1 \left(1 + \frac{h}{R}\right)^{3/2} \quad (11)$$

$$S_o \approx 30.1 \left(1 + \frac{3}{2}\frac{h}{R}\right) \text{ km} \quad (12)$$

The suborbital velocity v_s of the satellite will be less than the orbital velocity v by the ratio $R/(R+h)$; i.e.:

$$\begin{aligned} v_s &= \left(\frac{R}{R+h}\right)v \\ &= \left(\frac{R}{R+h}\right)\left(\frac{G_m}{R}\right)^{1/2}\left(1+\frac{h}{R}\right)^{-1/2} \\ &= \left(\frac{G_m}{R}\right)^{1/2}\left(1+\frac{h}{R}\right)^{-3/2} \quad (13) \end{aligned}$$

Substituting for G_m and R:

$$v_s = 1.69 \left(1 + \frac{h}{R}\right)^{-3/2} \quad (14)$$

$$v_s \approx 1.69 \left(1 - \frac{3}{2} \cdot \frac{h}{R}\right) \quad (15)$$

EFFECT OF ORBIT INCLINATION

Because of the limited area on the lunar surface of primary interest, extending $\pm$ 20° in latitude and $\pm$ 50° in longitude, it is not necessary to provide a polar orbit. Restricting the orbit inclination to some value α will reduce the perpendicular spacing d between the suborbital traces of successive orbits in such a fashion that $d = S_o \sin \alpha$. In turn, this will reduce the number of resolution elements required to be provided in a direction normal to the flight path, for a given desired ground resolution. For ground resolution ρ, the number of resolution elements required to be provided by the camera system will be:

$$\eta_\rho = \frac{d}{\rho} = \left(\frac{S_o}{\rho}\right) \sin \alpha \quad (16)$$

Substituting from Eq. 11, and setting $\rho = 10 \times 10^{-3}$ km:

$$\eta_\rho = 3.01 \times 10^3 \left(1 + \frac{h}{R}\right)^{3/2} \sin \alpha \quad (17)$$

Eq. 17 provides a relation permitting the trade-off of the number of resolution elements along the line scan direction with orbital inclination. A typical vidicon camera tube will have between 500 and 1,000 picture elements across the width of its target area (the exact number depending upon the type and size of tube and the criterion used in determining the size of the resolution element). Thus if $\alpha = 90°$ ($\sin \alpha = 1$), and if the camera tube resolution figure is 600, five camera tube targets would be required. Reducing the inclination angle to 30° would reduce the number of camera tube targets required to about three.

CHARACTERISTICS OF THE CAMERA TUBE

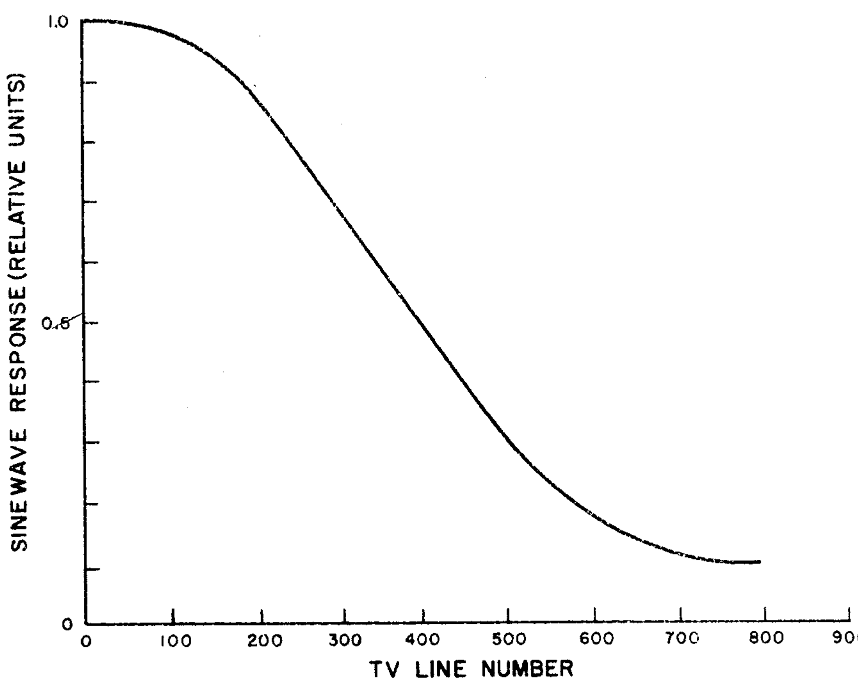
It was decided that existing space-qualified vidicon camera tubes would be used to fill the mission, so the degree to which such a camera tube can satisfy the requirements was considered. There are two basic characteristics to be considered: 1) the available resolution and the criterion used to determine it, and 2) the sensitivity of the camera tube expressed in terms of its ability to produce a video signal of a specified signal-to-noise ratio from objects of specified contrast ratio and of typical lunar luminances. These factors will now be considered in greater detail.

A vidicon camera is basically comprised of a camera tube containing a photoconductive target upon which is focussed, by means of a lens of suitable focal length, an image of the scene to be transmitted. This image causes a pattern of charge to be established upon the target. The target is then scanned by an electron beam provided by a gun contained in the camera tube, in a raster composed of parallel scanning lines. In response to this scanning operation, a video signal is generated and appears as a current flowing in an external resistor placed in series with the target electrode.

Considering, first, resolution along the scanning line, this is obviously affected by the effective diameter of the scanning beam. If a sine-wave pattern having a given cyclic pitch and a specified contrast ratio is imaged on the target, the relative video output signal can be expressed as a function of the cyclic pitch. The effect of the finite size of the scanning spot is, of course, to reduce the video signal output as the pitch is reduced. It is customary in TV practice to express the cyclic pitch of such a test image in terms of the number of half-cycles contained in the picture height; this is referred to as the number of television resolution lines. A typical response curve for the type 4431 vidicon is shown in Fig. 1. The illustration shows that the sine-wave response is reduced to 20% at approximately 650 lines.

Now, considering resolution in a direction transverse to the scanning lines, a further factor is introduced which expresses the fact that the scanning lines are fixed with respect to the target, whereas the details of the image required to be resolved in this direction may occur at arbitrary locations with respect to the target and therefore with respect to the scanning lines. Thus, a favorable location of the scanning lines will resolve a sine-wave pattern placed normal to them; but an unfavorable location displaced by just one-half cycle will completely fail to resolve such a pattern. Thus it is customary to count on resolving a pattern having only 0.7 of the number of scanning lines. This factor is usually referred to as the *Kell*

Fig. 1—Typical sine-wave response curve for type 4431 vidicon.



factor. The exact value of this factor has been debated for many years; however, a value of 0.7 is considered to be conservative. Thus, to obtain resolution of the same order as is furnished along the scanning lines (usually referred to as *horizontal resolution*) there would have to be provided a number of scanning lines equal to 1/0.7 times the horizontal resolution line number (assuming a square aspect ratio in the scanning raster). Thus, for the value of 650 lines given in the example above, 930 active scanning lines would have to be provided.

A typical sensitivity curve for a type 4431 vidicon is shown in Fig. 2. The curve is actually drawn for this tube as used in the NIMBUS camera, where the frame interval is 6.5 seconds. The frame interval for the Visual Instrumentation System (VIS) is yet to be determined. The noise level in terms of RMS current is indicated by the dashed line; it results from noise generated in the video load resistor R, which carries the signal current. For a given resolution figure, the signal increases directly with the frame rate since the beam current must be increased proportionately to be able to effect the same target discharge in the smaller time interval. Thus, $S = K_1 B_w$, where S is the peak-to-peak signal current at a given exposure and K_1 is constant of proportionality.

The noise current also depends upon the bandwidth B_w. In the first place, it increases directly as the square root of the bandwidth; in addition to this, it also increases by a further factor, proportional to the square root of the load resistance. Since the load resistance must decrease in inverse proportion to the bandwidth, it is apparent that the noise current is given by $N = K_2 B_w$, where N is the RMS noise current and K_2 is a constant of proportionality. Thus, it appears that $S/N = K$, for a given exposure in foot-candle-seconds. Thus, the signal-to-noise ratio for a given exposure is independent of the frame rate. This fact enables the curve given in Fig. 2 to be used universally, independent of frame rate, provided the actual values of current are scaled approximately, or are regarded as being only relative values.

A criterion of performance with respect to horizontal resolution was taken to be that the signal-to-noise ratio (expressed as a ratio of peak-to-peak video to rms noise) should be 20 db when resolving a test target having a contrast ratio of 2 to 1 at a given TV resolution line number. If this criterion is to be satisfied at a resolution of 650 TV lines (where the sine-wave response is down to 20%), the S/N ratio at low horizontal line numbers must be 50, for a test object with a contrast ratio of 2 to 1. Since the value of RMS noise is 0.04, the peak-to-peak signal must be 2.0 units (50 × 0.04). For a test object with a contrast ratio of 2 to 1, this will be seen to occur at a peak highlight exposure of 0.25 foot-candle-second by referring to the curve of Fig. 2.

EXPOSURE

Exposure is accomplished by opening a shutter and allowing a charge pattern to be built up on the vidicon target. Subsequently, when the target is scanned, a video signal is generated. After the stored charge has served its purpose of providing one frame of video signal, the target is erased and prepared for the next exposure.

Exposure time is limited by the amount of smear which is tolerable. The subsatellite velocity is given by Eq. 14 so that the time T_5 to travel half a picture element (5 meters) is given by

$$T_5 = \frac{5 \times 10^{-3}}{1.69}\left(1 + \frac{h}{R}\right)^{3/2} \quad (18)$$

If h is 100 km, then T_5 is 3.21×10^{-3} seconds. In other words, if a one-half element smear can be tolerated, an exposure time of 3.21 msec can be permitted.

The exposure E at which 650 TV lines of resolution is accomplished has already been shown to be 0.25 foot-candle-second. The corresponding target illumination I_c is then given by:

$$I_c = \frac{E}{T_5} \quad (19)$$

Since T_5 is 3.21 msec, $I_c = 78.0$ foot-candles.

OPTICAL SYSTEM

The optical system provides the illumination on the vidicon target. If Y_s is the scene luminance in foot-lamberts, τ is the lens transmission factor, and F is the lens aperture number, then:

$$I_c = \frac{\tau h_s}{4F^2} \quad (20)$$

If a lens transmittance of 0.8 and an F of 4 are assumed, the minimum value of scene luminance $Y_{s(min)}$ which will give the desired vidicon resolution performance at a target illumination of 78.0 is 880 foot-lamberts.

With a solar constant of 13,000 foot-candles, the minimum highlight albedo a_{min}, which could be observed at a contrast ratio of 2 to 1 is $a_{min} = 6{,}240/13{,}000 = 0.48$. That is to say, adjacent areas 10 meters wide in the direction of the scanning lines and having alternate albedos of 0.24 and 0.48 would be resolved within the conditions laid down above, namely, a signal-to-noise ratio of 20 db.

The above values are based upon normal illumination and viewing. Lower values of scene luminance will be obtained at other angles of viewing (since the moon is not a Lambert surface), and also at other angles of illumination. Performance can be extended to cover lower values of scene luminance by increasing the lens aperture to the limit set either by the state-of-the-art of lens design, or by the weight budget.

The resolution of the television camera tube corresponds to about 30

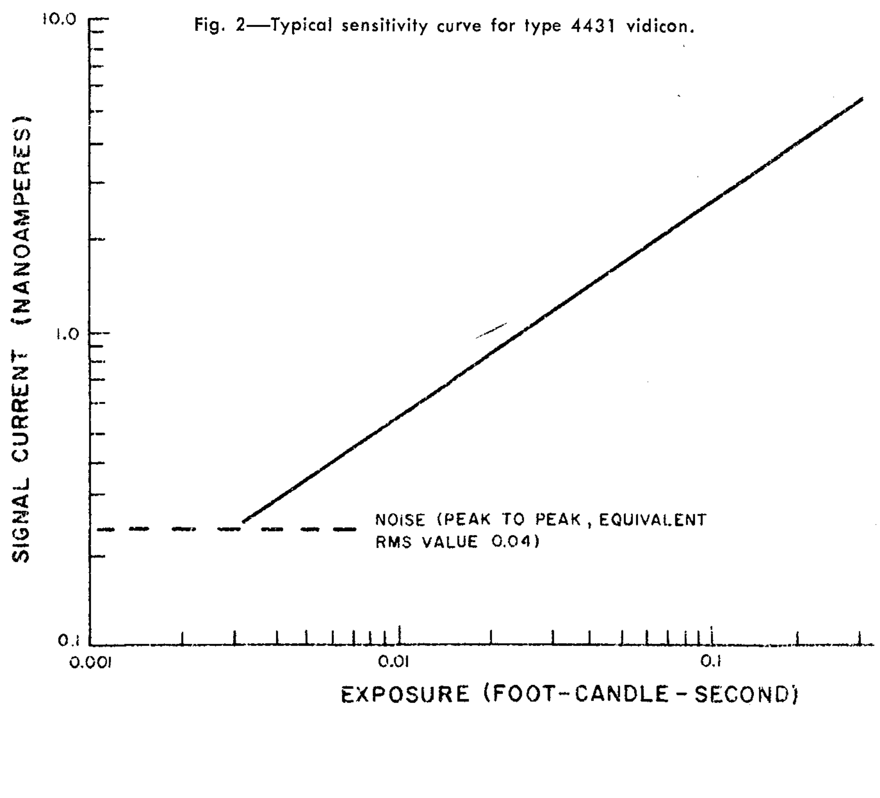


Fig. 2—Typical sensitivity curve for type 4431 vidicon.

cycles/mm. Since the limit on resolution imposed by the lens will substantially exceed the camera-tube resolution in a well designed lens, the lens has been considered not to materially affect system resolution.

The focal length of the lens required depends upon the flight altitude and upon the system magnification desired. The active target area of the vidicon is 11 by 11 mm, and 650 resolution elements are contained in the 11-mm dimension. Thus, the linear dimension of the vidicon resolution element is 0.0169 mm (11/650), and the system magnification m is 1.69×10^{-6} (0.0169 divided by 10×10^3).

If the flight altitude is 100 km, the focal length f will be 169 mm (6.7 inches). If other flight altitudes are used, the focal length will be reduced or increased proportionately.

The angular coverage of a single vidicon camera at an altitude of 100 km covering a field of 650 ten-meter resolution elements will be given by $\tan(\theta/Z) = 3{,}250/10^5 = 0.0325$, from which the total angular field θ is 2.06°.

RELATION BETWEEN VIDEO BASEBAND AND ORBIT INCLINATION

If the suborbital velocity is considered to result in describing new picture resolution elements at a fixed rate, V_s/ρ (where ρ is the resolution element on the ground, in kilometers), the rate N at which picture elements are fed into the system is given by:

$$N = \eta_\rho \left(\frac{v_s}{\rho}\right) \sin\alpha$$
$$= \frac{30.1}{\rho}\left(1+\frac{h}{R}\right)^{3/2} \frac{1.69}{\rho}\left(1+\frac{h}{R}\right)^{-3/2}$$
$$= \left(\frac{50.8}{\rho^2}\right)\sin\alpha \qquad (21)$$

Setting ρ equal to 10×10^{-3} km, we have $N = (5.08 \times 10^{-5} \sin\alpha)$ elements/sec.

To determine the corresponding video baseband B required to carry this information, we must recognize certain factors characteristic of a TV system:

1) To allow for line scanning, a Kell factor of 0.7 must be applied inversely, that is, in the direction to increase bandwidth.
2) Loss of elements due to blanking time must be provided for by increasing the bandwidth by the factor 1.11 for 10% blanking.
3) To allow for overlap, the number of elements will be increased by 10%.
4) Each cycle of baseband will carry information about two picture elements.

Applying these factors, the bandwidth B required becomes $4.4 \times 10^5 \sin\alpha$ (cps). The bandwidth B_s required for stereoscopic pairs will, of course, be twice this or $8.8 \times 10^5 \sin\alpha$ (cps).

Again there is a chance to trade latitude coverage for video baseband, through selecting values of α, by means of the above equation. The bandwidth considered in the present system is 350 kc, and substituting and solving for α gives $\sin\alpha = (350 \times 10^3) / (8.8 \times 10^5) = 0.347$. Thus, $\alpha = 23.4°$. This obviously permits coverage over the ± 20° of latitude desired.

GROUND COVERAGE

It has been shown that an orbit inclination of 23.4° will generate 10-meter picture elements at a rate just equal to that at which the bandwidth of the system can transmit them while providing for stereo coverage, blanking, and overlap. The number of resolution elements in the perpendicular distance between the suborbital tracks at the equator for this inclination is given by Eq. 17. Therefore, if h is 100 km, then η_e would be 1,300.

To cover 1,300 elements, just two vidicon cameras, having the resolution discussed above, will be required. This will permit no overlap of coverage in a direction perpendicular to the suborbital track at the equator. This is believed to be satisfactory, since there will be increasing overlap in the higher latitudes. At the same time, enough additional elements can be transmitted to permit an overlap of approximately 10% in a direction parallel to the suborbital track.

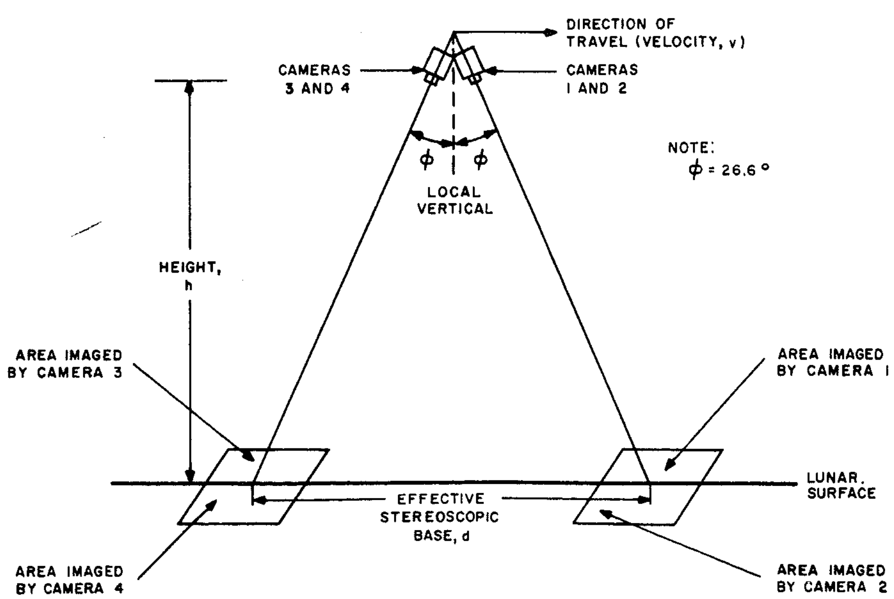
For the stereoscopic coverage required, a total of four cameras must be provided. The manner in which the cameras can be arranged to accomplish the desired coverage will not be described.

CAMERA COVERAGE PATTERN

A pair of cameras is arranged to view either side of the suborbital path. Two pairs of cameras provided, one pair viewing forward of the local vertical; while the other pair views aft of the local vertical (Fig. 3). In order to provide a base-to-height ratio of unity, the angle at which the two pairs of cameras are disposed in the fore-and-aft direction with respect to the local vertical is 26.6° as shown. In addition, the two members of a pair of cameras must have their axes displaced by half the field angle on either side of the orbital plane; that is by ± 1.03°. Camera *1* will view 26.6° forward and 1.03° port; camera *2* will view 26.6° forward and 1.03° starboard; cameras *3* and *4* will both view 26.6° aft and 1.03° port and 1.03° starboard, respectively. Cameras *1* and *2* will first view a given area ahead of the spacecraft; after the spacecraft has traveled a distance equal to the orbital height, that same area will be viewed by cameras *3* and *4*. The two views of this area so provided, one view from cameras *1* and *2* and the other from cameras *3* and *4*, constitute a stereo pair with a base-to-height ratio of unity.

Because the slant range is greater than the orbital height by about 12% due to the angle of 26.6°, the focal length of the camera lens will need to be increased over that previously calculated for a 100-km altitude. The new value of focal length required will be 203 mm, or 8 inches. Because the optical axes of the cameras are not normal to the lunar surface, a keystone distortion of the field of each camera at the lunar surface will occur. This distortion can be corrected in one of several ways. For exam-

Fig. 3—Arrangement of cameras.



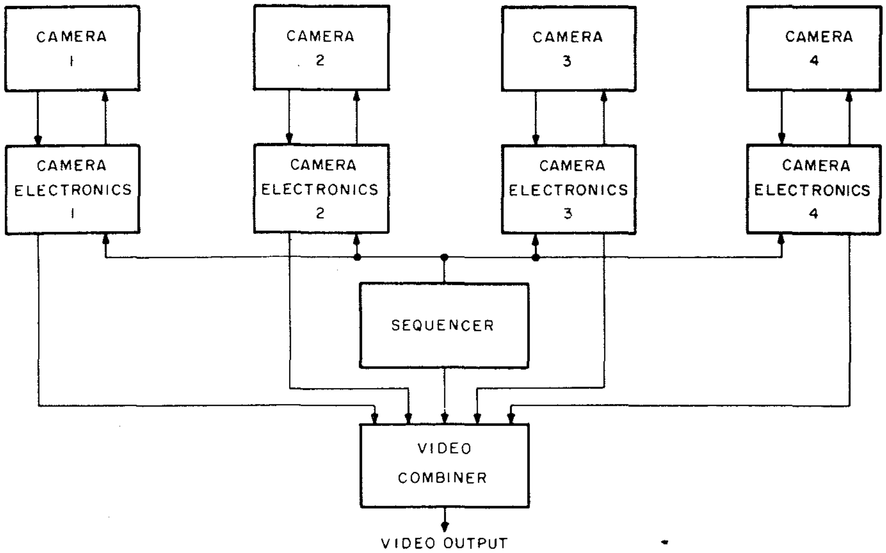


Fig. 4—Visual instrumentation subsystem.

ple, the scanning raster at each camera tube as well as the vertical deflection waveform could be distorted correspondingly to correct for this distortion; this method was employed successfully in the iconoscope camera used in early TV systems. Alternatively, the lens could be offset, maintaining the axis normal to the target. Correction could also be made by rectification at the ground station. The latter approach is probably the most practical.

DESCRIPTION OF CAMERA SYSTEM

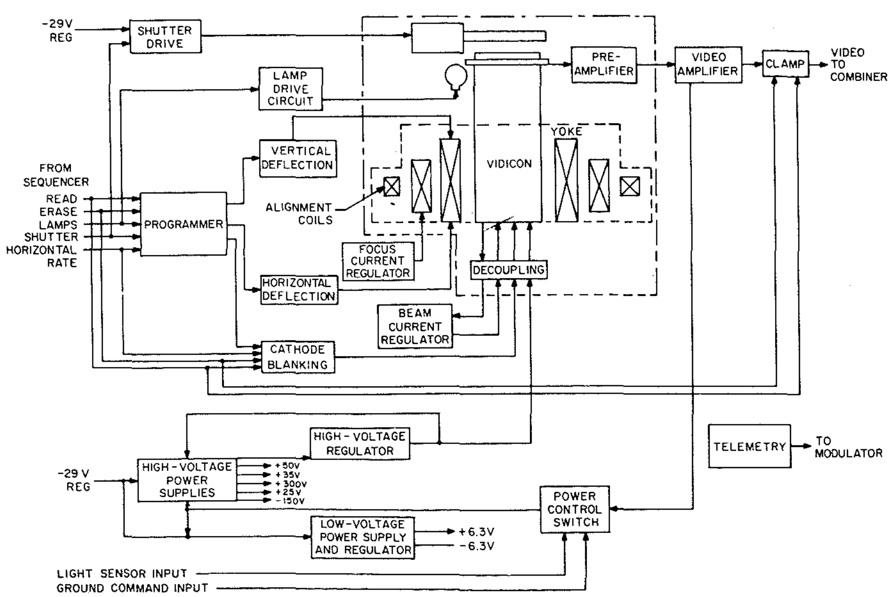
The cameras used are basically similar to those designed for the RANGER spacecraft, and use the 4431 vidicon. A pair of cameras provides each of the two stereo pictures. The four cameras will be sequenced so that each reads out its picture during one frame interval and spends the next three consecutive frame intervals in erasure, preparation, and exposure. By staggering the read-out frame timing, the picture signals generated by the four cameras can be read out in sequence, thus providing a continuous video signal with consecutive frames coming from each of the four cameras in sequence; this operation is repeated throughout the segment of the orbit along which pictures are desired.

Fig. 4 shows the arrangement of the four cameras and their interconnection with the sequencer which provides the master synchronizing signals and the timing which causes each camera to go through its cycle of expose, scan, prepare and to sequence with the other three cameras in the manner required. The four video outputs, suitably gated, are then fed to the combiner together with synchronizing signals for use at the ground station. The composite video signal output is then fed to the spacecraft transmitter.

A more detailed block diagram of one of the four cameras and the associated camera electronics is shown in Fig. 5. The vidicon tube is programmed through an expose, read, erase, and prepare cycle by the programmer which receives an initiating command from the sequencer unit. The cycle is begun with the exposure, which is effected by means of an electromagnetically controlled shutter. The vertical and horizontal deflections then commence to provide a single complete scan of the exposed photoconductive target, thereby generating a single frame of video signal. This signal is then amplified and clamped. A beam-current regulator ensures that variations in cathode emission do not affect the beam current.

After the single frame of video signal has been read from the target, the residual charge is erased by flashing a light on it. The target is then prepared for a new exposure by scanning it with the electron beam for three complete frames. During these three frames the raster is enlarged so as to overscan the normal read format; this overscan minimizes edge flare. The cathode blanking signal serves to cut off the scanning beam during retrace and also during the expose and flash intervals. The basic timing signals are generated in the sequencer by a crystal oscillator with a frequency of 38.6 kc by means of a frequency-divider chain (Fig. 6). This unit provides suitable timing signals for horizontal and vertical synchronizing and blanking, as well as a timing signal occurring at one-quarter of the vertical synchronizing frequency. The later timing signal is used to effect the programming of each of the cameras in turn throughout the expose, read, erase, and prepare phases. The basic pulses provided by the frequency divider chain are fed to the programmer unit which, by means of suitable logic circuits, generates the pulses required by the deflection circuits, the camera blanking, and clamping. These pulses are also used as synchronizing and gating signals in the video combiner unit. The system specifications are presented in Table I. The waveforms of the various timing and synchronizing signals are shown in Fig. 7.

Fig. 5—Camera and associated electronics.



PHOTOGRAMMETRY

With the system parameters provided, great circle arcs within the field of view will appear as straight lines on the vidicon face within a tolerance of one picture element. Rectification will be required to correct for keystoning and

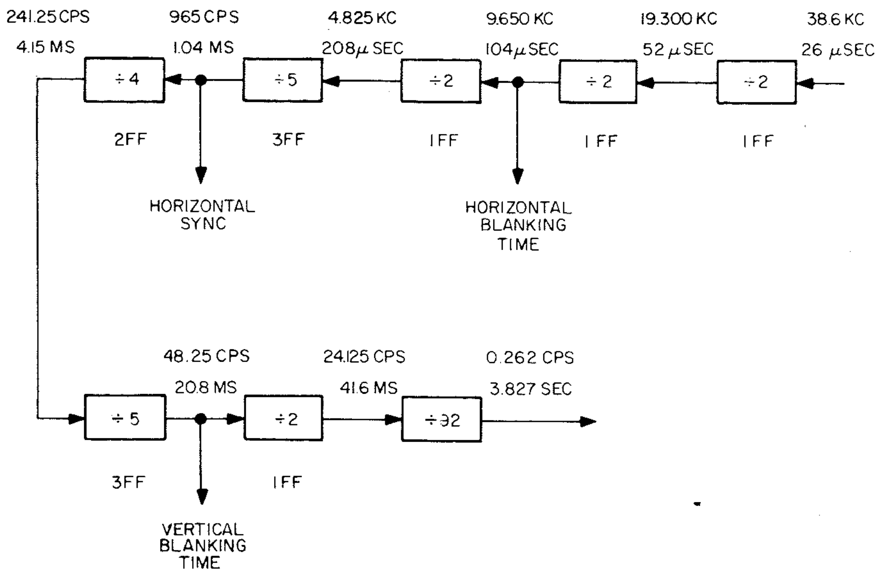


Fig. 6—Frequency divider chain.

TABLE I—SYSTEM SPECIFICATIONS

Number of scanning lines	920
Horizontal deflection frequency f_H (cps)	965 cps
Time to scan one line t_H	1040 μsec
Active line scan period (based on 10% blanking)	936 μsec
Vertical deflection frequency f_v	1.05 cps
Time to scan one frame	0.95 sec
Active frame scanning period (based on 2% blanking)	0.93 sec
Number of active scanning lines	900
Effective vertical resolution (based on a Kell factor of 0.7)	630
Video bandwidth	340 kc
Scale resolution	10 meters
Lens focal length	200 mm
Aperture	f/1.5

for variable scale (foreshortening) along the orbital path, as noted previously. In addition, correction for roll, yaw, and pitch of the vehicle will be required.

Satellite altitude can be computed on the basis of overlap between adjacent pictures. Altitude errors will affect the accuracy if appreciable change in altitude occurs in the interval between pictures. Since the interval between pictures supplied by a given camera is about 4 seconds, a pitch error rate of 0.05°/sec can account for a 5% error in a calculation of altitude when the altitude is approximately 100 km. The interval between pictures taken by the two cameras of a pair is only 1 second, so that less error is involved in this case.

To solve the photogrammetric geometry, the direction of the optical axis must be known. This could be determined by determining three angles. Two of these are: 1) the angle between the optical axis and the local vertical, and 2) the angle between the optical axis and the normal to the local vertical in orbital plane. (For a circular orbit, this latter direction is that of the velocity vector.) A third angle, the angle between the yaw axis and the orbital plane, must also be known. This information could be obtained from the lunar horizon-scanning subsystem and the azimuth-rate gyro in combination during the orbital phase. The information is obtained by sampling the error signals (two from the horizon sensor and one from the azimuth gyro) at the instant of exposure of each picture. This information is transmitted to the ground station, where hard copy of the images is made on photographic film. By associating each image with the three angular values specified above, rectified transparencies can be prepared by the usual photographic process. The rectified transparencies will not necessarily all be of the same scale, since altitude information has not been transmitted. However, as noted previously, altitude (or at least relative altitude) may be deduced by comparing the overlapping portions of adjoining areas and by correcting the magnification of one or the other to effect a match.

CONCLUSION

This television camera subsystem for lunar observation provides stereoscopic coverage enabling topographic features to be mapped at a resolution of 10 meters. The system could operate with a communication baseband of 350 kc, providing coverage between lunar latitudes of ± 20° when injected into a suitable lunar orbit.

ACKNOWLEDGMENT

The derivation of highlight exposure required to provide a given signal-to-noise ratio at a specified resolution was done by J. E. Armington.

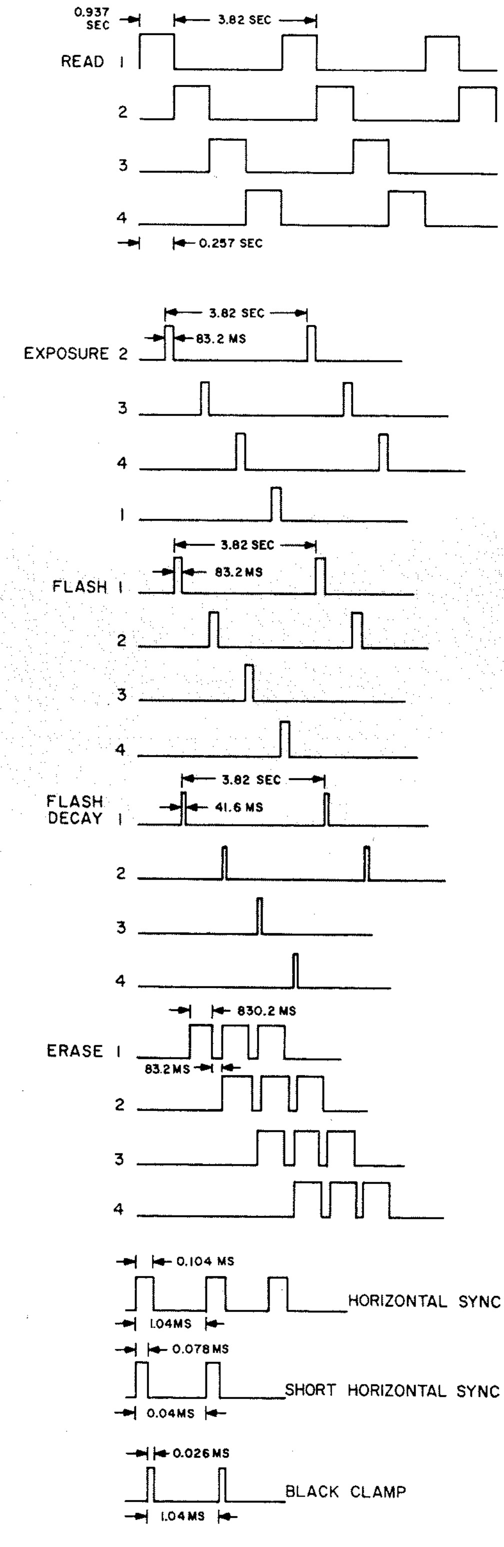


Fig. 7—Timing and synchronizing waveforms.

TV CAMERA FOR THE COMMAND MODULE OF THE APOLLO SPACECRAFT

This light-weight TV camera for the APOLLO Command Module is demountable for hand-held use by the astronauts during flight. Since the APOLLO Lunar Excursion Module will also utilize a TV camera for the astronauts' use in actual exploration of the Moon's surface, the system design of the Command Module camera was strongly influenced by the anticipated requirements of video coverage while on the lunar surface, in order to take maximum advantage of common design approaches. Special design considerations for the sensor, optics, power supply, and automatic light-level compensation are given. In addition, a description of the operation of the video amplifier, yoke and deflection circuits, beam current regulator, and sync generator is presented. Since low weight was a prime requirement, hybrid and monolithic integrated circuits are used to the extent that the state-of-the-art allows. The camera is easily adaptable to other space applications with different scan and frame rates, thus making it attractive as a utilitarian unit.

P. M. ZUCCHINO, and J. L. LOWRANCE, Ldr.
Spacecraft Electronics
Astro-Electronics Division
DEP, Princeton, N. J.

THE APOLLO three-man moon missions will be covered by television. This coverage will perform an important role in the scientific experiment and in the operational control of the APOLLO mission. Subsequent broadcasting of video recordings of the mission so obtained will also allow a vicarious participation by the public television audience in the most exciting and significant exploration of modern times.

This paper is concerned with the television camera for the Command Module of the APOLLO spacecraft. (RCA is designing and building this camera under contract to North American Aviation's Space and Information Division, Downey, Calif., principal contractor to NASA's Manned Space Flight Center.) The APOLLO mission will also include a camera system with which the astronauts can obtain television coverage of their actual exploration of the lunar surface. The design of the television camera for the Command Module was strongly influenced by the anticipated requirements of the lunar-surface camera for the Lunar Excursion Module.

During 1962, the National Aeronautics and Space Administration conducted a study of analog versus digital television for the APOLLO mission. These tests had a twofold purpose: 1) to empirically determine the optimum line and frame rates for the mission, and 2) to compare the performance, weight, and power of digital versus analog television systems designed for a specific requirement. A competitive demonstration of analog versus the digital technique showed conclusively that:

1) Analog television was better suited for the lunar mission.
2) A frame rate of 10 to 15 frames/sec appeared adequate.
3) A system resolution of approximately 200 lines per picture height was a satisfactory compromise between picture quality and bandwidth and the resultant system parameters such as transmitter power and antenna gain.

MISSION REQUIREMENTS

There are three mission requirements for the APOLLO Command Module television camera. First, the camera in the command module must take pictures of the astronauts during launch, requiring operation during vibration created by the booster rocket (Fig. 1). During launch, the camera will be attached to a bulkhead in front of the center astronaut. Secondly, after launch, the camera will be removed from this mounting and relocated behind the head of the center astronaut's couch. From there, the camera views both the center aisle and the work area of the Command Module. The third requirement is for hand-held operation by an astronaut. While in orbit or in transit, he will point the camera out of the command module window and take pictures of the Earth or Moon.

It is desirable to design both the Command Module camera and the Lunar Excursion Module camera as nearly alike as possible in order to reduce the overall cost of the APOLLO television system. As a result the command module camera has a self-contained sync generator and requires only the unregulated DC power of the Command Module to operate. These are the requirements anticipated for the lunar-surface camera, since it will be operated some distance from the Lunar Excursion Module.

Signal-to-noise ratio and transmitter power considerations dictate that the video signal be contained within a bandwidth of 500 kc for the long-range transmission from the Moon to the Earth. This bandwidth limitation requires that the television system have scan rates lower than standard broadcasts. Since the application of the camera requires that the video signal be suitable for commercial broadcast, a scan converter is required to convert the slow-scan video signal generated by the camera to the standard broadcast rates. However, this paper is primarily concerned with the slow-scan camera.

SYSTEM DESCRIPTION

The camera is shown in Fig. 2, and a block diagram of the camera is shown in Fig. 3.

System parameters and other salient features of the camera are listed in Table I. As previously mentioned, the frame rate and number of lines were selected on the basis of empirical results obtained during the study using a camera with variable line and frame rates. The most important design constraint has been weight with due consideration for performance and reliability.

SENSOR CONSIDERATION

The minimum weight and size requirements of the camera made the choice of a vidicon mandatory for the sensor. The next decision was to select the most appropriate vidicon family: magnetic, electrostatic, or hybrid (electrostatic focus, magnetic deflection). The focus coil required with magnetic vidicons is rather heavy and large, even on a ½-inch tube. The electrostatic vidicon was an attractive configuration, requiring neither focus coil nor deflection yoke. However, the hybrid vidicon was selected for the following reasons:

1) The limiting resolution is higher than the "all-electrostatic" vidicon.
2) The deflection yoke for the hybrid is very lightweight (0.1 pound). This weight is partially offset by the fact that the hybrid vidicon is somewhat lighter than the "all-electrostatic" vidicon.

Final manuscript received November 24, 1964
This paper was presented at the SMPTE Technical Conference in New York City, September 28, 1964.

TABLE 1—System Parameters of the APOLLO Command Module TV Camera

Parameter	Value
Size	7 x 3¾ x 3 inches
Weight	4.5 lbs, less optics
Frame rate	10 frames/sec
Line rate	320 lines/frame (3,200 cps)
Aspect ratio	4:3
Resolution	220 TV lines per picture height both vertical and horizontal
Bandwidth	500 kc
Sensor input	0.1 to 30 foot-candles, peak illumination
Power consumption	5.8 watts, maximum, from a 24- to 31-volt DC source
Operating temperature	—20 to +40°C.
Output	20 ma peak, into a receiving-end-terminated video line. (2 volts peak into 100-ohm load)
Sync	Conventional blacker than black pulses: 23% of peak-to-peak signal. See Fig. 8 for complete video waveform.
Signal-to-Noise Ratio	43 db, typically

3) The magnetic-deflection method affords more latitude in the design of the electronics for this application.
4) The power required by the two deflection methods is comparable when considering the complete circuit.

The selected vidicon is a ruggedized version of the RCA Model 8134 vidicon tube. Operating at the rates and bandwidth specified for the command module camera, the sensitivity of this vidicon is shown in Fig. 4. An opaque mask is deposited on the outside of the 50-mil faceplate to act as a black reference. Each scan line begins just within the masked area, allowing the black level to be clamped during each line.

There are ½-inch versions of the hybrid vidicon under development; however, the limited data on their performance and reliability made it advisable to choose the 1-inch vidicon.

OPTICS

The camera optical system has been selected to meet the rather broad mission requirements with minimum weight.

The camera in the Command Module will be located about 4 feet from the center astronaut. In order to view the faces of all three astronauts during launch, a lens with a field of view of approximately 80° will be required. On the other hand, the Moon subtends 0.7° when viewed from the Earth, and the Earth subtends 2.0° when viewed from the Moon. In order to meet this broad range, two lenses have been selected which are interchangable in flight. One is an f/1.9, 7.5-mm Argus lens, and the second is the f/2.5, 20-mm to 80-mm Argus zoom lens with a viewfinder. The lenses have been fitted with special "bayonet" attachments to facilitate changing lenses.

Illumination within the spacecraft will be provided by incandescent lamps

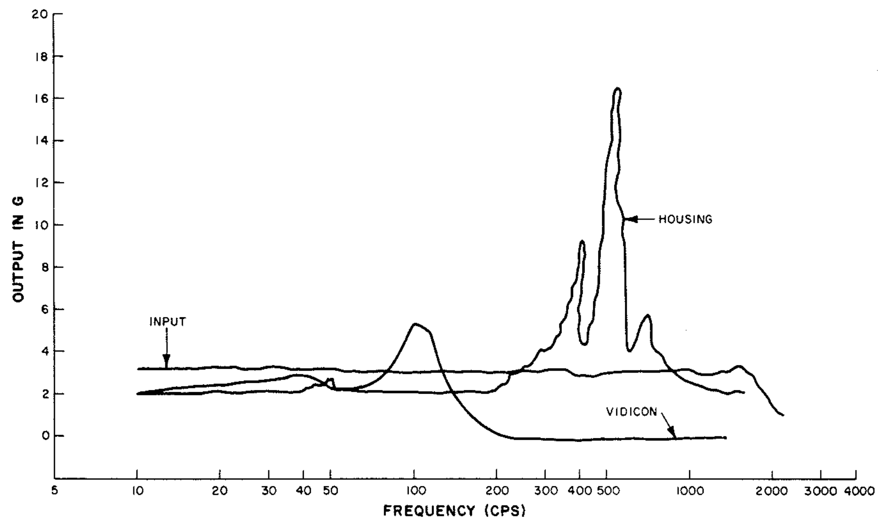


Fig. 1—Vibration profile of APOLLO spacecraft during launch.

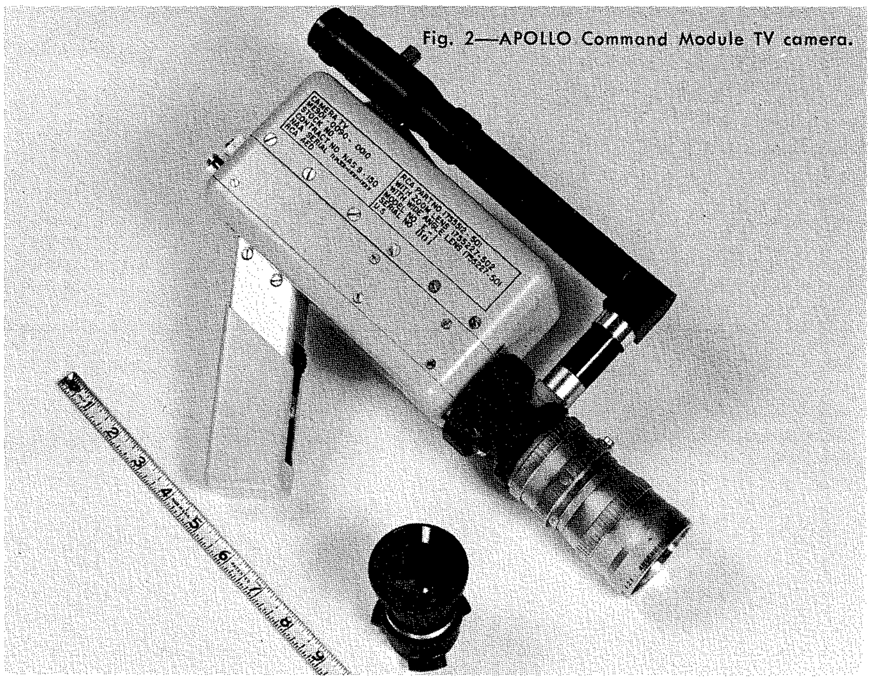
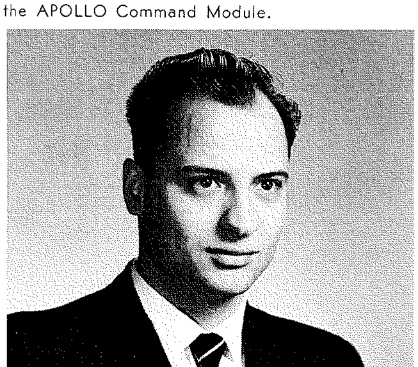
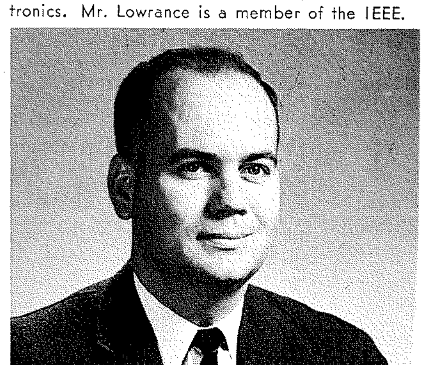


Fig. 2—APOLLO Command Module TV camera.

P. M. ZUCCHINO received the BSEE from Newark College of Engineering in 1962. He was employed from 1960 to 1961 by Foto-Video Electronics where his assignments involved both color and monochrome closed-circuit television systems. In addition, he worked on broadcast television, and on associated systems engineering. In 1961, he was employed by the Vare Industries where his responsibilities included television camera system engineering for underwater applications. He joined the Astro-Electronics Division of RCA in 1962 and since that time has participated in the design and development of several types of television cameras for space applications. His most recent assignment was as part of the project team which developed the television camera for the APOLLO Command Module.



J. L. LOWRANCE received his BSEE from the University of Tennessee in 1954 and joined Bendix the same year; his assignments there included anti-ICBM studies involving television techniques for re-entry measurements and development of an airborne reconnaissance system. The last three years of Mr. Lowrance's ten years of engineering design experience has been with RCA's Astro-Electronics Division as a space television camera designer. His RCA experience includes designs for several classified programs, TIROS weather satellite TV cameras, the new APT (Automatic Picture Transmission) camera on TIROS VIII, and the APOLLO Command Capsule camera. He has also worked on microminiaturization, and integrated circuitry. He has obtained several patent applications for this work. He is currently Leader, Spacecraft Electronics. Mr. Lowrance is a member of the IEEE.



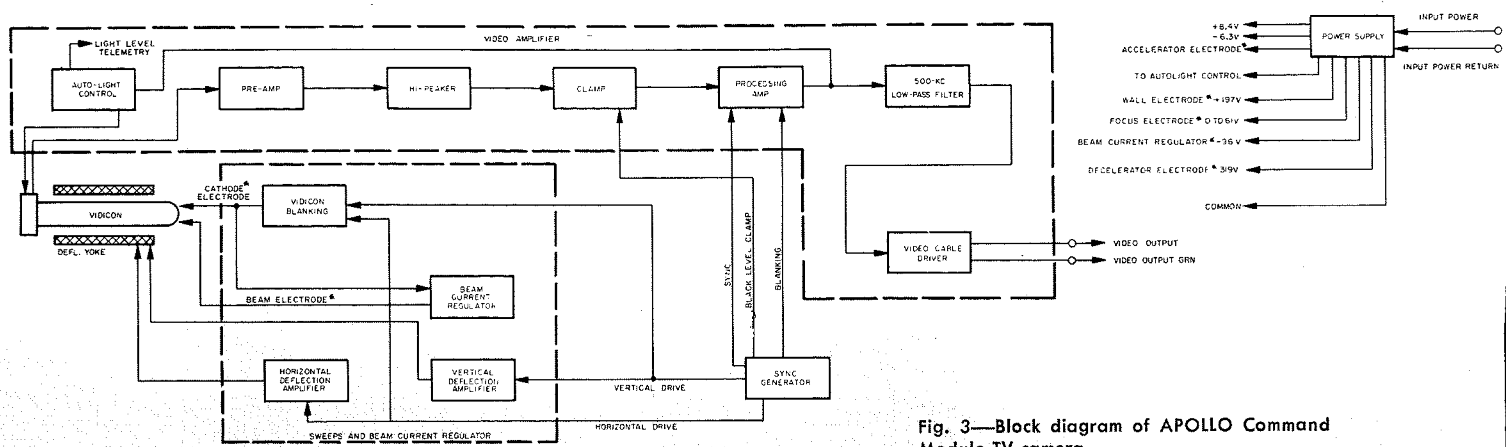


Fig. 3—Block diagram of APOLLO Command Module TV camera.

and by sunlight through the Command Module windows. The incandescent lamps provide 20 to 50 foot-candles of illumination.

The sunlit Earth has a brightness varying from 10,000 foot-lamberts for bright clouds to 100 foot-lamberts for certain terrain and has an average brightness of approximately 4,800 foot-lamberts. The Moon has a brightness of 1,000 foot-lamberts when illuminated by the sun. The moon's surface, when illuminated by Earth shine, is expected to be approximately 0.1 foot-lambert.

AUTOMATIC LIGHT-LEVEL COMPENSATION

The sensitivity of the vidicon is a function of the target-to-cathode voltage. This characteristic, shown in Fig. 4, is used to vary the system gain as a function of light level. The DC restored output of the video amplifier is peak detected and compared with a reference level. The error is amplified and used to control the target voltage, which swings approximately 40 volts over the light-level variation of 300 to 1.

This scheme is attractive for several reasons. The system will work with any lens, being independent of field of view, f-number, and lens transmission. It will also provide good signals with scenes containing bright objects that are a small part of the total field of view. This characteristic can be controlled by designing the peak detector to be responsive to the average of the peak signal. This is advantageous for scenes where specular reflection may be present.

A judicious choice is necessary in designing the response of the system to prevent oscillations and at the same time promptly follow variations in the illumination. The system, as currently designed, will correct for a 300 to 1 variation in approximately 3 seconds. The signal-to-noise ratio is essentially constant throughout this dynamic range. Gray-scale reproduction at the extremes of the light range is about six steps.

Good test-pattern pictures have been obtained, for example, with 0.1, 1.0, and 30 foot-candles of peak illumination on the vidicon faceplate.

POWER SUPPLY AND POWER CONSUMPTION

The power source for the camera is 24 to 31 volts-DC. At maximum voltage, the camera dissipates 5.8 watts of power. The system design of the APOLLO spacecraft requires that the power ground be isolated from the signal ground. The power supply consists of an input regulator that controls the voltage input to a Royer-type DC-to-DC converter. The rectified output of the converter provides voltages of +320, −96, +10, and −8.3 volts. The low voltages (+10 and −8.3 volts) are regulated and become the supplies for the camera electronics, with the saturating transformer of the DC-to-DC converter providing the necessary isolation between power ground and signal ground. The positive high voltage (+320 volts) provides the electrode potentials for the vidicon with the exception of G_1, the beam-control grid. The positive high voltage requires no further regulation, since the load is relatively constant; for proportional drifts, the vidicon will remain in focus at the resolution levels under consideration. The −96-volt supply is used by a beam-current regulating circuit for the control grid. The vidicon filament requires 95 milliamperes at 6.3 volts. This is provided by the low-voltage negative supply. The camera, operating from a regulated primary power source, consumes only 3.85 watts, 0.7 watt of which is for the vidicon filament. The camera was designed with minimum power consumption as an important, but secondary, consideration compared to minimum weight.

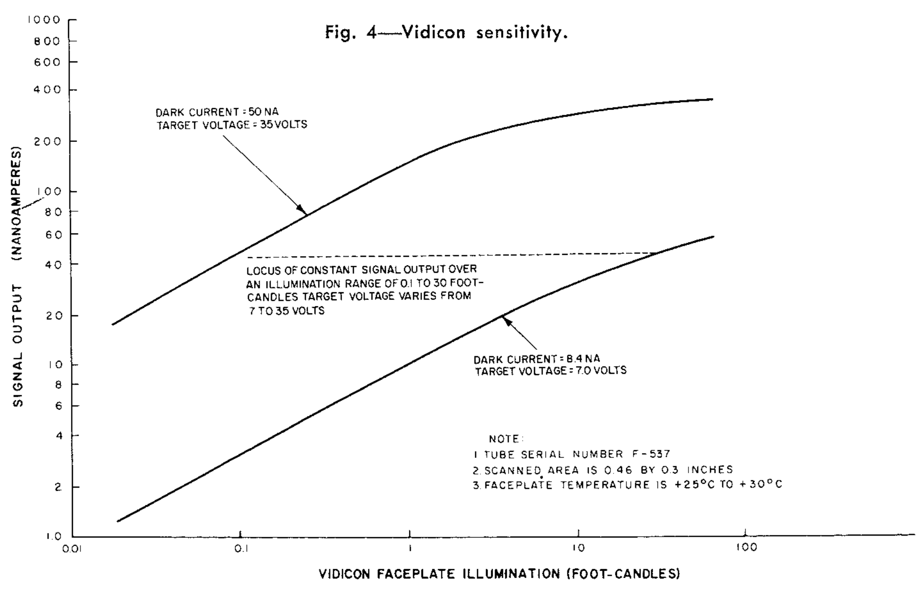


Fig. 4—Vidicon sensitivity.

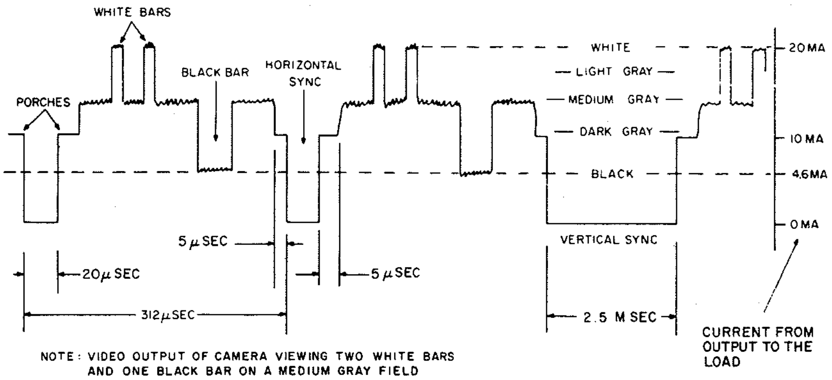


Fig. 5—Composite video output signal.

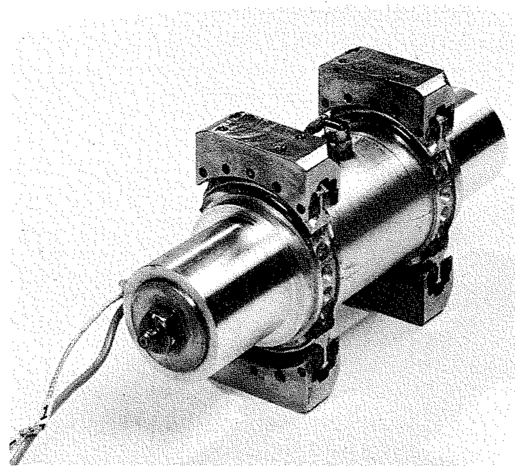


Fig. 6—Double-shear isolator.

VIDEO AMPLIFIER

The video amplifier utilizes nine hybrid integrated circuits and one monolithic integrated circuit.

The output signal from the vidicon receives initial amplification in a preamplifier which is a feedback-pair circuit using low-noise silicon planar transistors. The equivalent input noise current of this preamplifier is less than 0.3 nanoampere-RMS over the 500-kc bandwidth of the system. The vidicon provides a black-to-white signal current of about 40 nanoamperes. The ratio of the peak-to-peak signal-to-RMS noise is then 43 db, typically.

The signal is then compensated for the effect of the input circuit's inherent roll-off characteristic above 30 kc and given further AC amplification. A line-to-line clamp restores the DC component of the signal and provides the reference black signal for the clamp operation.

In the remaining, direct-coupled, stages of the video amplifier, the signal is subjected to black- and white-level clipping, to sync and porch insertion, to bandwidth limiting in a filter stage, and to output-stage amplification to drive a video line.

The resultant composite video signal is shown in Fig. 5. The sync tip is the zero output-current level, and the peak white is the 20-milliampere output-current level.

The 500-kc low-pass filter's response is down more than 20 db at 1 Mc. The filter exhibits a 10% overshoot on step transitions; however, the video is not significantly distorted since the rate of rise of the video signal is limited primarily by the response of the vidicon and the optics.

Before entering the 500-kc low-pass filter and the output stage of the video amplifier, the video signal is peak-detected by the first stage of the automatic light-level compensation circuit. The second stage controls the target voltage of the vidicon on the basis of how the peak-detected video signal compares with a reference level.

YOKE AND DEFLECTION CIRCUITS

The frame and line rates for the Command Module camera fall between normal broadcast rates and slow-scan rates, such as the 2-second frame rate used in the cameras of the TIROS satellite. The type of circuit that best meets the requirements of this region is the operational class *B* amplifier with feedback, operating from a double-ended power supply. A sawtooth waveform is generated by charging a capacitor from a constant-current source. The source is the collector of an emitter follower, with a reference voltage at its base. The sawtooth drives one side of a differential amplifier. The other input to the differential amplifier is the feedback voltage developed by the yoke current flowing through a small resistor in series with the yoke. The differential output voltage drives the class *B* push-pull amplifier, which in turn drives the yoke.

The yoke is a miniature design suitable for permanent bonding to the vidicon. (The yoke was developed by RCA Communications System Division, Graphic Display Group.) It has the following electrical characteristics:

$L_h = 1.15$ mh	$L_v = 19$ mh
$R_h = 12.5$ ohms	$R_v = 130$ ohms
$I_h = 50$ ma (peak-to-peak)	$I_v = 9$ ma (peak-to-peak)

Fig. 7—Video amplifier and automatic light-level control board (length, about 4 inches).

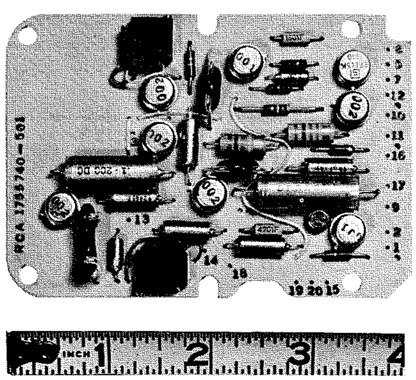


Fig. 8—Sync generator board assembly (length, about 4 inches).

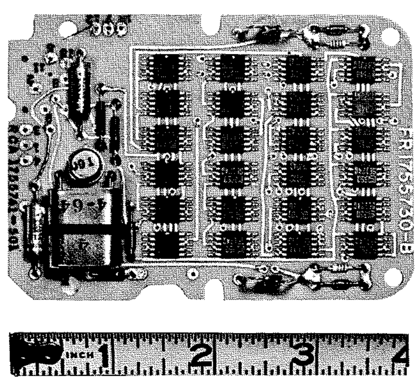
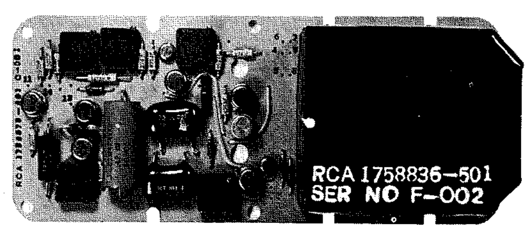


Fig. 9—Deflection circuitry and beam-current regulator board assembly.



The resultant retrace time is a maximum of 20 μsec for the horizontal scan and 1 msec for the vertical scan, operating from the -6.3- and $+8.4$-volt power supply.

The vertical scan is started four scan lines ahead of the transmitted picture to eliminate edge effects that may cause white lines at the beginning of the frame. This spurious white would affect the automatic light-level compensation circuit.

BEAM CURRENT REGULATOR

Cathode emission decreases with vidicon age and, of course, with decreasing cathode temperature. The cathode current is a function of the G_1-to-cathode voltage; that is, decreasing the voltage increases the current. Since the scanning-beam current is essentially a fixed percentage of the cathode current, regulating the cathode current is an effective method of regulating the beam current. The beam-current regulator is a one-transistor circuit that samples the cathode current and controls the G_1 voltage accordingly.

Beam blanking during retrace is effected by switching the cathode 15 volts positive with a transistor switch.

SYNC GENERATOR

The sync generator of the camera provides all the timing pulses for operation. This circuit consists of a crystal oscillator running at a frequency of 102.4 kc. This oscillator drives a series of 14 binary counters with feedback that provides vertical sync and drive at 10 pulses/sec; and horizontal pulses, drive, sync, clamp, and porch, at 3,200 pulses/sec. The 102.4-kc crystal oscillator employs a hybrid integrated circuit.

The sync waveforms required are generated by gating the outputs of the 14 binary counters in the sync generator. The front and back porch for the vertical sync is actually the front porch of the first horizontal line and the back porch of the ninth horizontal line, since the vertical scan is precisely synchronized and in proper phase with the horizontal scan.

Twenty-five monolithic integrated circuits and one hybrid integrated circuit are used in the sync generator.

MECHANICAL DESIGN

The primary constraints on the mechanical design of the camera are weight, size, and operation during a vibration environment. The camera must also be properly proportioned for handheld operation, and the lenses must be easily interchanged in flight, without tools.

The only component significantly affected by vibration during operation is the vidicon. The first approach was to obtain a ruggedized vidicon that would perform satisfactorily at the vibration levels specified for the camera, with some margin for resonance in the camera vidicon assembly. Vidicons have been developed that are considerably superior to the commercial product. However, these vidicons cannot meet the requirements over the entire vibration spectrum from 20 to 2,000 cps. The solution has been to suspend the vidicon-yoke-less assembly within the camera housing. The suspension system resonates at approximately 100 cps and rolls off at approximately 16 db/octave. The vidicon has a high threshold of susceptability at low frequencies. A typical susceptability curve is shown in Fig. 1. As long as the composite curve falls below the susceptability curve, the picture quality will not be seriously degraded. The actual suspension system is a double-shear isolator as shown in Fig. 6. This type of isolator can be made to have controlled and independent resonant frequency in each axis of vibration.

To minimize the volume required for the camera electronics, integrated circuits are used where practical. The camera electronics consist of 25 monolithic integrated circuits, 20 hybrid integrated circuits, a minimodule, and miscellaneous components that cannot be put in an integrated circuit. The minimodule contains the power-supply transformer and most of the power-supply components that are not compatible with integrated circuit packaging, such as the filter capacitors and the high-voltage rectifiers.

Fig. 7 shows the video amplifier and the automatic light-level control board assembly. Fig. 8 shows the sync generator, and Fig. 9 shows the deflection circuitry and beam current regulator mounted with the minimodule power supply on the bottom board. The preamplifier is packaged separately and mounted on the vidicon yoke assembly to minimize electrical interference generated by the power supply.

INTEGRATED CIRCUIT DESIGN CONSIDERATIONS

The exclusive use of monolithic (single crystal) integrated circuits for the entire TV camera is not yet practical. The current state of the art in monolithic integrated circuits is not well developed for analog circuits. The video processing and deflection circuits in the command module camera fall into that category. On the other hand, the timing, pulse, and synchronizing circuits of the camera lend themselves well to the use of monolithic integrated circuits.

The APOLLO Command Module television camera uses monolithic integrated circuits primarily in the sync generator circuitry. Most of the other camera circuitry is done with hybrid integrated circuits.

The hybrid integrated circuits used in the camera are made with discrete, diffused silicon chips and thin-film components, all mounted in a single transistor case.

Circuit design with hybrid integrated circuits differ little from that with conventional components. Of course, electrolytic capacitors and inductive components are not integrated, and with weight and space constraints, their use must be minimized. A wide variety of transistor characteristics can be supplied in a hybrid integrated circuit. Single resistors are available from 10 ohms to 40,000 ohms. For values above 100 ohms, thin-film resistors, with the stability associated with conventional thin film resistors, can be used. Capacitors, up to a few hundred picofarads, diodes, and zener diodes are also available as components in a hybrid integrated circuit.

Video processing and deflection circuits tend to be rather specialized circuits fitted to the particular requirements of the system under consideration. This is not the case with sync or logic circuitry, which can be readily approached from a building block point of view and which lends itself to the use of standard monolithic integrated circuits. The hybrid integrated circuit fabrication technique provides a custom designed circuit in small quantities at relatively low cost. However, in the event that a circuit is needed in large quantities, it becomes economical to have even a rather specialized circuit produced by a monolithic technique.

OTHER APPLICATIONS OF THE CAMERA

As previously mentioned, the design of the Command Module camera was carried out with the requirements of the lunar-surface camera in mind. The camera is also applicable for the GEMINI missions to serve essentially the same function as on APOLLO.

The deflection circuits have been designed to accommodate easy modification to slower scan rates and frame rates. The video chain can be easily modified for higher gain and narrower bandwidth. This adaptability makes the camera attractive as a utilitarian unit, capable of being used for other space applications with different frame and line rates.

THE 4102-S SPACE TRACK PROGRAM

E. T. GARNER and J. OSEAS, Ldr.
Real Time Digital Systems
Digital Information, Systems Engineering
Missile and Surface Radar Division, DEP, Moorestown, N. J.

The Space Track program is a real time application written for the 4102-S, a multilevel interrupt processing computer (built by RCA, Van Nuys). The program, in conjunction with the radar system, provides automatic detection and tracking of satellites. The program identifies satellites and transmits radar observations to the USAF Spacetrack Center, Colorado Springs, Colorado. In addition to real-time functions, the program will on command of the operator produce a hard copy listing of expected penetrations of the surveillance sphere. This allows the director of the facilities operation to preplan missions. This paper deals with the Space Track mission and the organization of the computer program to meet that mission. The hardware will be explained in general terms as background for the particular program arrangement.

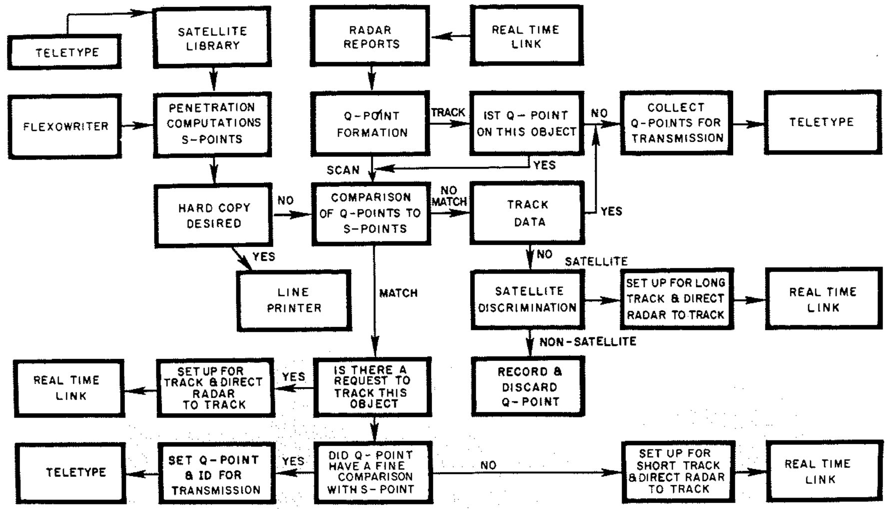


Fig. 1 — Data flow in the SPASEC program.

THERE are five functions which the *SPA*ce Track *SE*nsor *C*omputer (SPASEC) real-time program performs as part of an effective satellite surveillance system. It locates new satellites soon after launching; keeps up to date records of known satellite orbits; provides positional data of high accuracy for use by other systems; provides information on size, shape and stability; and indicates orbital change. The radar associated with this system can operate in both a surveillance mode to provide data on orbiting objects passing through the volume scanned or in a tracking mode to provide more accurate orbital data on observed objects.

The mission of the satellite surveillance system is to identify and acquire track or scan data on the satellites. Care is exercised in the gathering of data so that the minimum amount of information is collected that will satisfy the requirements of the particular satellite observation. This insures that the radar will be available to gather information on other objects and that redundant information will not be transmitted. The information leaves the computer as smoothed radar observations in the form of time, range, azimuth, elevation, range rate and identification of the satellite, if known. This information is transmitted over teletype lines to the Spacetrack Center.

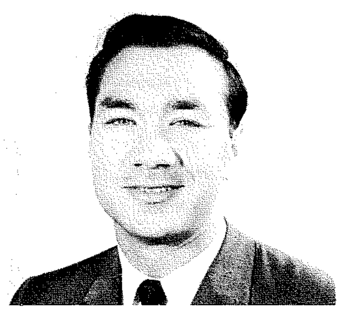
In addition to the real-time aspects of the mission, the site must produce its own schedule of what it is able to see (called *penetration listings*). The site is furnished with orbital elements by the Spacetrack Center on all known satellites. This list of known satellites is constantly being updated by means of teletype messages from the Center. A list of desired observations (called the *priority list*) is also furnished by the central agency. Fig. 1 indicates the overall data flow within the SPASEC program.

Fig. 2 shows the operational system

Final manuscript received August 18, 1964.

JONATHAN OSEAS received his AB in Physics from Bard College in 1952 and his MS in Physics from New York University in 1956. He was an Engineering Mathematical Analyst at Sylvania Electric Products from 1952 to 1956. At Eitel McCullough from 1956 to 1959, he was an Electrical Group Leader designing automatic vacuum tube machinery; he later became Chief of Mathematical Services there. In 1959 he joined RCA as a programmer analyst specializing in real-time and special-computer problems for BMEWS. In 1961 he was appointed Leader, Real-Time Digital Systems. In this capacity he completed the programming and subsequent installation of the Checkout Data Processor Program at the U.K. BMEWS Site. His group designed, programmed and installed the first automatic satellite sensor and detector using the RCA 4102-S as part of the SPADATS network. He is currently engaged in automatic evaluation of ECM as associated with the BMEWS System. Mr. Oseas is a Member of the IEEE, ACM, and ASQC.

EDWARD T. GARNER received his BS in mathematics from the University of Georgia in 1960. He joined RCA, Moorestown, N.J. in June 1960. His duties have centered about analysis and programming of real-time problems. As a member of the Systems Engineering Department at Moorestown he was engaged in the program design and implementation of the BMEWS Site III Checkout Data Processor. In 1962-63 was concerned with the design and implementation of the SPASEC program. (Mr. Garner left RCA in 1964.) He is a member of ACM and AAAS.



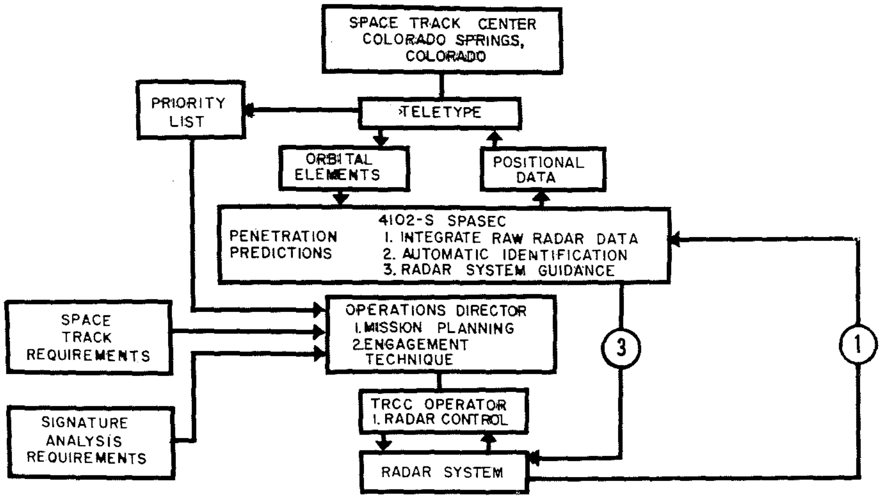


Fig. 2 — Operational systems organization.

organization. The Operations Director has the responsibility of coordinating the data requirements with the detailed problems of site operation. Missions are planned based on new information requests, object priority, number of expected sightings, and probability of detection. Changes in an objects status are entered into the computer using simple mnemonic codes and decimal numbers. Changes or additions to the satellite file received over the teletype lines are automatically entered into the computer ephemeris file and on the master tape. The expected satellite penetrations are computed periodically and a hard copy is produced. This allows an operational check against the master plan based on the most current information at all times.

The plan is executed by the tracking-radar control console operator who exercises gross manual control over the radar system directing the radar to scan the selected sector. Under these manual constraints, the system is automatic and is controlled by the 4102-S computer.

The raw data collected by the radar system is processed and filtered by the computer. Data identification, data quality and data consistancy checks are performed by the computer. The program directs the radar in the gathering of additional information and returns it to the surveillance mode of operation when it is satisfied that no more useful data can be collected. The tracking radar control console operator then executes the next phase of the plan.

4102-S COMPUTER

The 4102-S is the most recent addition to the 4100 series[3] built by RCA, Van Nuys, California. The RCA 4102-S is a 16-level, 30-bit-word-length, parallel, binary 2's, complement, fractional, interrupt input-output, stored-program computer. The computer has 16 program counters and 96 full-length index registers. An *add* instruction requires 19.2 μsec, and a *multiply* 75.5 μsec.

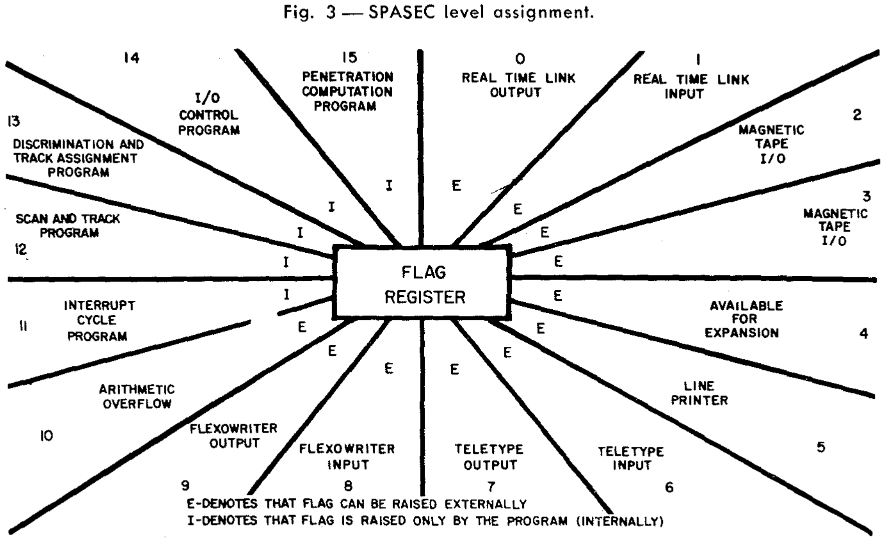
The prime requirements for the SPASEC system demanded that the computer be reliable, binary, economical and capable of communicating with the radar system in real-time. The RCA 4102-S met the real-time requirements with interrupt input-output as opposed to interleave input-output.

With the interrupt processing method used, a section of coincident-current memory is set aside and designated as *executive storage*. This area is used by hardware to store the program counters and the index registers. There is an internal 15-bit register known as the *flag register* which is examined each time an instruction is executed. If a higher-priority-level flag is set, the program counter for the higher level is accessed and a new instruction sequence is begun. When a level is through operating, it may erase its own flag (called *suicide*). All levels may set any bit in the flag register, but the bit may be cleared only by the level associated with the flag. With these *set* and *reset* commands, programs and external devices can intercommunicate.

Interrupt processing uses the hardware level control to accomplish input-output while tying up main frame only a small portion of the time. Each command and input-output instruction suicides, and the particular input-output device will set the priority flag when it is ready to accept or transmit more data. This allows the program to proceed normally in processing data—being interrupting when input-output devices need servicing. Fig. 3 shows the level assignment.

Economies in computer hardware were achieved by the interrupt processing method, by fixed point logic, and by medium-speed circuitry. Effective computer utilization was realized through the use of a simple assembly language and fixed-point coding.

Fig. 3 — SPASEC level assignment.



4102-S CONFIGURATION

In the 4102-S, both program units and hardware devices have been assigned priorities. The level assignment is shown in Fig. 3. The hardware devices are fixed priorities and are arbitrarily assigned according to the maximum allowable time lag between request and service of the device. Hence the faster, more "impatient" devices have higher priorities. The configuration is shown in Fig. 4.

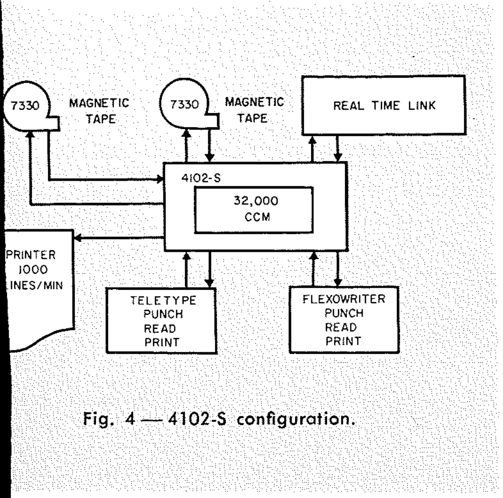


Fig. 4 — 4102-S configuration.

The real-time interface is the computer's connection with the real world. Through this interface, the computer receives target information and radar system status and transmits radar system direction.

There are two magnetic tape units, (7330's) which are used in low density only. The units are used for fast program load and historical recording. The line printer is an Analex 41000, capable of printing 1,000 lines per minute. The printer has a 64-character selection and a 120-character line. The printer is used to provide a hard copy of the penetrations of the surveillance sphere.

A Model 28 Teletype is connected to the computer through a special interface which can recognize sequences of teletype characters as a request to start or end a message. The Flexowriter is a standard two-case, 5-bit-Baudaut-code machine with *read*, *write*, and *punch* capabilities. The Flexowriter reader is used to enter control messages to the program. The Flexowriter typewriter is used to print direction messages to the operator, equipment status messages, and smoothed radar data.

PHILOSOPHY OF PROGRAM DESIGN

SPASEC was conceived to be a single-purpose computer system as opposed to a general-purpose system. Its task was to fulfill the Space Track mission 24 hours a day, 7 days a week.

Throughout the design and coding phases of the development of this program, particular attention was paid to relieving operating personnel of responsibility for determining detailed system action and response. This design concept, which stresses completely automatic operation, is coupled with additional features to allow manual direction and/or intervention. The blending of operational flexibility and automatic control has made this system adept at gathering data for general and special purpose missions. This concept has allowed an operation which has significantly reduced the number of technical specialists necessary to conduct the most complicated assignments.

The Space Track program is segmented and planned in such a way that the operation can continue with reduced capability. If the Flexowriter is inoperable, the Teletype will be directed to perform the Flexowriter output function in addition to its own. If as much as half of core memory is inoperable, the program continues relocated into the good half. In this case the satellite identification feature is lost. If the program is destroyed by a transient signal or intermittent error, the program can be quickly reloaded from magnetic tape.

The logic of the program and the system assumes that any changes in operating mode due to manual intervention are correct, unless such changes are of such a nature as to physically damage the radar. If any procedure is unexpected, the program will notify the operating personnel of such change by specific English reference to what has occurred. (e.g. *track denied, radar inop* (erable), *track mode)*. System malfunction is determined quickly and operator intervention is confirmed.

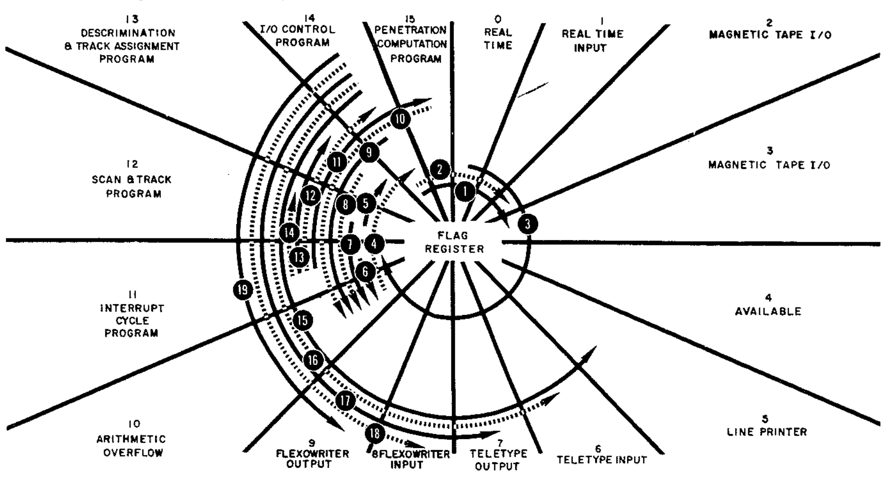
It was realized that as additional operational requirements become known, program changes would be required. The actual requirements for changes which are being implemented attest to the validity of this concept. Based on this concept, features were incorporated into the program to facilitate modification, debugging, and historical recall.

Historical recording is closely allied to the debug features within the SPASEC program. These features are used for program maintenance, system, and hardware debugging as well as special studies. Access is allowed to the program and its data in real-time or off-line modes of operation.

TABLE I—Program Communication

Flag	
1	Magnetic tape input-output
2	Magnetic tape input-output
3	Real-time interrupt.
4	Start message output!
5	Compare data!
6	File error message!
7	File error message!
8	File error message!
9	File error message!
10	File error message!
11	Start penetration calculations!
12	Cycle through input-output devices!
13	Check for data to compare!
14	Smooth data!
15	Printer control
16	Teletype input control
17	Teletype output control
18	Flexowriter input control
19	Flexowriter output control

Fig. 5 — SPASEC program organization. Arrows show communication via the flag register. (Table I shows meanings of the arrows.)



PROGRAM ORGANIZATION

Initialization

The 4102-S is paper-tape oriented, which for small programs is not unwieldy. For the SPASEC program, a "bootstrap" procedure is used: that is, the program is assembled on another computer with card input-output and brought to the 4102-S on a low-density binary tape; that magnetic tape enters the 4102-S under control of a small paper-tape program loaded through the Flexowriter.

An integral part of the SPASEC program is the ephemeris file, which is constantly being changed. In order to reflect this change, a new program tape is written during initialization and is positioned to receive changes to the ephemeris file. Each day, a new tape is generated which is used for input on the next day. To enhance the reliability needed for an operational system, the program can be quickly reloaded from the next day's master without destroying any of the above capability.

Real-Time Data Handling

The interrupt cycle occupies the highest program-priority (Fig. 5); that is, program-priority as opposed to the priorities assigned to the hardware devices. The duty of the interrupt-cycle program is to act as an executive routine and clearing house for other sections of the program that communicate with the real-time interface or are concerned with real time. The rationale for this is that the communication with the real-time interface must be done at certain times within the radar pulse interval; to avoid confusion, it was advisable to have one section of program control the data flow. This section must be executed periodically—hence the high priority level. The interrupt cycle is activated as a program once per radar pulse interval; therefore, it is well suited to update timers and in general furnish the program with a pulse. Periodic entry to lower priority levels is effected through this program.

Since the radar system can be in *track* or *scan* but not both, data processing is performed on the same level by two mutually exclusive programs. The scan portion of the program looks at returns from two complete scans and attempts to associate the various returns. The data that the scan program has access to consists of end-of-scan and scan reports. When reports from two consecutive scans are believed to be from the same object they are said to *associate*. When it is determined that there is no data to update a previously smoothed data report, the cumulative information on this object is given to a track decision routine for further action.

Smoothed scan reports (scan Q-points) are developed from weighted radar parameters (range, doppler, azimuth, elevation, time, and credences). Additional parameters are developed from this base data such that a final-scan Q-point contains range, range rate, range acceleration, azimuth, azimuth rate, elevation, elevation rate, time, and an accuracy index. Q-points generated from scan data and initial-track Q-points are compared with the ephemeris file (S-points) by the comparator program. The results of the comparison test yields one of the following results: *fine*, passed comparison within close time and position tolerances; *coarse, passed comparison* within broad time and position tolerances; *coarse, tentatively identified* with more than one object; *uncorrelated*, object unidentified.

Uncorrelated object Q-points are processed through discrimination tests which are designed to determine if the object is a satellite. These tests are based upon energy considerations and are designed to eliminate meteors, the moon, and noise. Q-points which pass these tests are placed on a tracker waiting line and are tagged as *uncorrelated.* Those which fail are discarded as being of no interest.

Each object on the tracker waiting line has associated with it a track priority. This priority is a function of the object identification, data age, and probability of detection. The program selects the object with the highest tracking priority and attempts to track for a period of time based upon the track criteria.

To automatically track an object, the program directs the radar to a point along the object's path slightly ahead of the object. This designation message is transmitted to the radar system through the real-time interface, causing the radar antenna to be directed to a point in space. For a short period of time, the object's path can be described as a second-order curve in each of the radar's parameters. The six Q-point parameters are used to find values for the second derivatives or range, azimuth, and elevation.

The designation point is *current time* + ½ second and is valid for 1 second. If the object is not detected, a new designation point is computed. This procedure may continue for 30 seconds. If the object is detected, the radar automatically locks-on to the object and the track is begun.

Track data is smoothed using unweighted arithmetic means with least-square fits to develop the rates. The final track Q-point contains range, range rate, azimuth, azimuth rate, elevation, elevation rate, average angular credences, and orbital elements consisting of inclination, period, semimajor axis, eccentricity, and right ascension. The track Q-point presently is developed from 10 seconds of radar data.

The track program examines the reports and will terminate the track if the radar antenna should attempt to enter unavailable regions in the sphere of surveillance.

Penetration Computations

The S-point file is generated from the set of current orbital elements contained in the memory. Satellite elements, radar site coordinates, radar sector, and time period of interest are used to compute predictions. Nonpenetrating satellites are quickly rejected from consideration based on tests of the satellite's inclination and time of horizon passage.

There are five types of penetration schedules available to the Operations Director to preplan missions. The five penetration requests are: 1) penetration for all objects ordered by time; 2) penetrations for all objects ordered by satellite number in increasing order; 3) penetrations for a priority class of objects ordered by time; 4) penetrations for a priority class of objects ordered by satellite number; 5) look angles, a series of penetrations of a single object separated in time between two elevations.

When operating in real time, penetrations (S-points) are automatically generated for all azimuths at a specified elevation and filed for use by the comparator program. The file always contains one penetration interval normally 40 minutes ahead of the current time. When S-points become more than 6 minutes old, they are automatically deleted. This allows continuous operation with no loss of S-point storage. The S-points are printed after the computations for an entire interval are completed. When a print request is received in real time, the real-time S-points are deleted and the print request is honored. Upon completion of that printing, the real-time S-points are automatically regenerated and printed.

INPUT-OUTPUT CONTROL

The prime considerations in the design of the input-output control program were ease of use and movement of data at the acceptance rate of each device. The input-output control routine communicates with each of the following devices: magnetic tape units, Flexowriter, Teletype, and line printer. This master control routine is responsible for scheduling each of these devices based on availability, speed of operation, and message priority. For output, the user program notifies the input-output routine through a calling sequence which specifies the input-output device, the address of the data, and the type of message. From the point of view of the user program the data is considered transmitted to the output device after the calling sequence has been executed. In reality the request is stacked and will be processed when the device is available.

For input, the entire transfer of information is automatic and no processing is done on any message until the transfer is complete. The message is identified, converted and delivered to the responsible routine. This is accomplished by flagging the proper subprogram and giving the location of the data. Movement of large blocks of data is eliminated through use of simple list techniques. Only references to data are communicated between subprograms. These methods are discussed in more detail in the next section, *Data Manipulation Techniques*.

Real-time input-output is treated similarly but independently of the main input-output control program to assure minimum response time.

DATA MANIPULATION TECHNIQUES

Data handling in this program makes use of simple list structures, e.g., chained lists, and key buffers referencing lists. Nearly all sections of the program work with chained lists. Fig. 6 shows a general block-to-block list with key reference. The only predictable order is within the block. The ordering is a function of the data rates of the various sections of the program which use the lists. To keep track of the list, the location of the first item on a list is remembered in a *key* word. One word in each block is set aside for linkage, this word is known as the *head cell.* When the linkage contained in the head cell of a block is *0*, it denotes that this is the last item in this list.

Initially, there is only one chained list in memory, termed *available storage.* This list is exactly what its name implies: i.e., storage which is available for use by various programs upon demand. This is the list from which an item (data block) is drawn to be used by any section of the program. Control of an item may be passed among several programs with the understanding that when the data is no longer pertinent, the item will be returned to available storage.

The penetration filing scheme is an example of a key buffer referencing a list. A *penetration* consists of a set of spherical coordinates plus time. The time word is used to order the coordinates of a penetration. Filing utilizes a key buffer and fluid storage to store coordinates. The key buffer is a time-referenced buffer of 128 *key* locations representing 64 seconds each (Fig. 7). In addition to this buffer, there is a section of fluid storage consisting of 190 blocks of 13 words each. When the penetration of the radar fan is computed, it is stored in one of the blocks of fluid storage and the location of the block is stored in the time referenced buffer according to the time of penetration. When there is more than one penetration in a 64-second time interval the penetration will be chained. Previously filed data is recovered easily, and if no data is available in the pertinent time slot, this is determined quickly.

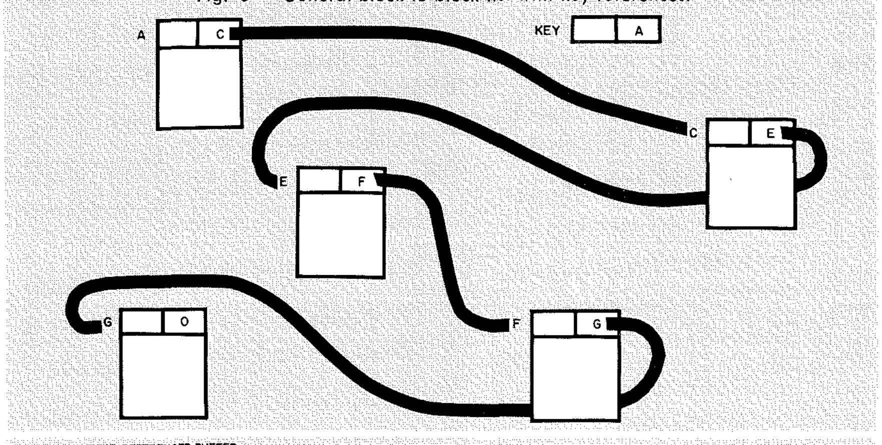
It should be noted that it is not necessary to achieve sophistication in list structures to make use of them. List structures can be programmed in varying degrees of complexity tailor-made for the particular program. In programming for the Spacetrack mission, list processing was found to be efficient in terms of space and time and was a convenient way to visualize data transfers.

SYSTEM GROWTH

As with any experimental system, certain growth can be expected in the hardware configuration and in the sophistication and diversification of the programming effort. This expansion may be divided into two categories: that which is presently being implemented, and future planning. Present implementation includes transmission of pointing data in real time to a narrow-beam, short-range radar in Baltimore, Maryland. A high-speed (2,400-bit/sec) data link will provide communications. This service may be expanded in the future to provide similar data to other sites. Push-button input for control of program options is under development. This will allow faster response to requests. Program changes are being installed to allow automatic recognition of radar coverage changes and to recompute *S*-points based on this new sector.

Plans for future improvement and growth include: additional storage for system enhancement; a card reader-punch; and displays. Additional storage would allow an expanded ephemeris file when the known satellite population becomes much larger than the present 400 objects, and would be used to store different production programs which would time share with the operational program. A card reader and punch would allow a desirable re-orientation of our present paper tape system. A displays facility with computer control of a slide projector would allow a concise picture and quick human identification in most cases.

Fig. 6 — General block-to-block list with key references.



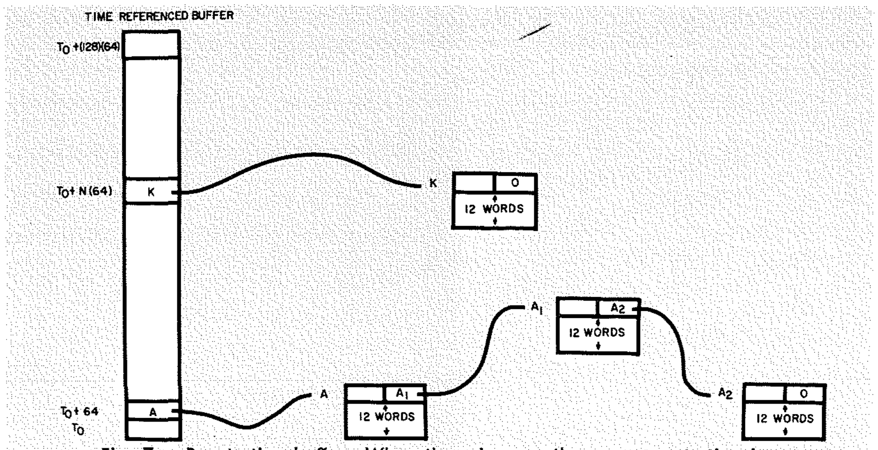


Fig. 7 — Penetration buffer. When there is more than one penetration in a 64-second time interval the penetration is chained. This Figure shows three penetrations at $T_0 + 64$ and one penetration at $T_0 + N(64)$.

CONCLUSION

The 4102-S SPASEC program has proved itself to be a flexible and reliable satellite surveillance program. Working as part of Moorestown Space Track facility, it has demonstrated its ability to identify satellites and direct the radar system in the collection, reduction, and forwarding of data. The use of this program has enhanced the operations of the Space Track mission and made this site one of the networks more important members.

ACKNOWLEDGEMENT

J. F. Russell assisted with the preparation of material presented herein.

BIBLIOGRAPHY

1. E. T. Garner and J. F. Russell, *Description of the 4102-S Space Track Program,* Technical Report SPA-1100-2A, 31 January 1964.
2. E. T. Garner, "List Processing Techniques Used in the BWEMS Engineering Model Building Space Surveillance Program," RCA Information Processing Symposium, Princeton, New Jersey, October 1963.
3. J. A. Cornell, "The RCA 4100 Series Military Digital Computers," RCA ENGINEER, *8*-6, April-May 1963.

INFRARED FIBER OPTICS

The phenomenon of transmitting visible light by multiple internal reflections along the walls of a glass fiber was described in previous papers[1,2] and throughout technical literature on fiber optics. Visible light, however, occupies only a portion of the useful electro-magnetic spectrum and most forms of glass will only transmit electromagnetic radiation of wavelengths less than 2.5 microns. The widespread application of infrared detection and imaging devices provides the need for longer wavelength transmission properties of fiber optic materials for the imaging of the infrared spectrum. While many materials can be used for infrared energy transmission, relatively few have properties to produce suitable infrared fiber optics. More recently, however, techniques have been improved for processing fiber optic materials for infrared applications, thus adding greater flexibility to the design of optical elements for infrared systems. This article describes the fundamentals and characteristics of infrared fiber optics, and their application to a line-to-raster converter that is believed to be the first coherent infrared bundle to be fabricated for a specific application.

N. ARON, Ldr, and L. ARLAN

Electro-Optical Engineering
Aerospace Systems Division
DEP, Burlington, Mass.

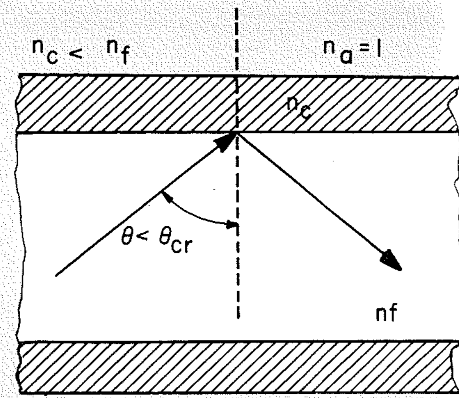


Fig. 1—Criteria for internal reflection in a fiber.

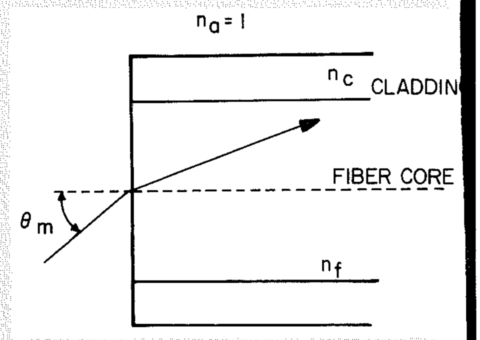


Fig. 2—Maximum acceptance angle.

THE transmission of radiation in fibers by multiple internal reflections is based on a simple physical principle. This is that total reflection of radiant energy at a boundary will occur if the index of refraction of the medium in which the radiation exists is greater than the index of refraction of the medium on the other side of the boundary (that which the radiation would normally pass into if not internally reflected back). Thus, if the radiation is in a medium of index n_f (the fiber core material) and the index of the material on the other side of the boundary is n_c (the fiber cladding material) the criterion for internal reflection is that $n_c < n_f$.

The index of refraction of the fiber material is such that any entering radiation incident on the internal fiber walls at an angle greater than the critical angle θ_{cr} is continually reflected (Fig. 1). The fiber optics thus acts as a smooth transparent cylinder transmitting the radiation by multiple internal reflections. The diameter of the rod must be larger than the longest wavelength to be transmitted. No substantial change occurs in the behavior of this phenomenon until the diameter of the rod becomes comparable to the wavelength of light (about 5 microns).

If many such fibers are gathered together into an orderly array, an image placed at one end will be transmitted to the other end, the fibers breaking up the image and transmitting each component separately. Transmission is improved by cladding each fiber with a coating that has an index of refraction n_c, which is lower than that of the fiber material n_f. The cladding prevents leakage or cross talk from one fiber to another.

Final manuscript received July 8, 1964

INFRARED FIBER OPTICS MATERIALS AND PROPERTIES

The infrared region covers a broad spectral span from roughly 0.8 micron to 100 microns, for practical purposes. As a result, most infrared materials transmit selectively in the infrared and do not, therefore, pass the radiation with equal efficiency at all wavelengths over the complete infrared spectrum. Some are difficult to fabricate into optical elements and some are even toxic and require special treatment and careful handling.

If to this is added the requirement that the material be capable of being drawn into a fiber, a severe limitation is placed on those materials which are otherwise acceptable. Some work has been done on germanate and calcium aluminate glasses[3] to extended infrared transmission out to about 5 microns, at least in short fiber lengths. However, the material that has thus far proven most suitable and easily drawn into fibers is arsenic trisulphide (As_2S_3) glass. This material, when clad with a modified arsenic sulphide (AsS), has exhibited spectral response in short lengths of 7 mm to a wavelength of 12 microns.

Fabrication Methods

The fiber is fabricated from a melt of arsenic trisulphide glass. The liquid glass is drawn through a die together with the cladding material. Extreme caution must be used in heating of the arsenic trisulphide glass when drawing the fibers, since it emits toxic fumes at a critical temperature of 300°F.

A method of fabricating the fibers into a coherent bundle draws the fibers around a drum in complete loops. These are then fixed in place by an epoxy before cutting and polishing to keep the fibers at each end in the same relative position and to maintain coherency between the input and output ends of the finished bundle. Since arsenic trisulphide does not transmit in the visible region, locating individual fibers to check bundle coherency is a problem. Minimum bundle fiber lengths are limited by drum size.

Use of Fibers

The fabrication of the infrared fibers into useful bundles invariably results in mechanical defects such as broken fibers, nonuniformity of fibers in cross-sectional dimension along the fiber length gaps between the fibers, and fiber displacement. Broken fibers reduce the total energy transmission, lower the resolution capabilities of the bundle in those

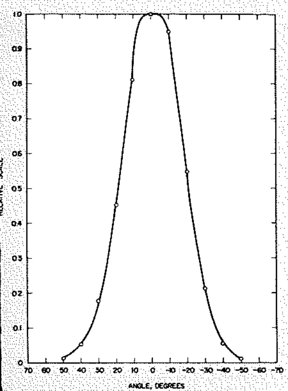


Fig. 3—Output radiation pattern for 4.8 inch long fiber optics bundle for normal incidence when angle subtended is 0.7°. (Ref. 4.)

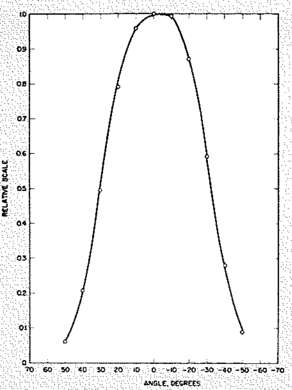


Fig. 4—Output radiation pattern for fiber optics bundle 4.8 inches long and 0.156 inch in diameter at normal incidence and using an f/1 lens.

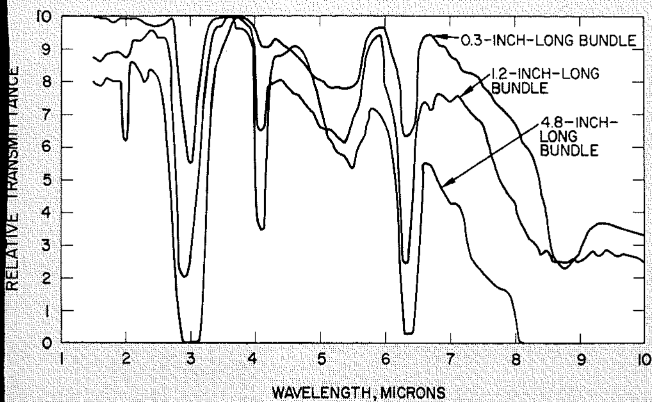


Fig. 5—Relative spectral transmittance of arsenic trisulfide fibers.

dead areas, and contribute to the background noise of a transmitted image. Breakage of fibers up to 1 or 2% of the total is common in bundles used in the visible spectrum. Present day state-of-the-art infrared fibers can experience up to 5% breakage. However, flexible infrared bundles have been made and flexed as many as 1.5 million cycles without sustaining any apparent damage.

Arsenic trisulphide fibers with diameters of 0.001 inch have been fabricated, but in most of the work that has been done the fibers used are approximately 0.002 inch (50 microns) in diameter with a cladding thickness that is about 10% of the core diameter. In addition to variation of fiber diameter between fibers of a bundle, a variation occurs in the cross-sectional area along the length of the fiber. This contributes to a spreading of the transmitted energy at the output end.

Gaps occurring between fibers and fiber displacement result in image resolution deterioration. Present state of the art for infrared fiber optics indicate a fiber displacement tolerance of ± ½ fiber diameter. Packing density can be increased by fusing the ends of the fibers together since distortion from the circular shape does not significantly affect the optical properties of the fibers.

CHARACTERISTICS OF FIBER OPTICS

The optical characteristics of the fibers are related to the physical properties of the fiber material and to its index of refraction. Those of greatest interest are usually the numerical aperture, the spectral response and the transmission. These characteristics together with the feasibility of producing fibers with the proper coating determine the infrared fiber optics material to be used for a specific application.

Numerical Aperture

The numerical aperture, NA, is a measure of the light-gathering ability of an optical device. For an optical fiber this is related to the maximum radiation acceptance angle θ_m (Fig. 2) which is a function of the indices of refraction of the core and cladding materials. The relationship for the numerical aperture is given by:

$$NA = \sin \theta_m \tag{1}$$

Where: $\theta_m = \sin^{-1}\sqrt{n_f^2 - n_c^2}$, and $\theta_m =$ maximum half-angle accepted, $n_f =$ index of refraction of fiber core material, and $n_c =$ index of refraction of fiber cladding material.

The range of numerical apertures available in fiber optics is limited only by the materials from which the fibers can be made. For visible bundles made of selected pairs of glasses, any value of numerical aperture to 1.2 can be fabricated. Infrared materials such as arsenic trisulphide glass have higher refractive indices; it is, therefore possible to obtain larger numerical apertures for the same coating-to-core refractive index ratio. If the arsenic trisulphide glass fiber whose index of refraction is 2.47 is coated with a lacquer having an index of refraction of 1.5, a nominal numerical aperture as high as 1.96 is achieved. On the other hand, with the arsenic trisulphide fiber coated with arsenic sulphide, the numerical aperture is 0.7.

Energy travels from the entrance end of the fiber to the exit end by means of total internal reflection. If the fibers were perfect, the entrance cone would be equal to the exit cone. However, since the fiber walls are not perfectly parallel and smooth, the output radiation pattern exceeds the entrance cone. The measured output radiation pattern for a 4.8-inch-long fiber optics bundle for normal incidence when the angle subtended is 0.7°, as shown in Fig. 3 and at normal incidence in Fig. 4. The curve spreads as the length of the bundle increases.

L. ARLAN graduated from Clarkson College of Technology in 1954 with a BSEE and from Drexel Institute of Technology in 1961 with an MSEE. He joined RCA in 1954 to work on system analysis for the shoran navigational bombing system and later for the TALOS missile radar ground station. Mr. Arlan performed development work for infrared detection and later for a slow scan, missile-borne television system. He also investigated the missile detecting capabilities of the infrared vidicon and image intensifier orthicon. He worked on the development and evaluation of a feasibility model infrared vidicon camera employing fiber optics and to be used for strike reconnaissance. As a project engineer, he performed initial feasibility studies, circuit design and system testing. Mr. Arlan is a member of Tau Beta Pi, Eta Kappa Nu and the IEEE.

N. ARON graduated from Northeastern University in 1940 with a BSEE and from Polytechnic Institute of Brooklyn in 1954 with an MSEE degree. Mr. Aron worked with the Signal Corps and later was in charge of a quality control group at the Western Electric Company. He taught electronics, optics, and mathematics at City College of New York and the RCA Institutes. He worked on circuit and logic design for the Electronic Computer Division of Underwood in 1953, and later on computer development at Sylvania Electric's Waltham Labs. He joined RCA in 1956. He has since been responsible for the development of several analog-to-digital conversion units using solid-state devices exclusively. He directed the development of a complete PCM telemetry system for small missile application and the development of an infrared seeker for missile application using television techniques. More recently he was program manager of the Vidicon Strike Reconnaissance Research Program. He is a senior member of the IEEE.

N. Aron

L. Arlan

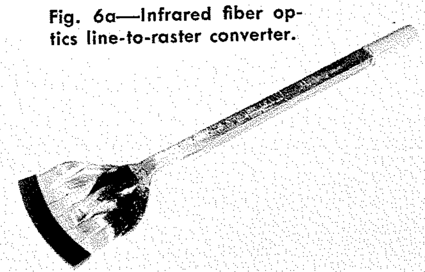


Fig. 6a—Infrared fiber optics line-to-raster converter.

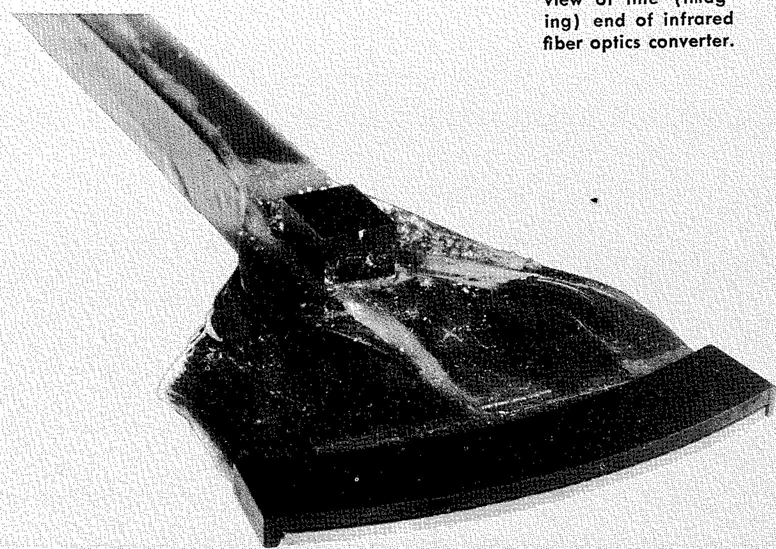


Fig. 6b—Enlarged view of line (imaging) end of infrared fiber optics converter.

Spectral Response

The relative spectral transmissivity of several lengths of arsenic trisulphide fiber bundles is shown in Fig. 5. There is very little transmission beyond 7 microns and there are absorption notches at 2.95, 4.1, and 6.3 microns.

Transmission

The overall transmission of an infrared fiber optics bundle depends on internal transmittance, dead areas due to packing density, broken fibers, the type of cladding material used, the efficiency of and anti-reflection coating used, and the length of the bundle.

The high index of refraction of arsenic trisulphide causes a considerable portion of the incident energy to be lost because of Fresnel reflection. For normal incidence at the air-glass surface, the reflectance for one surface only is given by:

$$R = \frac{(n-1)^2}{(n+1)^2} \qquad (2)$$

Where n = index of refraction of the core material. For arsenic trisulphide, whose index of refraction $n = 2.47$, Eq. 2 gives $R = 17.9\%$.

The absolute transmission per unit length is a function of cladding thickness and efficiency of anti-reflection coating. Best available data to date show the average internal transmittance in the 3.2-to-5.5-micron wavelength region is about 90% per inch of bundle length.

APPLICATIONS

Infrared transmitting fiber optics bundles can be either rigid or flexible. One of the most valuable applications for rigid bundles is for image conversion. For example, it is often desirable to use a slit pattern in the primary image plane and a circular pattern on a detector cell in the secondary image plane. This is easily achieved with a fiber optics converter. Another application is found in converting from a line to a raster for a television display. This enables a wide angle, high resolution image to be broken up into segments so that the detecting device will not limit the overall resolution.

Flexible fiber bundles can be utilized in infrared systems by transmitting the energy from a gimbaled optical system to a stationary detector and cooling system. Other uses might be found in the form of infrared fiber scopes for medical diagnosis where internal temperature differences can be detected and imaged.

In any application one of the most important considerations is overall transmission but other parameters such as cooling of the bundle and methods of efficient coupling of the fiber bundle to the detector or imaging device must be determined in order to utilize an infrared bundle in the best manner.

FIBER OPTICS LINE-TO-RASTER CONVERTER

An application of infrared fiber optics in a bundle configuration converts a line to a raster for a television display (Figs.

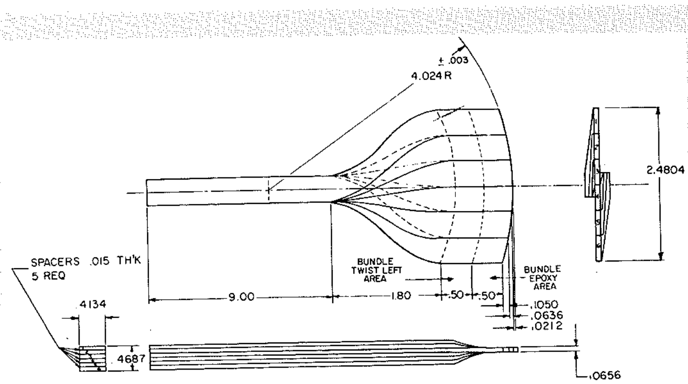


Fig. 7—Infrared fiber optics bundle.

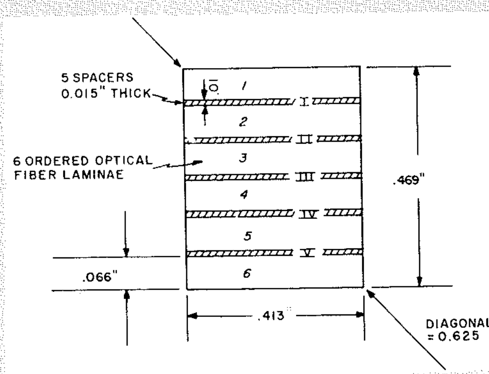


Fig. 8—Laminated end of infrared fiber optics bundle.

6a, 6b). Such a bundle[5] was fabricated of 0.002-inch-diameter arsenic trisulphide fibers for the purpose of obtaining a 0.94° by 36° field-of-view optical system. The wide-angle image is divided into six segments (Fig. 7) which are imaged on an infrared-sensitive device. The six segments are stacked one above the other to fill the sensitive surface of the device. A higher degree of overall resolution is thereby achieved than would otherwise be obtainable from a single line display on the imaging device. Spacers are used between the segments (Fig. 8) on the raster end of the fiber bundle to prevent garbling or carryover of information from one segment to another. Each segment has a rectangular cross section that is 0.4134 by 0.0656 inch and are displayed end to end to form a spherical rectangle that is 2.4804 inches long by 0.0656 inch high at the line end. The bundle length is 12 inches and was dictated by the method of fabrication rather than the application. For the application a shorter length would have been preferable to reduce optical transmission losses.

A photograph of the output or raster end of the bundle was made with Kodak spectroscopic type film which has a maximum sensitivity at 1.09 microns but is sensitive to 1.22 microns. The input end of the bundle was illuminated with a microscope illuminator. Fig. 9 shows the illuminated bundle taken at *f*/5.6 and an exposure of four minutes. The uniformity of the fiber diameters as well as that of the spacing or packing of the fibers is evident. The dark spots indicate either broken fibers or spaces between fibers. The nonuniformity of illumination or shading is attributed in part to variations in surface polish of the fibers.

Four visible fibers running the length of the bundle were added in the center of the top and bottom and of the extreme ends as an aid in optical alignment of the bundle in the system. Use of visible fibers for this purpose was possible in this system since the other primary optics consisted of all reflective elements. The sharp absence of transmission at the bottom center of the lowest segment in the photograph was produced by the tape necessary to block transmission of the visible fiber at this point. It is thought that future bundles would exhibit better uniformity of fibers by grinding and polishing each segment separately. Resolution of the fiber bundle was measured as being eight line pairs per millimeter.

Fig. 9—Infrared fiber optics converter illuminated on line end.

An orderly (nonrandom) fiber pattern acts as a raster. Hence, if used as an optical element in an electronic scan imaging system, it will generate spatial intermodulation products (beat patterns) in the recorded image if the distance between fiber centers is not small compared to the resolution element. Similar beat patterns will occur if cascaded rasters have the same center distance between fibers. Random placement of fibers of very fine fiber diameters would be indicated. At present there are no techniques to produce fully random fiber patterns and the fineness of the pattern is limited by the minimum available arsenic trisulphide fiber diameter of 0.002 inch. However, no beat patterns were noticeable in the use of this fiber bundle.

The transmission of an image from the end of a fiber optics bundle to the photosensitive surface located on the back of an image tube faceplate requires the use of a fiber optics faceplate to avoid loss of resolution, or the use of an optical relay lens to focus the image through the faceplate onto the photosensitive surface. If the radiation sensor requires cryogenic cooling, as do most sensitive infrared devices, the imaging must usually be performed through windows of a dewar. A better approach to imaging on the infrared sensor directly would be to butt the end of the fiber optics converter through windows and against a fiber optics faceplate of the photosensitive surface of the infrared imaging sensor. However, butting the fiber bundle against the faceplate of a cooled infrared image tube tends to raise the temperature of the photosensitive surface and also precludes the use of windows in the dewar. The end of the fiber bundle next to the faceplate would then have to be an integral part of the dewar. While this solution presents severe design problems, some simple preliminary experiments have been made to determine resistance of fibers to the thermal shock of cryogenic cooling.

Loose fibers of arsenic trisulphide immersed into liquid nitrogen did not shatter, crack, or craze. Furthermore, they could be readily bent while immersed in the liquid. Therefore, it is felt that with proper thermal design fiber optics assemblies can be built capable of successfully operating at cryogenic temperatures.

CONCLUSIONS

Most of the work done in infrared fiber optics has been directed toward the fabrication of arsenic-sulphur coated arsenic trisulphide fibers because of useful transmission properties of these fibers in the short and medium wavelength infrared regions. Present day technology has resulted in the fabrication of coherent bundles but degradation of overall transmission and resolution due to minimum available fiber size, fiber breakage, fiber spacing, and fiber uniformity all result in fiber bundles which cannot compare favorably to present-day visible fiber optics bundles. However, improved fabrication techniques and usage of other materials should result in higher quality fiber optics bundles for use throughout the infrared spectrum. The fiber optics converter discussed in this article is believed to be the first coherent infrared bundle to be fabricated for a specific application. As with every state-of-the-art development, experience has indicated better fabrication techniques and methods.

ACKNOWLEDGEMENTS

This acknowledges the contributions of L. Sachtleben in the optical design of the coherent bundle and of R. C. Guyer in the mechanical design.

BIBLIOGRAPHY

1. Leo J. Krolak, "Fiber Optics for High-Resolution Displays and Pickup Systems," RCA ENGINEER, 7-3, Oct.-Nov. 1961.
2. Leo J. Krolak, "Fiber Optics—Valuable Engineering Principle," RCA ENGINEER, 4-1, June-July 1958.
3. Walter P. Siegmund, *Fiber Optics: Principles, Properties and Design Considerations*, American Optical Co., July 1962.
4. R. Standel, *Infrared Fiber Optics Measurement Program*, Progress Report on Hughes Aircraft Co.-Sponsored Infrared Fiber Optics General Research Program, July 17, 1963.
5. This development was the result of an effort in cooperation with American Optical Co., Southbridge, Massachusetts, and was sponsored by the Reconnaissance Laboratory of the Air Force Systems Command, Aeronautical Systems Division, Wright Patterson Air Force Base, Ohio, on Contract No. AF33(657)-7986.

ELECTRO-OPTICAL SIGNAL PROCESSING

Effective utilization of image-scanning sensors (for example a TV pickup tube) in automatic electro-optical systems for detection, acquisition, tracking, and recognition requires signal processing equipment for extraction of desired information. Several signal processing techniques have been successfully implemented for use with both standard and slow-scan systems. This paper describes such techniques, including point-source and extended-background discrimination, image motion processing, and coordinate generation, and includes data on performance and applications to electro-optical systems.

M. J. CANTELLA and R. KEE

Electro-Optical Engineering
Aerospace Systems Division
DEP, Burlington, Mass.

IMAGE-SCANNING sensors, such as television pick-up tubes, have wide application in automatic systems for detection, acquisition, tracking, and recognition. These sensors are particularly desirable because of their high sensitivity, large capacity for information storage, and high-speed sequential readout. Information on image intensity, shape, position, and velocity is acquired rapidly and unambiguously.

Full utilization of image scanning sensors in electro-optical systems requires signal-processing equipment for automatic filtering and decision making. Functions performed by signal processors include noise discrimination, spatial filtering, velocity filtering, and coordinate generation. Techniques for implementation of these functions must be rapid and efficient to be compatible with the sensor. The techniques described herein have been implemented successfully for use with sensors operating at normal and slow scanning speeds.

SPATIAL FILTERING

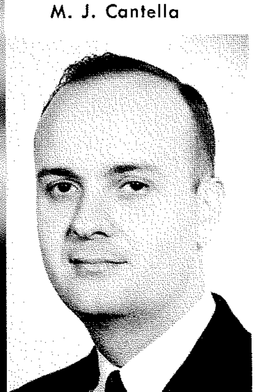
In a TV pick-up tube, spatial distributions of irradiance are converted to temporal patterns by convolution of the charge patterns on the storage surface with a scanning electron beam. Automatic spatial filtering requires that the output signal be processed to recognize

Final manuscript received August 24, 1964.

MICHAEL J. CANTELLA received his BEE degree and Ensign, USN commission from Rensselaer Polytechnic Institute in 1954 and his SMEE degree from Massachusetts Institute of Technology in 1959. From 1954 to 1957, Mr. Cantella served with the U.S. Navy and attended MIT Graduate School from 1957 to 1959. Mr. Cantella was employed by MIT Lincoln Laboratory and worked on the MIT Research Staff. His experience includes the design of transistorized circuits for a high-speed digital computer and the design and instrumentation of high-vacuum apparatus. Mr. Cantella joined RCA in 1959. His experience includes system analysis, technique development, and equipment design for various radar and electro-optical systems. He has developed special modes of operating image tubes and techniques for background discrimination. He is currently a member of the electro-optical engineering section at ASD and is responsible for a program for the development of semi-active systems utilizing lasers and image tubes. Mr. Cantella is author of several technical papers and is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the Society of Motion Picture and Television Engineers.

R. C. KEE received his BSEE degree from Worcester Polytechnic Institute in 1955 and his MSEE from Northeastern University in 1961. His professional experience includes assignments in audio facilities development, metallurgical and acoustical research at Bell Telephone Labs. Since joining RCA in 1956, Mr. Kee has worked on the design and development of magnetic modulator and transistor circuits for airborne conversion equipment, the design of logic and digital circuits for weather balloon telemetry, and the design of transistor circuits for video tape servo and infrared seeker systems. He completed work on Video Image Processor circuits and logic for a satellite borne Optical Tracker. Recently he directed the design of circuits and logic for a master timer synchronizer and slow-image motion processor subsystems for the AN/FSR-2 Optical Surveillance System. At present he is designing low-weight, high-efficiency DC-to-DC converters and DC-to-AC inverters for the LEM project using semiconductor and magnetic techniques. Mr. Kee is a member of IEEE, Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

M. J. Cantella



R. Kee

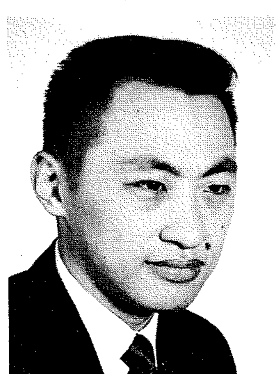


Fig. 1—Discriminator for horizontal dimension.

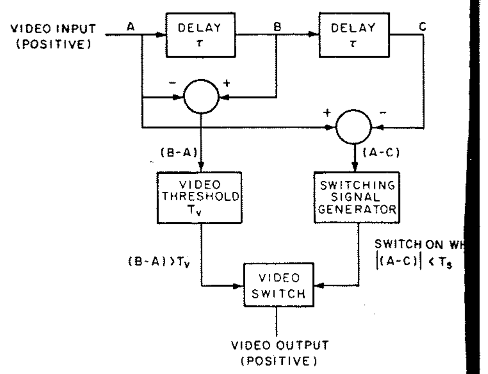


Fig. 2—Magnitude and phase vs. frequency characteristics of delay/difference filter.

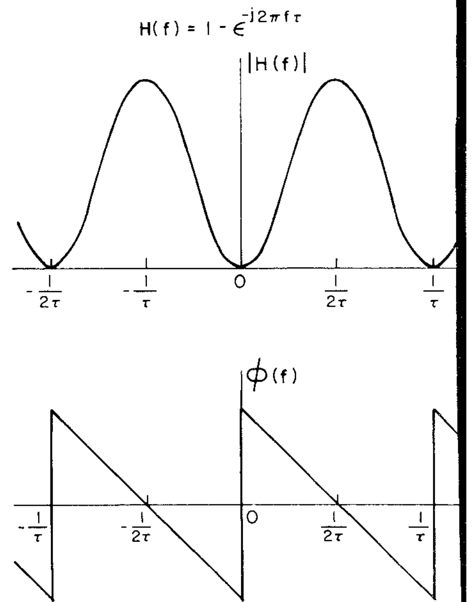
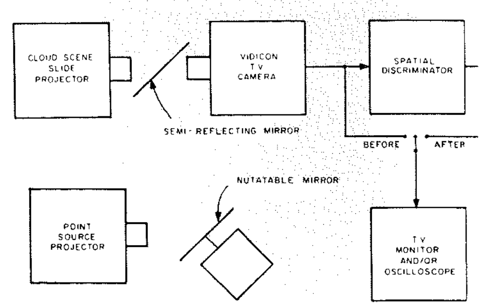


Fig. 3—Configuration for discriminator evaluation.



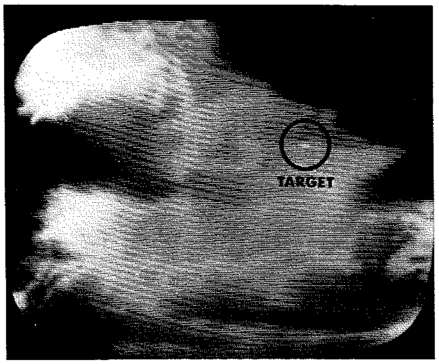


Fig. 4—Scene 1: video displayed on monitor.

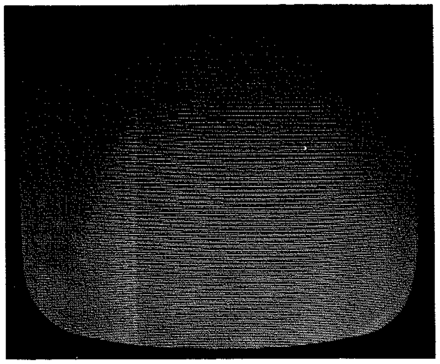


Fig. 5—Scene 1: discriminator output displayed on monitor.

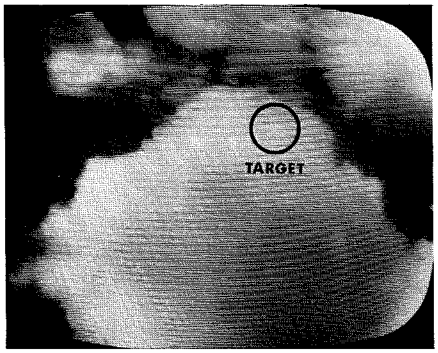


Fig. 6—Scene 2: video displayed on monitor.

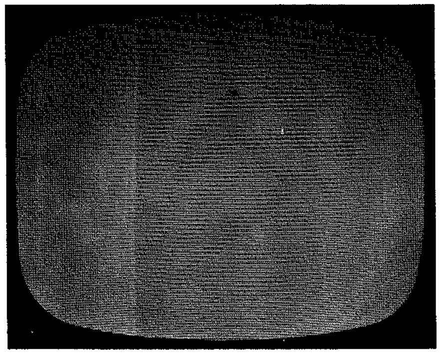


Fig. 7—Scene 2: discriminator output displayed on monitor.

waveforms corresponding to patterns of interest. The scanning raster converts two-dimensional information to amplitude versus time. Generally speaking, the recognition process must compare video amplitude at several points in time in order to make a discrimination between desired and undesired pieces of information.

The technique to be described was developed to process the output of a TV pick-up tube to detect automatically the presence of a point source in a cloud background and eliminate the cloud background. Design of the discriminator is based on a time-domain synthesis technique which utilizes delay lines to provide waveform sample points for discrimination decisions. Synthesis in the time domain permits straightforward implementation of both linear and nonlinear functions. The linear functions are compatible with frequency-domain concepts of filtering. This basic technique can be extended to even more complicated discrimination functions.

Fig. 1 is a block diagram of the discriminator which makes decisions based on illumination patterns in the direction of the scanning raster (horizontal). Discrimination in the vertical direction is an extension of this basic technique. The major difference between the wanted and unwanted waveforms is that of video pulse width. The desired point-response waveform is narrow, while the waveforms from cloud backgrounds are relatively wide.

Delay-line pulse-width selectors, for pulse trains composed of isolated pulses, are given in the literature.[1] There is, however, a substantial difference between the usual pulse-width discrimination requirement and the requirement for detection of a point target in a cloud background. In the latter case, the narrow-width pulse must be detected while superimposed on relatively high-level and high-gradient cloud-background signals. To eliminate most of the video level produced by the cloud background, successive delay-time taps are connected to the inputs of a difference amplifier. The delay-difference filter is used as a basic building block and is compatible with frequency-domain concepts.

By taking the Fourier transform of the impulse response, it can be shown that the transfer function $H(f)$ is:

$$H(f) = 1 - \exp(-j^2\pi f\tau)$$

Expressed in terms of the magnitude and phase functions:

$$|H(f)| = 2(1 - \cos 2\pi f\tau)$$

And for $0 \leq f \leq 1/\tau$:

$$\theta(f) = -\pi f\tau + \frac{\pi}{2}$$

And for $-1/\tau \leq f \leq 0$:

$$\theta(f) = -\pi f\tau - \frac{\pi}{2}$$

Sketches of magnitude and phase vs. frequency are shown in Fig. 2.

From the standpoint of optimum filtering in the frequency domain, the delay-difference filter has the proper basic magnitude-frequency characteristic. The frequency components of interest from a point target occur in the range $-1/\tau < f < 1/\tau$. The amplitude frequency characteristic from extended cloud backgrounds are approximately $1/f^k$ in form. The system resolution and delay (τ) would be so chosen that most of the energy from the cloud background would fall in the vicinity of the zero-frequency null of the delay-difference filter, and most of the energy from the point target would fall within the band-pass region of the delay-difference filter. In this manner, the target-to-background ratio can be maximized.

Frequency-domain synthesis is limited to linear systems, and design criteria are based on energy components from

TABLE I: Summary of Mathematical Discrimination Criteria

	Limiting Conditions for Discriminator Output	
Type of video waveform	$W<2\tau$	$W>2\tau$
Isolated Video Pulse	$\frac{P}{T_v} > 1$	$\left(\frac{2\tau}{W}\right)\left(\frac{P}{T_v}\right) > 1$
Point Target in a High-level Background	$\frac{P}{T_v} > 1$	$\left(\frac{2\tau}{W}\right)\left(\frac{P}{T_v}\right) > 1$
Point target in a constant-gradient background	$\frac{P}{2m\tau} > 1$ and $2P\left(1 - \frac{\tau}{W}\right) > T_v + 2m\tau$	$\frac{2P}{mW} > 1$ and $\tau\left(\frac{2P}{W} - m\right) > T_v$

desired and undesired classes of waveforms as observed in the frequency domain. Time-domain synthesis permits direct analysis of the waveforms in question and permits direct accomplishment of both linear and nonlinear operations.

Beyond the linear delay-difference filters, two nonlinear operations are accomplished. One operation is a video threshold which requires that the difference waveform be positive and above a minimum amplitude. The other nonlinear operation requires that the other difference signal be below some maximum amplitude. If and when both of these conditions exist simultaneously, an output is obtained indicating the presence of a point source. This discrimination logic precludes any other class of video waveform from yielding an output and permits detection of the point source even when superimposed on high-level and high-gradient backgrounds.

A mathematical analysis has been made to predict discriminator performance in several types of backgrounds. The point response of the system was assumed to be approximately triangular and of amplitude P and width W. Discriminator parameters are delay time T, video threshold T_v, and switching signal T_s. One background parameter considered was the slope m. The results of this analysis are given in Table I. These results indicate that:

1) The detectability of a point source increases with increasing amplitude P and decreases with increasing video threshold T_v. The ability to reject the crests of waveforms increases with increasing video threshold and decreases with video amplitude. Optimum threshold setting requires a trade off between probability of detection of a point target and false alarm rate from waveform crests.
2) Constant, high-level backgrounds neither decrease the detectability of point targets nor cause false alarms. The ability of the discriminator to reject high-level backgrounds is a result of the difference technique and is limited, in a practical sense, only by the dynamic range of the system and the accuracy with which the difference operation can be performed.
3) Constant-gradient backgrounds reduce the detectability of a point target but do not produce false alarms. The degradation in detectability is not serious in a system capable of high resolution.
4) Detectability of a point source depends upon the relationship between the width of the point response W and the length of the delay lines τ. Optimum performance is realized for $W = 2\tau$.

Performance of the discriminator has been measured with a target/background simulator. The experimental configuration is depicted in Fig. 3. The simulator is capable of projecting, on the faceplate of a vidicon, a point source superimposed on a cloud background obtained from a photographic slide. Brightness of the point source and cloud background can be adjusted independently and the point source can be positioned on any part of the cloud scene. Video output from the vidicon camera chain is passed through the discriminator. The video output either preceding or following the discriminator can be displayed on a monitor and an oscilloscope.

Monitor photographs illustrating discriminator performance with two representative cloud scenes are presented in Figs. 4 through 7. In both of these scenes, the point source was approximately 10^{-4} times as bright as the average total illumination of the background. No false alarms were produced by the background and detection of the point source was accomplished easily over almost all parts of the scenes.

This technique for spatial discrimination has recently been extended to include both vertical and horizontal dimensions. Two-dimensional discrimination is accomplished sequentially in two steps. The sensor is first scanned in one direction and the output of the delay line discriminator is written on a storage tube. The storage tube is then read while scanning orthogonal to the direction of the written information and the output is again passed through the delay line discriminator.

From the theoretical and experimental results obtained, it is concluded that the high data rate capability of the electronic discriminator combined with a high-resolution image sensor such as a *TV* pick-up tube provide particularly good performance in wide field-of-view detection, acquisition, and tracking systems.

VELOCITY FILTERING

Many image-scanning systems require sorting of video data on the basis of velocity. Velocity can be measured by making comparisons between successive frames to measure displacements of objects in known time intervals. The required velocity filter functions are shown diagrammatically in Fig. 8. Frames *1* and *2* are separated in time by a known interval T. This system has associated with it a high-pass velocity filter characteristic as shown in Fig. 9. The cutoff velocity V_c is determined by the comparison interval T and the ideal-

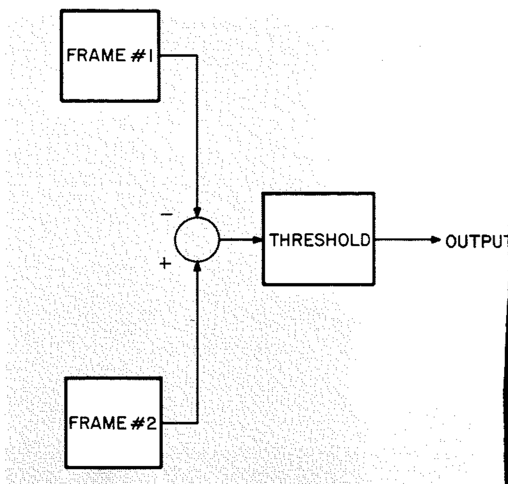


Fig. 8—Typical velocity filter.

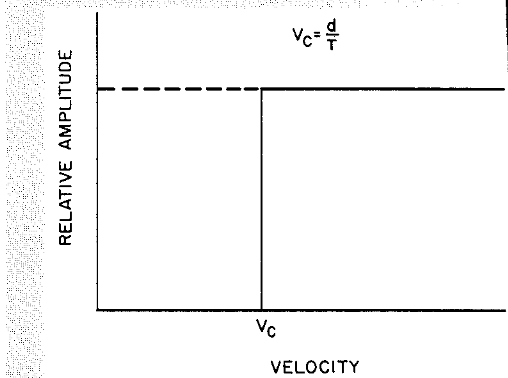
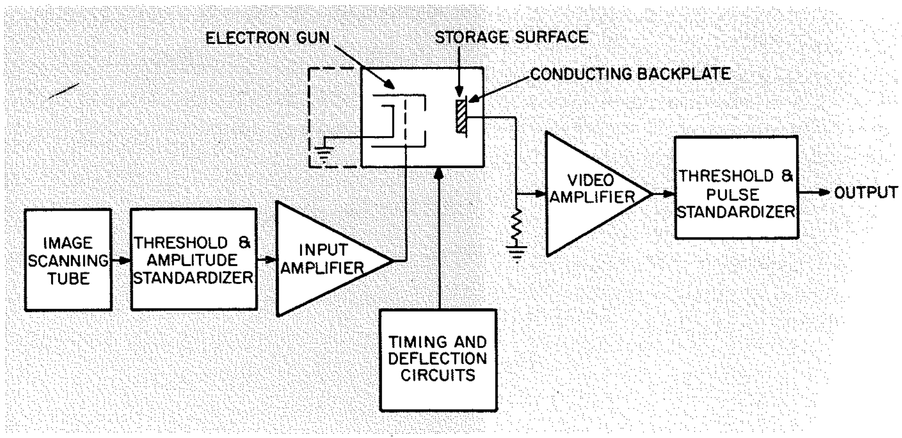
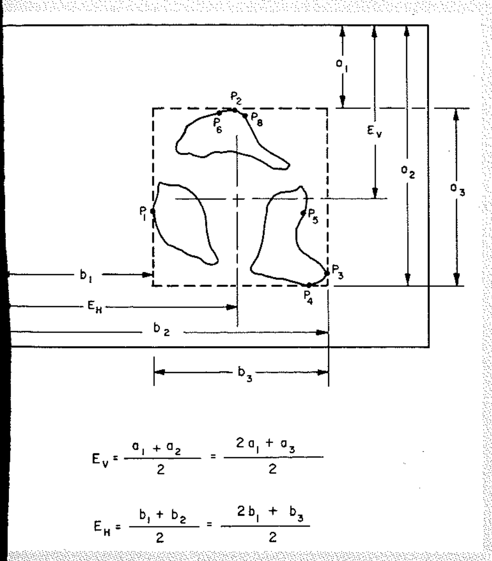


Fig. 9—Velocity cutoff characteristic.

Fig. 10—Electrostatic storage system for star background cancellation.





$$E_V = \frac{a_1 + a_2}{2} = \frac{2a_1 + a_3}{2}$$

$$E_H = \frac{b_1 + b_2}{2} = \frac{2b_1 + b_3}{2}$$

Fig. 11—Tracker principles of operation.

ized diameter d of a system resolution element. Multiple comparisons with different intervals can provide velocity bandpass characteristics.

Any one or a combination of several methods can be used to implement velocity filters. Basic functional elements include data storage, delay, and comparison. In principle, the filter can be made of circuit components or be implemented with a computer. Considerable success has been attained in the use of electrostatic and magnetic storage media and in analog and digital methods of video comparison.

Electrostatic storage tubes are particularly attractive components for use with image scanning sensors because storage capacity, resolution, writing speeds, and data location are fully compatible. Both two-tube and one-tube systems are feasible. In a two-tube system, frames of video information are written and stored alternately on each tube. Between each successive write-in sequence, the two tubes are read out simultaneously, and video comparison and thresholding are accomplished with external circuits. In the one-tube system, two or more frames of video information are superimposed on the same tube in an equilibrium writing mode. The write-in signal is used for video output and contains only the differences between presently written information and all previously stored information. In this manner, the functions of storage and comparison are accomplished directly within the tube. A basic block diagram of a one-tube system for star-background cancellation in an optical surveillance application is shown in Fig. 10. In addition to the functions shown, the tube is periodically erased, and the video is gated.

Magnetic storage media are particularly useful for relatively long term storage. However, writing speeds are generally lower and information indexing is somewhat more cumbersome.

From the experience obtained thus far, it is concluded that velocity filtering of video information can be accomplished most efficiently and effectively at the signal processing level.

COORDINATE GENERATION

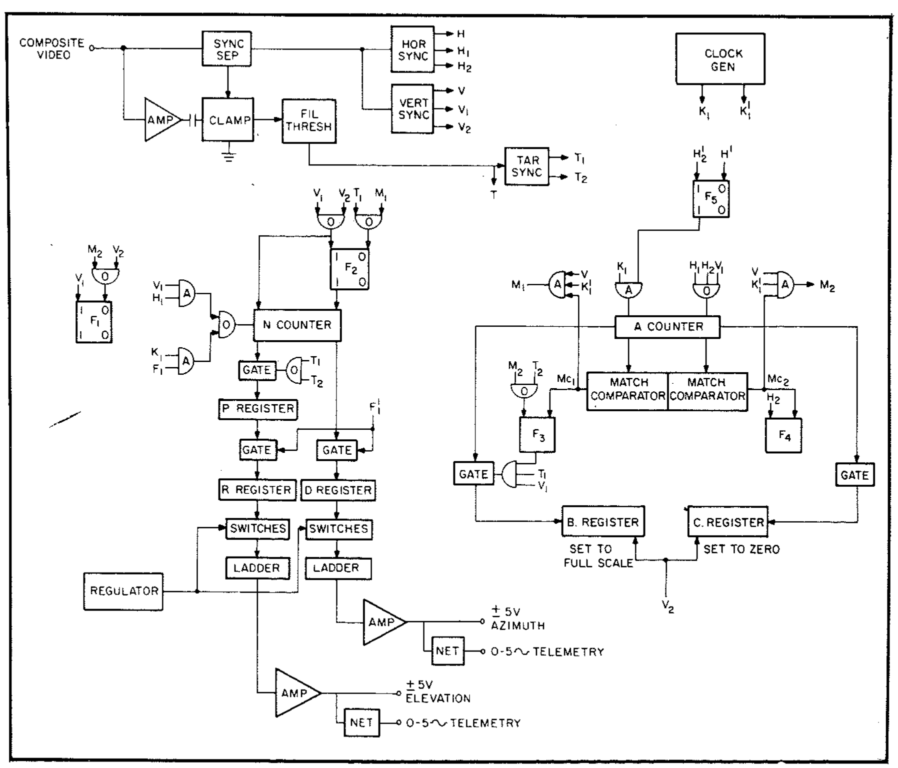
Automatic generation of positional information is vital to many electro-optical systems. This positional information can be used for closed and open loop tracking of point and extended images and for determination of detailed properties of extended images such as size, shape, aspect-angle, and range.

Coordinate generation is accomplished by combining video information with the timing signals of the scanning system to produce x-y data from each frame. Both analog and digital methods have been implemented with a high degree of success.

A digital, optical tracker for use with an image scanning sensor will be described in detail. This tracker is capable of providing the coordinates of the geometric center of an extended image outline and is applicable to single and multiple objects.

Fig. 11 illustrates the principles of operation of the tracker. The signal processing is done digitally using a composite video waveform from the sensor. As the camera scans the field of view, the composite video output will essentially be at black level except for the times the scan crosses the target area. At the start of scanning from the top of the field of view, the first line that contains target video will be the line that crosses point P_2, i.e., a_1 lines from the top. The last line that will contain target video will be line A_2 which crosses point P_4. The number of lines, a_1 and a_2, could be added and divided by two to obtain the desired vertical error E_v. However, E_v may also be obtained by adding $2a_1$ to a_3, and dividing by two. This latter method is more desirable from a component standpoint since a single counter may be used to do the computation. By counting two into the counter for every line in a_1 and then counting one into the same counter for every line in a_3, a total of $2a_1 + a_3$ is obtained in the counter at the end of the scan. The desired output, $(2a_1 + a_3)/2$ is obtained by shifting the contents of the counter one bit to the right at the time information is transferred to the store register. In a similar fashion, E_H may be obtained by counting two into a counter for b_1 block pulses along the horizontal line and to count one into the same counter for b_3 clock

Fig. 12—Tracker system block diagram.



pulses provided, of course, that the horizontal scan is divided into fixed time increments as defined by the clock pulses.

Fig. 12, shows the functional operations within the system. The incoming composite video waveform as delivered by the TV camera enters a separator circuit and amplifier. The separator obtains the horizontal sync from the composite video. The horizontal sync is used by the horizontal and vertical synchronizers and also to generate a clamping pulse to reference the output of the amplifier to ground during the black level time. The horizontal sync pulses are synchronized to the internal clock, and other timing pulses are derived within the horizontal and vertical synchronizers. The video signal is filtered, thresholded, and synchronized to the internal clock to transform it into a standard logic waveform T. The target synchronizer derives digital signals representing the leading edge T_1 and trailing edge T_2.

The vertical coordinate E_v is computed in the N-counter and B register. At the beginning of the vertical scan, the N-counter (a 10-bit binary flip-flop counter) is reset to zero and starts to count two into the counter for every horizontal sync pulse. Flip-flop F_2 controls whether the counter counts two or one for every horizontal pulse input; F_2 remains in the *1* state from the top of the scan to the first line containing target video. Thus, the N counter accumulates $2a_1$ counts. At this time the F_2 flip-flop changes to the *O* state and all remaining horizontal sync pulses add only one count into the counter. The number in the N-counter is transferred to the P-register for each horizontal line containing target video. Therefore, at the end of the frame, the P-register will contain whatever count was accumulated in the N-counter at the time point P_4 was scanned, since P_4 was the last target video observed for the frame. This count is the desired number $2a_1$ and a_3 and is left stored in the P-register until the end of the frame. At this time, the number in the P-register is transferred and shifted one bit to the right and stored in the R-register where it will remain until the end of the next frame, at which time it will be updated. The R-register is a flip-flop register which now contains the desired number $(2a_1 + a_3)$ / 2 in digital form. A ladder network of precision resistors converts the digital number to an analog voltage representing the vertical coordinate.

Computation of the horizontal coordinate is more difficult because each line must be examined to locate target video and each line containing target video must be compared to preceding lines containing target video in order to obtain the extremities of the outline of the target. Fig. 12 shows a target with one horizontal target extremity P_1 on a different line than the other extremity P_3. Storage is required to remember the minimum and maximum target extremities. The horizontal computation is accomplished first by dividing the horizontal scan into approximately 128 increments. At the beginning of a frame, the A-counter (Fig. 13) and the C-register are set to zero, and the B-register is set to full scale. The A-counter counts clock pulses. During each clock period, the number in the A-counter is compared with the numbers in the B-register and C-register by means of comparator networks. The comparator networks generate an output only when the two binary numbers being compared are identical. Therefore, each comparator will generate an output sometime during each horizontal line. Flip-flop F_3 indicates when a number in the A-counter is identical to the number in the B-register. It is set to a *1* state at the beginning of each horizontal line and is set to a *0* state when the identity occurs. In a similar fashion, the F_4 flip-flop indicates that a number in the A-counter is identical to the number in the C-register. The number in the A-counter is transferred into the B-register at the instant the front edge of the target video occurs provided the F_3 flip-flop is a *1* at that instant. The number left in the B-register at the end of what horizontal line will then be the target video edge position of that line only if it is smaller than the number previously transferred into the B-register. The B-register was set to a "full scale" at the beginning of the frame and, therefore, the first target edge position will be inserted into the B-register (position P_2 in Fig. 12). When the next line of video occurs, P_6 position will be transferred to the B-register because it will occur before the match of position P_2, since P_6 is a smaller number. The number left in the B-register will be position P_1 which equals b_1. Similarly, the lagging edges of target video are measured by transferring the number in the A-counter to the C-register only if the lagging edge of target video occurs after an identity between the numbers in the A-counter and C-register. Then the extreme right edge of the target video (equal to b_2) is stored in the C-register at the end of the frame. With b_1 in the B-register and b_2 in the C-register at the end of the frame, the desired horizontal error may be obtained by averaging b_1 and b_2. This is accomplished in the N-counter which was previously used to compute the vertical error and may now be used for combining b_1 and b_2. The N-counter and the F_2 flip-flop is reset to zero at the end of the frame. Clock pulses are accumulated by counting two counts into the N-counter for every clock pulse. During this time the A-counter is also counting clock pulses. When there is an identity between the numbers in the A-counter and the B-register, the signal M sets F_2 to zero so that the N-counter will now count only one count for each clock pulse. When there is an identity between the number in the A-counter and C-register, M_2 is generated to reset flip-flop F_1, which in turn inhibits its clock pulses K_1 from entering the N-counter. At this time, the N-counter contains the number $(2b_1 + b_3)$. This number is now shifted one bit to the right and transferred to the D-register. Thus, the D-register contains $(2b_1 + b_3)$ /2. The D-register, like the R-register consists of flip-flops that are used to control a ladder network to obtain an analog horizontal coordinate. The D-register is also updated at the end of every frame.

If the tracker receives a frame of video without target information, a *no-target* signal is generated. This is done with flip-flop Z_2 which initially is set to a *0* state at the beginning of each frame and will be set to a *1* state if a target video signal occurs. The Z_2 flip-flop output is sampled at the end of each frame.

The digital optical tracker has been fully evaluated. It is concluded from the results that highly accurate and reliable positional information can be obtained automatically from image scanning sensors.

CONCLUSIONS

Signal processing equipment has been used effectively in electro-optical systems to provide vital functions of noise discrimination, spatial and velocity filtering, and coordinate generation. These functions are accomplished rapidly and efficiently by hybrid combinations of analog and digital techniques. Signal processors can be used with image scanning sensors in a variety of automatic and semi-automatic systems for detection, acquisition, tracking, identification, and sorting.

BIBLIOGRAPHY

1. J. Millman and H. Taub, *Pulse and Digital Circuits*, McGraw-Hill, 1956, pp. 309-315

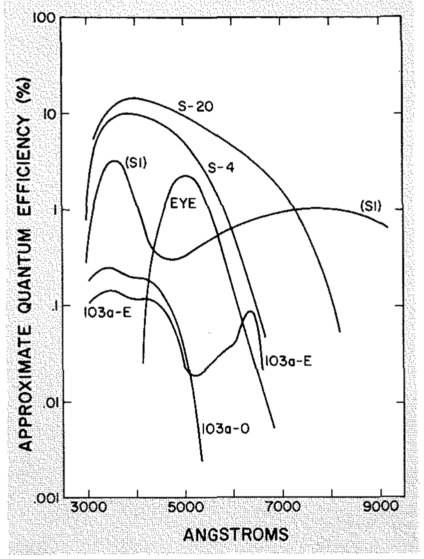
ASTRONOMICAL IMAGE SENSORS

High-altitude rocketry, satellites, and high-altitude balloons offer means for overcoming the limitations that the atmosphere places on ground-based astronomical sensors. This paper reviews the progress made to date on these new approaches to astronomical sensors and points out their special problems as well as their advantages. Discussed are imaging sensors, signal-generating sensors, pickup devices, and systems applications such as the Stratoscope I and II balloons, telescope orientation, and the possibility of using television to present visual data directly on the ground from an orbiting telescope.

L. E. FLORY*

Astro-Electronics Applied Research Laboratory
Astro-Electronics Division
DEP, Princeton, N. J.

Fig. 1—Relative quantum efficiencies of some photoelectric and photographic sensors. (After William A. Baum.)



ASTRONOMY, unique among the sciences, depends entirely upon observation and analysis with no opportunity for experimental verification. It is, therefore, entirely dependent upon its ability to overcome the limitations in its observational instruments and methods. With the exception of a few nearby objects such as the sun, the moon and the brighter planets, the quest for new knowledge centers around the detection of fainter and fainter objects. Thus, the sensors employed are almost always required to work at or near their threshold. Sensor sensitivity is therefore a fundamental limitation. A second limitation encountered by the astronomer is that interposed by the earth's atmosphere which absorbs some of the radiation from distant objects (completely absorbing the far ultraviolet), creates a spurious background due to atmospheric ionization and light diffusion and, lastly, introduces a time variant optical effect know as "seeing" due to convection and turbulence of the atmosphere.

To overcome "seeing", astronomers have long sought out mountain peaks to place their instruments outside as much of the atmospheric effect as possible. Recent techniques utilizing ballistic vehicles, orbiting devices and high altitude balloons offer at last a possibility of overcoming atmospheric effects, but place an additional requirement on sensing devices because of the separation of the sensors from the observers. Some means of telemetry of the information is required in this type of operation.

Aside from direct visual observation, the photographic plate has been the accepted recording medium for astronomical information although photomultipliers have in recent years come into almost universal use where photon reception from a single point is to be measured and a two-dimensional image is not required.

Photoelectric sensors offer two fundamental advantages over photographic methods. First, the quantum efficiency of the photoelectric process is many times ($\cong$ 100) more efficient than the photographic emulsion.[1] Second, the photoelectric process is perfectly linear and does not suffer from the reciprocity failure of photographic plates. This characteristic can account for an additional factor of the order of ten times at threshold. Fig. 1 indicates the relative efficiencies of several types of sensors.

IMAGING SENSORS

Many astronomical observations require a two-dimensional presentation and thus require some type of imaging device. For example, a study of galaxies requires a simultaneous presentation of all image points in the field to properly quantitate the light distribution. Since a mechanical scanning by a photomultiplier detector would be too time consuming to benefit from the efficiency of the photoelectric process, some type of electronic imaging device is required. Considerable work has been done with direct image converters on ground-based telescopes.[2] These devices consist of an extended area photocathode, an electronic focusing means and some means of converting the electron image back to a visual image. This means can be: 1) direct impingement of the electron image on a photographic emulsion inside the tube; 2) passage of high velocity electrons through a thin window to impinge on a photographic emulsion outside the tube; 3) excitation of a phosphor inside the tube and exposure by light of a photographic emulsion either through an optical system or by close proximity of the emulsion to the phosphor screen. A sensor of this type depends for its gain in threshold signal to-noise ultimately on the superiority of the quantum efficiency of the photoelectric emitter over the photographic emulsion. To realize this advantage, however, some gain mechanism must be provided to raise the signal level to a point where it can overcome the signal-to-noise limitation of the ultimate photographic recording. This is generally done in one or more of four ways:

1) Acceleration of the photoelectrons to increase their energy before striking the emulsion or phosphor;
2) Electron optical reduction of the image to increase the current density;
3) Passing the electron image through one or more stages of secondary emission; and
4) Cascading two or more stages using optical coupling between phosphor and photoemitter.

By these various methods it has been possible to observe the full gain of the photoelectric process, limited in some cases by the restriction of the resolution of presently available tubes.

SIGNAL GENERATING SENSORS

While the direct-image conversion offers a means of realizing the efficiency of the photoelectric process in an imaging device, for several reasons a signal generating sensor is attractive in spite of its complexity: 1) integration of the signal over long periods can be accomplished electrostatically ahead of the signal generation; 2) the integrated signal can then be handled by electrical methods with the possibility of automatically extracting information difficult to obtain by other means; 3) many applications require the radio transmission of the information so its availability directly in electrical form without the

---

Final manuscript received November 6, 1964
* Mr. Flory is a *Fellow* of the RCA Laboratories

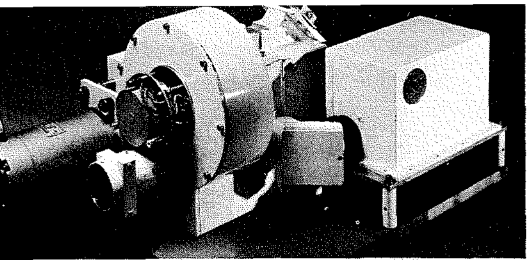


Fig. 2—A vidicon camera used in conjunction with a photographic camera on Stratoscope I.

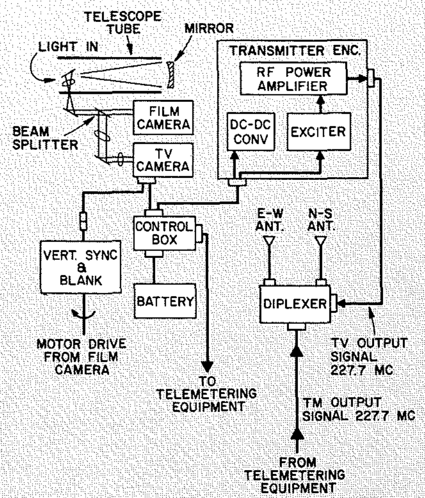


Fig. 3—Television system on Stratoscope I.

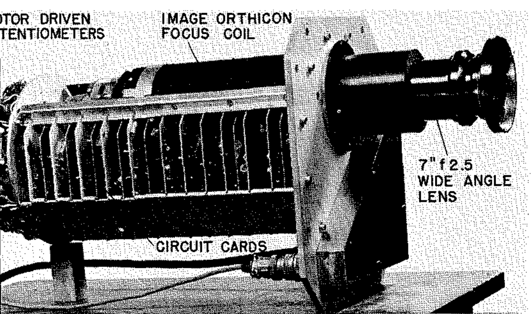


Fig. 4—Image orthicon camera as designed for Stratoscope II.

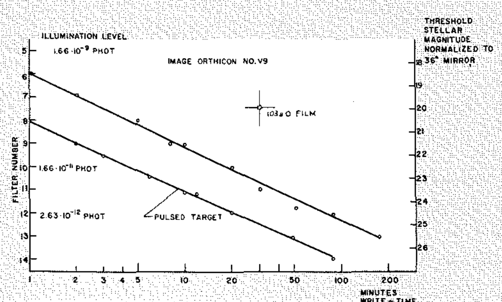
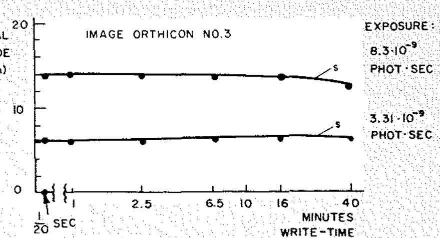


Fig. 5—Limiting stellar magnitude vs. exposure time for integrating image orthicon.

Fig. 6—Integrating image orthicon response for equal total exposures taken at different exposure times.



intervention of a photographic process is desirable.

The type of sensor used for astronomical imaging depends upon the exact use to which it is put. For the detection of faint stars, the images are not resolved and the amount of light in the faint image is a direct function of the area of the lens. In case the diffraction image formed by the optics is larger than a picture element of the television system, the signal produced by the pickup device will be dependent on this image size and thus indirectly upon the focal length of the optics. This condition does not usually occur, however, and the signal from a star is dependent only upon the area and the efficiency of the optical system. Astronomical optical systems for stellar observations usually have rather long focal lengths for two reasons. First, it is impossible to make optics of large aperture in short focal length since even in a reflective system the minimum theoretical f number is 0.5 and the practical one somewhat larger. So the focal length of astronomical optics is usually many times the diameter (i.e., 10 to 200 times). Another reason for a large f number in optics designed for observation of faint sources is to reduce the effect of sky background. As was pointed out, to a first order the signal from a faint source is dependent upon the area of the lens. On the other hand, the signal from the sky background (or any extended source) will be inversely dependent on the f number and thus for a given lens diameter, on the focal length. A practical design is usually a compromise since often the specific field of view required dictates the focal length.

TYPES OF PICKUP DEVICES

Two types of signal-generating pickup devices are generally used for astronomical purposes. They are the vidicon photoconductive camera tube and the image orthicon (or isocon) photoemissive tube. In addition, for the ultimate in sensitivity, the image intensifier orthicon may be used. The choice must usually be made of the optimum tube for a particular application on the basis of: 1) sensitivity; 2) complexity of equipment—and thus cost and weight of complete system; and 3) cost of pickup device itself. Since there is a spread of some 10^6 times in sensitivity between the standard commercial vidicon and the supersensitive image intensifier isocon,[3] the choice is wide and a careful evaluation must be made of all factors involved. Following are three example of signal generating equipment designed for astronomical uses, each tailored for the specific task to be performed.

STRATOSCOPE I

STRATOSCOPE I was the first of the balloon-borne telescopes designed by The Perkin Elmer Corporation for Princeton University. It was designed to photograph the surface of the sun from an altitude of 80,000 feet. Because the best sun photographs taken on earth do not equal the theoretical resolving power of a 12-inch telescope, it was decided to design the first stratoscope around optics of this diameter. After some successful "blind" flights in 1957,[4] the need for some visual monitoring from the ground was realized in order to check the focus of the optical system, and to locate areas of the sun's surface of interest to photograph—for example, regions in the vicinity of sun spots.

The primary data recording system of STRATOSCOPE I was a photographic camera that exposed one frame of 35 mm film each second with an exposure of one millisecond. Therefore a television system for monitoring through the exact optics used for photography would have to operate under these same conditions of exposure. Because of the high intensity of the luminous flux from the sun, a quick calculation indicated that a vidicon would have adequate sensitivity. Since information was available only once per second, a 1-frame/sec system with 1-msec exposure during vertical flyback was indicated.

Such a system was designed and constructed for the STRATOSCOPE I 1959 flights[5] and was used with complete success in four flights. A photograph of the vidicon camera as integrated into this photographic camera is seen in Fig. 2, while a block diagram of the airborne system is given in Fig. 3. The visual information received enabled the astronomers to focus the telescope precisely and, by ground command, to direct the telescope to precise regions of the sun's surface. As a result, the STRATOSCOPE I program brought back hundreds of the finest pictures of the sun's surface ever made.[6]

VISUAL ORIENTATION OF TELESCOPES

Another use for television on astronomical instruments is for the visual recognition of constellations or star fields. When a telescope instrument is launched either by balloon or orbiting vehicle, it will be blind until a chosen guide star can be brought into the field of automatic tracking systems. A television system with suitable ground control can provide a means of bringing the desired object into proper range. Again, the choice of pickup device depends upon the use to which it is to be put. A recent system designed for use as a visual monitor for the OAO (Orbiting Astronomical

Observatory)[7] uses a vidicon to detect stars down to fifth magnitude with a 3-inch-aperture lens. STRATOSCOPE II, on the other hand, required the detection of stars of ninth to twelfth magnitude, so an image orthicon is required even though the aperture of the mirror is 36 inches.

STRATOSCOPE II

STRATOSCOPE II is a balloon-borne telescope[8] with an aperture of 36 inches, designed to photograph stars and obtain spectra from an altitude of 80,000 feet. Since many stars to be observed or used as guide stars are very faint (less than ninth magnitude), it was necessary to provide a television system of high sensitivity.[9] Further, because of the relatively high rates of motion of the stellar images provided by the long focal length optics, it is necessary to provide a rather high information rate. Therefore, it was not possible to take advantage of a slow scan. A rate of 20 frames/sec was used. Two television cameras were supplied, one a coarse camera with its own 3.5-inch-diameter lens with a field of 10°, and a second (fine camera) looking through the main optics with a field of 50 minutes. Fig. 4 shows the camera design. Not shown is the cover necessary to hermetically seal the camera to withstand the 1/40 atmosphere pressure conditions existing at 80,000 feet. Image orthicons of the 7967 type are used to obtain adequate threshold sensitivity. Transmission is by means of a 1,500-Mc FM channel, and the operational range is about 200 miles.

Two flights have been made, both to obtain infrared spectra of stars and planets.[10] The television system functioned perfectly and permitted the astronomers to proceed routinely from one body to another throughout the flight. Astronomers are analyzing the results of these flights while a third flight now in preparation will directly photograph planets and other astronomical objects to obtain the high resolution provided by the 36-inch optics.

INTEGRATING TV SYSTEMS

So far, the specific applications of television described have used television only as a tool to assist in proper operation of the telescope. An even more interesting and potentially more important use of television lies in its use as the primary data recording medium. Of interest in all astronomical applications because of the potential increase of sensitivity and consequent reduction in exposure time but essential as a practical means of returning visual data to earth from an orbiting observatory, the integrating TV system has been the subject of a thorough investigation under the STRATOSCOPE projects.[3] This work confirmed that it is indeed possible to obtain the high sensitivity in an integrating image orthicon as predicted by theory. A C74034 (7967) image orthicon operating at reduced temperature ($<-10°C$) shows integration linear within our ability to measure to as long as 3 hours. Fig. 5 indicates the threshold characteristics of long integration operation while Fig. 6 shows operation at two higher levels of illumination out to 40 minutes. These results demonstrate the practicability of using an image orthicon tube under these conditions as a primary recording medium. Consequently, equipment now approaching completion will be used in connection with the Stratoscope to obtain visual information directly on the ground from the telescope aloft.

Another application of the integrating system of interest even on the ground is to reduce the exposure time for taking spectra where often a full night's exposure to light from a weak star is not sufficient. So a hundred, or even tenfold reduction in exposure time would be of prime importance.

CONCLUSION

Signal-generating astronomical sensors are only beginning to show their real potential. With the increasing sophistication proposed in scientific satellites, more and more demands will be made for sensors to meet certain specifications. With the wide variety of camera tubes available and more knowledge being obtained about their operation in special modes, sensors should be available to meet these demands.

ACKNOWLEDGEMENT

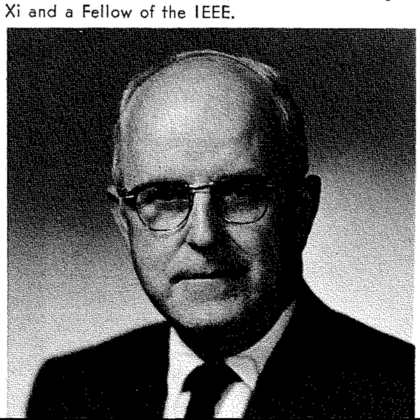
The STRATOSCOPE projects have all been under the direction of Prof. Martin Schwarzschild and Prof. Robert Danielson of Princeton University and have been supported by The National Science Foundation, The Office of Naval Research and NASA.

BIBLIOGRAPHY

Refs. 1-10 are cited in the text; Refs. 11-13 are included as additional basic source literature.

1. Wm. A. Baum, "Counting Photons One by One", *Sky and Telescope,* May 1955.
2. W. A. Hiltner, "Image Converters for Astronomical Photography", *Stars and Stellar Systems,* Vol. II, Chapter 16, University of Chicago Press 1962.
3. E. Luedicke, A. D. Cope and L. E. Flory, "Astronomical Image-integration System Using a Television Camera Tube", *Applied Optics,* Vol. 3, No. 6, June 1964.
4. Martin and Barbara Schwarzschild, "Balloon Astronomy", *Scientific American,* May 1959.
5. L. E. Flory, G. W. Gray, J. M. Morgan, and W. S. Pike, "The STRATOSCOPE I Television System", *RCA Review,* Vol. XXI, No. 2, June 1960. *Also see:* Flory, et. al., "Television in Astronomy—The STRATOSCOPE I," RCA ENGINEER *6*-1, p. 24, June-July 1960.
6. "Project Stratoscope" Robert E. Danielson, *American Scientist,* Vol. 49, No. 3, Sept. 1961.
7. W. Sensenig and M. Kravitz, "Television for Stellar Orientation of the Orbiting Astronomical Observatory", RCA ENGINEER, *10*-2, Aug.-Sept. 1964.
8. E. R. Schlesinger, "Aiming a 3-Ton Telescope Hanging From Balloon", *Electronics,* Feb. 8, 1963, Vol. 36, No. 6, p. 47.
9. L. E. Flory, W. S. Pike, J. M. Morgan, and L. A. Boyer, "The STRATOSCOPE II Television System", *Journal of the SMPTE,* Vol. 73, No. 1, January 1964.
10. Robert E. Danielson, "The First Flight of STRATOSCOPE II", *American Scientist* Vol. 51, No. 4, December 1963.
11. J. D. McGee, "Image Detection by Television Signal Generation", *Stars & Stellar Systems,* Vol. II, Chapter 14, University of Chicago Press 1962.
12. W. A. Baum, "The Detection & Measurement of Faint Astronomical Sources", *Stars and Stellar Systems,* Vol. II, Chapter 1, University of Chicago Press 1962.
13. G. A. Morton and J. E. Ruedy, "The Low Light Level Performance of the Intensifier Orthicon", *Advances in Electronics and Electron Physics,* Vol. 12, p. 183, Academic Press 1960.

LESLIE E. FLORY received his BSEE at the University of Kansas in 1930. From 1930 to 1942 he was a member of the Research Division of RCA Manufacturing Company in Camden, New Jersey. During that time he was engaged in research on television pickup tubes and related electronic problems, particularly in the development of the iconoscope. In 1942, he was transferred to RCA Laboratories Division, Princeton, New Jersey, continuing to work on electronic tubes and special circuit problems, including electronic computers, infrared image tubes and sensory devices. From 1949 to 1953, he was in charge of work on storage tubes and industrial television at RCA Laboratories. Since 1953, he has continued in charge of work on industrial television with emphasis on transistor circuitry and has supervised the work on Electronic Vehicle Control and Medical Electronics as well as all of the television work connected with the Stratoscope Projects. Mr. Flory is a Fellow of the Technical Staff of RCA Laboratories. At the present time, Mr. Flory is the Leader of the Special Systems Research Group of the AED Physical Research Laboratory. He has published numerous articles, particularly in the field of television. Mr. Flory is a Member of Sigma Xi and a Fellow of the IEEE.



PREDICTING SYSTEM CHECKOUT ERRORS

During checkout of space or weapon systems, two types of errors can occur: 1) not detecting an existing defect, and 2) calling a nondefective system defective. This paper develops equations which relate the two error types to test equipment accuracy and specification limits of system parameters. The problem is considered on both the individual measurement level and the total system test level. The results can be used to specify test equipment accuracy design criteria, or to determine the probabilities of the two types of errors when test equipment design is already fixed.

W. D. MOON*
Aerospace Systems Division
DEP, Burlington, Mass.

THE object of checkout is to determine whether the system being tested is or is not in a state of operational readiness at the close of checkout. Two types of error are associated with this determination. The first involves the presence of undetected mission-failure-causing defects at the close of checkout. The second involves saying that a defect exists in the tested system when, in fact, it does not—called a *false alarm.*

Undetected defects in the tested system directly affect the success of its mission because the system may be put into service under the mistaken idea that it is completely operational. False alarms directly cause needless loss of time and money through unnecessary delays in use of the system. Indirectly, false alarms could affect mission success through deleterious effects on the tested system caused by the time delays.

The highly accurate, complete, and timely testing required for present day space and weapon systems makes it necessary that attention be given to developing testing techniques and test equipment design criteria aimed at reducing *both* the number of undetected defects and false alarms. The results of this paper can be used to indicate the test equipment accuracy required to keep the probabilities of false alarm and undetected defects below specified tolerable limits. Or, for already designed test equipment, the probabilities of false alarm and undetected defects can be determined.

Equations are developed in this paper which show the relationship of the probability of an undetected defect, probability of a false alarm, test equipment accuracy, specification limits of system parameters, and decision limits on which go/no-go decisions are based. This relationship is considered at both the individual measurement level and the total system test level.

INDIVIDUAL MEASUREMENT

For any one of the specific measurements comprising the total test of a system, the actual value of the parameter is assumed to be related to the measured value according to a normal probability density function. That is, a random measurement error only is assumed with no bias error such as would be caused by miscalibration of the measurement equipment. The existence of a normally distributed random error is generally accepted in measurement analyses and can be observed in actual practice. For example, H. L. Mirick of IBM says[1] of measurement error that, "Over a relatively long history of measurement these variations assume a normal or Gaussian distribution."

Two *equivalent* ways of considering the normally distributed random error relationship are:

1) The density function with standard deviation σ is always centered at the measured value, M. The probability that the actual value falls within a given range is just the area under the density curve in the given range.
2) The density function with standard deviation σ (the same σ as above) is always centered at the actual value. The probability that the measured value M falls within a given range is the area under the density curve in the given range.

The concept used in this paper is the first of the two described above. In this case, the probability density function has the form

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\tfrac{1}{2}\left(\frac{x-M}{\sigma}\right)^2\right]$$

The plot of $f(x)$ is shown in Fig. 1. Also shown in Fig. 1 are the upper and lower specification limits, S_U and S_L, within which the actual value of the measured

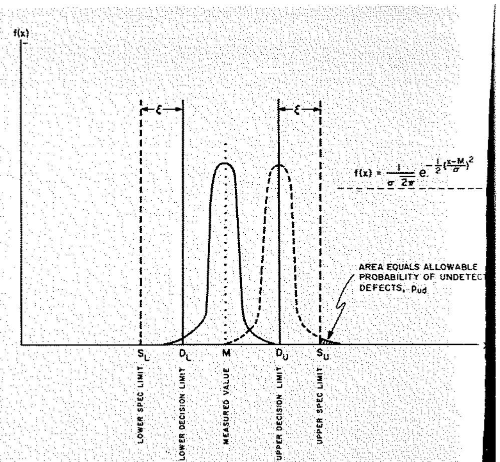


Fig. 1—Probability density function for test equipment measurement error.

parameter must fall in order for the system to be operable. In order to assure that the probability of an undetected defect does not exceed some specified maximum, the measured value M must fall within even tighter limits called decision limits (upper and lower decision limits are designated as D_U and D_L). If a measured value falls outside of these limits, a *no-go* decision results. The center of the density function establishes the location of a decision limit when the function is located such that the area under the tail protruding beyond the specification limit equals the maximum allowable probability of an undetected defect (see Fig. 1). The maximum probability of an undetected defect is hereafter designated as p_{ud}.

Probability of an Undetected Defect

When the function is centered at the upper decision limit, the area under the tail of the curve protruding beyond the upper specification limit is:

$$p_{ud} = \frac{1}{\sigma\sqrt{2\pi}} \int_{S_U}^{\infty} \exp\left[-\tfrac{1}{2}\left(\frac{x-D_u}{\sigma}\right)^2\right] dx$$

By a change of variables and by defining $\xi = S_U - D_U = D_L - S_L$, the above equation can be put into the standard form that is tabulated in the standard tables of normal probability density function integrals as follows:

$$\frac{1-2\,p_{ud}}{2} = \int_0^{\xi/\sigma} \frac{1}{\sqrt{2\pi}} \exp\left(-\tfrac{1}{2}t^2\right) dt \quad (1)$$

Equation 1, then, relates: 1) the maximum allowable probability of an undetected defect, p_{ud}; 2) the distance that the decision limits lie inside the specification limits ξ; 3) and the test equipment accuracy σ.

Probability of a False Alarm

When the measured value falls outside the decision limits, a *no-go* decision re-

Final manuscript received January 21, 1964.
* This paper is one of those that has been nominated for the *Alfred A. Noble Award*, presented annually to an author under 31 years of age by the five Engineers Joint Council founder societies.

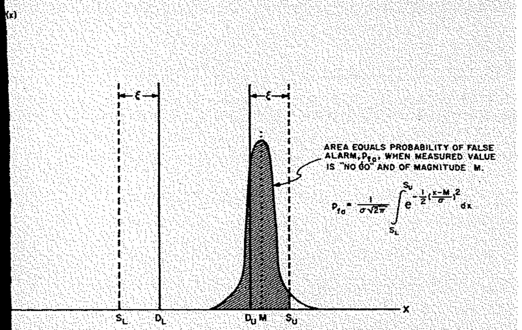


Fig. 2—Probability density function for test equipment measurement error.

sults. The probability that this is a false alarm is simply the probability that the actual value of the measured parameter falls within the specification limits even though a *no-go* decision is made. This probability is the area under that part of the density function curve (Fig. 2) that lies within the specification limits. Fig. 2 shows that the probability of a false alarm is a function of the measured value M. That is, the further M is outside of the decision limits, the less is the probability that the *no-go* decision is erroneous. Mathematically, the expression for the false alarm probability p_{fa} for a specific measured value M outside of the decision limits is:

$$p_{fa} = \frac{1}{\sigma\sqrt{2\pi}} \int_{S_L}^{S_U} \exp\left[-\tfrac{1}{2}\left(\frac{x-M}{\sigma}\right)^2\right] dx$$

The above expression for p_{fa} is just the cross-hatched area under the curve in Fig. 2.

The above equation can be put into a form that is tabulated in the standard tables of normal probability density function integrals as follows:

$$p_{fa} = \int_{0}^{S_U - M/\sigma} \frac{1}{\sqrt{2\pi}} \exp\left(-\tfrac{1}{2}t^2\right) dt - \int_{0}^{S_L - M/\sigma} \frac{1}{\sqrt{2\pi}} \exp\left(-\tfrac{1}{2}t^2\right) dt$$

The plot of the probability of a false alarm p_{fa} versus the measured value M can now be made and is shown in Fig. 3. Note that the integral equation for p_{fa} is only meaningful for M's outside of the decision limits. Inside the decision limits the probability of a false alarm must be zero because the decision is *go.*

Linear Approximation for p_{af}

The above integral equation for p_{fa} cannot be solved in closed form. Therefore, it would be convenient for further development of this problem, if some approximate closed form expression could be found for p_{fa}. It can be seen from Figs. 2 and 3 that for σ's much less than $S_U - S_L$, the actual curves in Fig. 3 can be approximated by straight lines. These straight line approximations are also shown in Fig. 3. They intersect the M axis at:

$$\phi_L = S_L - \frac{\xi}{1 - 2\,p_{ud}}$$

And:

$$\phi_U = S_U + \frac{\xi}{1 - 2\,p_{ud}}$$

Expected Value of p_{fa}

Because of the large number of individual measurements in a total system test, it now becomes justifiable and useful to find the "expected value" of p_{fa} and thereby provide a single value for p_{fa} which is not a function of the measured value M. (It is pointed out, however, that since the probability of false alarm p_{fa} is a function of the measured value M, it may be of value to consider programming of automatic test equipment that evaluates p_{fa} as a function of M. Such programming could be designed to warn the test equipment operators when *no-go* measurements had high associated probabilities of false alarms or it could be designed to take action to reduce a high false alarm probability, such as repeating the measurement.) Statistical theory states that the expected value of the function p_{fa} of the random variable M whose density function is $f(M)$ is:

$$E[p_{fa}] = \int_{-\infty}^{\infty} p_{fa}\, f(M)\, dM.$$

As a worst-case consideration, it is assumed that the measured value M is equally likely to occur over the range of p_{fa}. Fig. 3 shows that the straight-line approximations for p_{fa} range from ϕ_L to ϕ_U. Thus, the constant value for $f(M)$ over this range must be $1/(\phi_U - \phi_L)$ in order to assure a unity area under the $f(M)$ probability density distribution. Fig. 4 is a plot of $f(M)$.

The equation for $E[p_{fa}]$ now becomes:

$$E[p_{fa}] = \frac{1}{\phi_U - \phi_L} \int_{\phi_L}^{\phi_U} p_{fa}\, dM.$$

The above equation is quite easy to evaluate, since it is simply $1/(\phi_U - \phi_L)$ times the area under the two triangles formed by the straight line approximations in Fig. 3. The solution for the expected value, $E[p_{fa}]$, of the probability of false alarm is:

$$E[p_{fa}] = 2\left[\frac{(1 - p_{ud})^2 \xi}{(S_U - S_L)(1 - 2\,p_{ud}) + 2\xi}\right]$$

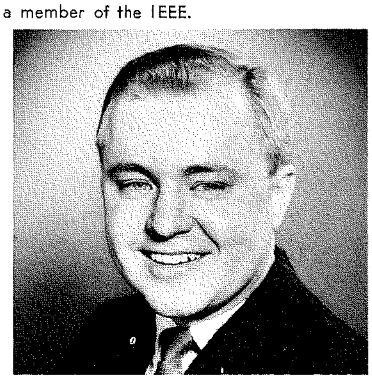
The above expression shows that the expected value of the probability of false alarm is a function of: 1) the specification limits, S_U and S_L; 2) the distance ξ that the decision limits lie inside of the specification limits; and 3) the probability p_{ud} of an undetected defect.

Parametric Plots

Figs. 5 and 6 were made using the two basic equations developed above for $(1 - 2\,p_{ud})/2$ and $E[p_{fa}]$. Fig. 5 shows plots of expected value of false alarm $E[p_{fa}]$ versus the probability of undetected defects p_{ud}, for various ratios of σ to $S_U - S_L$. Fig. 6 shows a plot of $E[p_{fa}]$ versus the ratio of σ to $S_U - S_L$ for various p_{ud}'s. It should be noted that the magnitude of σ is only important relative to $S_U - S_L$. Therefore, it is the ratio of σ to $S_U - S_L$ that appears in Figs. 5 and 6.

Fig. 5 shows that unless the requirement for the probability of undetected defects p_{ud} is very low, a change in the probability of undetected defects has little effect on the expected probability of false alarm $E[p_{fa}]$. However, when very small p_{ud}'s are required, high $E[p_{fa}]$'s can be expected. In addition, it should be noted that if the probability

WARREN D. MOON received a BS in Geophysics from the Massachusetts Institute of Technology in 1958, and an MSEE from the California Institute of Technology in 1959. Early job experience included earth resistivity work for the Phelps Dodge Mining Company and seismic work for the Gulf Oil Company. From 1959 to 1962, Mr. Moon was employed by the AC Spark Plug Division of General Motors Corporation. His positions there included Project Staff Engineer in the project management group for the B-52 AN/ASQ-48 Bombing Navigational System Program, and Project Staff Engineer in the Advanced Concepts Research and Development department working on inertial guidance system analysis. In 1962, Mr. Moon joined RCA in the DEP Aerospace Systems Division, where he is now a Senior Member of the Technical Staff. His responsibilities have included the development of all of the mathematical models describing checkout for the Lunar Excursion Module portion of the APOLLO program and for Army Automatic Test Equipment Programs. He is the author of several papers and is a member of the IEEE.



p_{ud} of undetected defects is required to be too small or if the accuracy of the test equipment is too low (σ too large), it is possible for the upper and lower decision limits to coincide. At this point, there is no region left in which to get a *go* decision; and, therefore, measurement of the parameter becomes meaningless.

Fig. 6 shows the dependance of the expected probability of false alarms on the ratio of σ to $S_U - S_L$. In practice, certain lower limits may exist on σ relative to the specification limit difference $S_U - S_L$, and the absolute nominal value of the measured parameter $\frac{1}{2}(S_U + S_L)$. In such cases, it may be necessary to: 1) perform tradeoffs between the two types of errors in order to optimize the overall situation; and 2) develop testing techniques which effectively reduce σ, such as making repeated measurements.

TOTAL SYSTEM TEST

Thus far, consideration of undetected defects and false alarms has been done on the individual measurement level. This section presents the problem of these two errors at the level of the total system test which consists of many individual measurements. The purpose of this section is to show how decisions regarding maximum probabilities for these two errors at the level of the total system test can be translated into a required test equipment accuracy σ at the individual measurement level.

Three new parameters are introduced here. They are:

$P_{UD} \equiv$ Probability of having at least one undetected defect in a series of individual measurements comprising the total system test.

$P_{FA} \equiv$ Probability of having at least one false alarm in a series of individual measurements comprising the total system test.

$m \equiv$ Number of individual measurements comprising the total system test.

Relationship of P_{UD}, p_{ud}, P_{FA}, and p_{fa}

Since the total system test consists of a number of individual measurements, it is easily seen that:

$$P_{UD} = 1 - \prod_{i=1}^{m} [1 - (p_{ud})_i]$$

And:

$$E[P_{FA}] = 1 - \prod_{i=1}^{m} (1 - E[p_{fa}]_i).$$

Where: $(p_{ud})_i \equiv$ Probability of not detecting a defect in the ith individual measurement; and $E[p_{fa}]_i \equiv$ Expected probability of false alarm during the ith individual measurement.

If it is assumed that all $(p_{ud})_i$'s are equal and all $E[p_{fa}]_i$'s are equal (this can be forced), the above expressions for P_{UD} and $E[P_{FA}]$ become:

$$P_{UD} = 1 - (1 - p_{ud})^m$$

And:

$$E[P_{FA}] = 1 - (1 - E[p_{fa}])^m.$$

Earlier in this paper, the relationship between the error probabilities p_{ud} and $E[p_{fa}]$ was shown at the individual measurement level. At the total system test level, a relationship between the probabilities of the two error types P_{UD} and P_{FA} also exists. At this level, two parameters act to affect the relationship: the number of individual measurements m, and the standard deviation σ, for individual measurement accuracy.

Fig. 7 shows a plot of expected false alarm probability $E[P_{FA}]$ versus the undetected defect probability P_{UD} at the total system test level. For this plot, m is varied while p_{ud} and $E[p_{fa}]$ are held constant. Fig. 7 demonstrates the need to keep the number of measurements, m, as low as possible while assuring that the number is adequate to detect all defects.

Fig. 8 shows a plot of $E[P_{FA}]$ versus the ratio of σ to $S_U - S_L$ for various values of P_{UD}. It is important to notice that $E[P_{FA}]$ is affected much more by a change in the ratio of σ to $S_U - S_L$ than is $E[p_{fa}]$. Compare Figs. 6 and 8.

Determination of Required Test Equipment Accuracy

For a total system test, decisions should be made as to the tolerable maximum probabilities of both errors, P_{UD} and $E[P_{FA}]$. (It must be remembered that if the maximum expected probability $E[P_{FA}]$ is placed too low, the requirements for test equipment accuracy can become extraordinarily high; refer to Fig. 8.) These decisions are based on requirements relating to the probability of success of the system mission and the tolerable time delays and costs resulting from false alarms. With a specified P_{UD} and $E[P_{FA}]$, the above equations for P_{UD}

Fig. 3—Probability of false alarm versus measured parameter value.

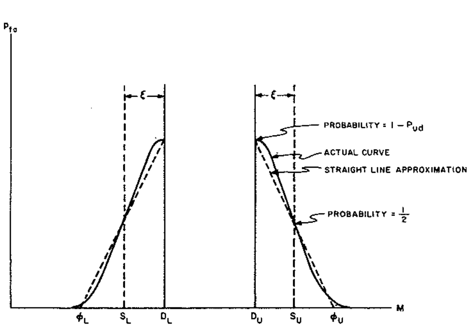
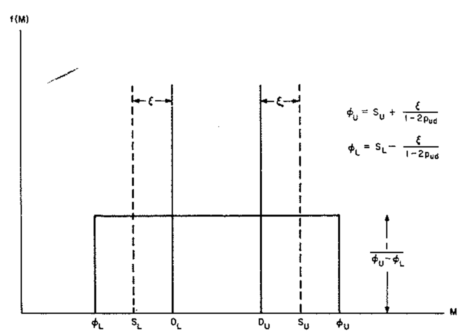


Fig. 4—Probability density function for measured parameter value.



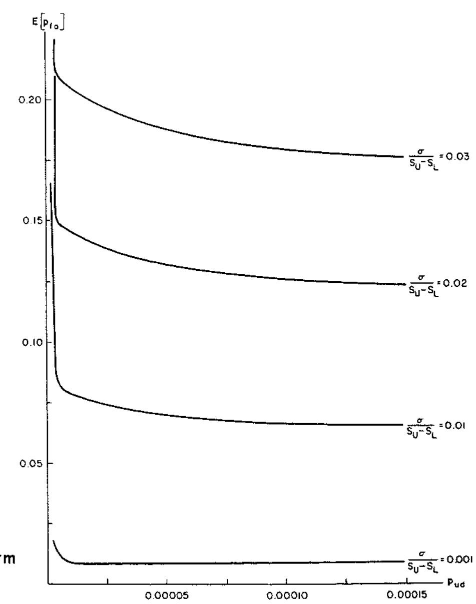


Fig. 5—Expected probability of false alarm versus probability of undetected defect.

and $E[P_{FA}]$ can be solved for the maximum p_{ud} and $E[p_{fa}]$ at the individual measurement level. The solutions are:

$$p_{ud} = 1 - (1 - P_{UD})^{1/m}$$
$$E[p_{fa}] = 1 - (1 - E[P_{FA}])^{1/m}$$

With p_{ud} and $E[p_{fa}]$ numerically specified according to the above discussion, the required test equipment accuracy σ and decision limits ξ can be determined by solving Equations 1 and 2, developed in the *"Individual Measurement"* section of this paper.

In solving Equations 1 and 2 for σ and ξ, some arbitrary value for $S_U - S_L$ can be used. The ratios of σ and ξ thus determined to $S_U - S_L$ are now the quantities that must remain constant for all measurements comprising the total system test. To find the required σ and ξ for a specific measurement, the ratios determined above would be multiplied by the $S_U - S_L$ for the specific measurement.

CONCLUSION

Basic Assumption Consideration

A random normally distributed measurement error was assumed in this paper. However, as the problem analysis begins to deal with almost infinitesimal probabilities of undetected defects, the assumption may no longer be valid. Reasons for this are: 1) the extreme "tails" of a normal probability density curve may not faithfully describe the true distribution; and 2) the measurement bias error, assumed negligible in this paper, may become relatively significant when treating very small probabilities of undetected defects. The area of doubt on the assumed density curve is probably that which lies outside of the four- to five-sigma region. This means that treatment of undetected defect probabilities less than 0.00003 to 0.0000003 by methods in this paper may be doubtful. However, in the absence of empirical data which would support use of some density curve other than normal, the problem treatment in this paper was approached assuming validity of the normal density distribution.

Measured vs. Non-Measured Parameters

The considerations in this paper regarding undetected defects involved only the probability of not discovering that a parameter is outside of specification limits when that parameter *is* measured. Another class of undetected defects can also exist in the overall system which are those involving parameters that *are not* measured. The probability of the existence of this second class of undetected defects is a function of the inherent reliability of the equipment and prior test history when these parameters *were* measured. This means that the overall probability that there is an undetected defect in the system at the close of checkout must be determined as a function of both classes of undetected defects described above. This problem is treated in part by Firstman and Voosen.[2]

σ Related to Accuracy

The common way of expressing measurement accuracy is not in terms of σ as was done in this paper. Accuracy is more commonly expressed as plus or minus a certain percentage of full scale reading with a certain confidence. The relationship of the σ discussed in this paper to this more common method of stating accuracy is as follows when the measurement is made at nearly full scale:

$$\pm X\% = \pm\left(\frac{y\sigma}{F.S.}\right)(100)\%$$

with $y\sigma$ confidence.

Where: $\pm X\% \equiv$ accuracy in percent of full scale reading; $y\sigma \equiv$ desired confidence in stated accuracy, i.e. 1σ, 2σ, 3σ, etc.; $\sigma \equiv$ accuracy as determined by methods in this paper. (Numerical value to be inserted into equation only, not into confidence expression to the right of equation); and $F.S. \equiv$ full-scale reading of measurement device.

As an example, assume that the full scale reading of the measuring device is 10 volts and σ as determined by methods in this paper is 0.05 volts. The required accuracy of the measuring device in percent of full scale can now be expressed as:

$\pm 1.5\%$ with 3σ confidence

Or: $\pm 1.0\%$ with 2σ confidence

Or: $\pm 0.5\%$ with 1σ confidence

etc.

Thus, it can be seen that any accuracy can be stated provided the appropriate confidence in that accuracy is also stated.

BIBLIOGRAPHY

1. H. L. Mirick, "A Statistical Approach to Test Equipment Reliability," *Journal of the Electr. Div. of Amer. Soc. of Quality Control.*
2. S. I. Firstman and B. J. Voosen, *Missile Prelaunch Confidence Checkout*, Rand Corporation Research Memorandum, RM-2485, Feb. 22, 1960.

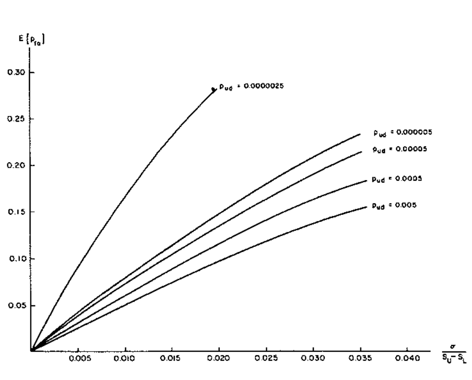


Fig. 6—Expected probability of false alarm versus sigma to spec. limit ratio.

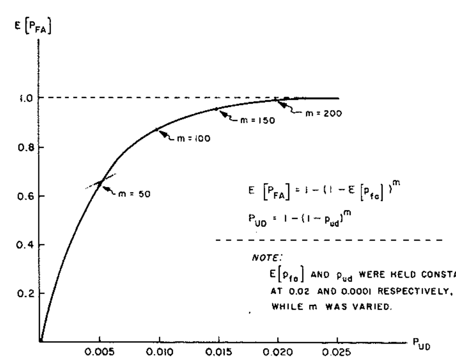
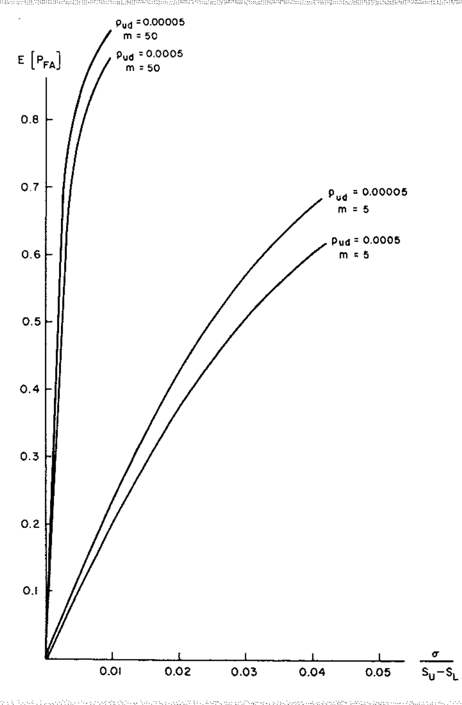


Fig. 7—Probability of false alarm for system test versus probability of undetected defect for system test.

Fig. 8—Expected probability of false alarm for system test versus sigma to spec. limit ratio.



COMPUTER-CONTROLLED AUTOMATIC TESTING—A REVIEW

The digital computer has assumed a very active and powerful role in controlling automatic test equipment. It has become a vital component of the test system because of its inherent abilities for high-speed calculation, large-capacity memory, and programmed decision-making—abilities that enable the test system to isolate faults to a level normally attainable only by skilled test personnel. The computer provides the test designer with a flexibility that eases the planning of test procedures and reduces the size of the total test program. It readily accommodates mathematical diagnostic techniques as they are perfected and opens the door to simplifications in the stimulus and measurement equipment that it controls. This paper reviews the philosophy of computer-controlled automatic testing, and presents specific cases of the powerful role that the computer plays and will play therein.

B. T. JOYCE and E. M. STOCKTON

Aerospace Systems Division, DEP, Burlington, Mass.

AUTOMATIC test equipment has been going through a natural evolution.[1,2] In particular, we have watched the changes in the basic digital control of the stimuli generation, the measurement facilities, and the test-point selections. Control was at first realized by manual patch boards, then by programmer-comparators of varying complexity, and more recently by general purpose computers.

The decision for using or not using a general-purpose computer for control of automatic test equipment is dictated by a number of operational, environmental, and economic factors. However, computer control is essential in maintenance type test equipment where diagnostic test programs must be prepared for many different kinds of units. Why? Simply, diagnosis in depth can only be accomplished in an indirect way through detailed examination of basic performance characteristics. Data must be collected and stored and then operated on by a series of calculations in order to obtain a measure of circuit performance. The same kind of test process followed by an engineer in laboratory testing, analysis and trouble-shooting must be translated to a test program. Such a program can be reasonably handled only with the power of computation, storage, and manipulation inherent in the general-purpose computer.

Final manuscript received August 14, 1964

With this type of need clearly established, we have included the general purpose digital computer in automatic test equipment, and we are materially rewarded in many other ways. Let us highlight some of the dividends:

1) The computer comfortably handles a large test-programming load. Literally thousands of independent test programs will be prepared for use in diagnostic testing at the assembly or subassembly levels in different systems. The bulk-storage problem becomes acute. Magnetic tape provides practical storage for this volume of test data and test control. The general-purpose computer with its own internal memory and timing provides the natural vehicle for temporarily holding and processing those blocks of magnetic-tape information associated with specific units-under-test.
2) The program modification features of a computer reduce the length of a stored program having a given technical content. Basic subroutines can be stored in memory, used over and over again, and modified to suit special test requirements.
3) The computer gives considerable flexibility to the programmer in preparing a test design because he has at his disposal a number of tools for making logical manipulations and decisions. The computer has built-in instructions that permit transfers (branching) on various digital conditions—positive, negative, overflow, and zero. Other instructions allow manipulations of digital data through masking, complementing, shifting, and sign changing.
4) The general purpose computer can handle sophisticated mathematical analysis in isolating failures, assuring the future growth of diagnostic testing.

All of these statements favoring the use of a computer in automatic testing are quite general. Much of the material that follows departs from generalizations and shows specific cases of the powerful roles that the computer does play and will play in automatic testing.

THE "TYPICAL" TEST PROGRAM

Before we examine specific samples of computer utilization in diagnostic testing, let us review some summary data collected from an analysis of a number of actual computer-controlled test programs. These programs covered analog and digital devices, and combinations of both. They were prepared by personnel with varying skill, ability, and equipment familiarity. The programs were all associated with assemblies, such as chassis, containing replaceable subassemblies, such as module boards. It would be very helpful to be able to define a so-called "typical" test program; but it is sure that what is typical today will not be so tomorrow. For one thing,

BRADFORD T. JOYCE received his BS in Engineering Physics from the University of Maine in 1948 and his S.M. degree from M.I.T. in 1950. From 1950 to 1955, he was employed by the Electronics Corporation of America, designing and developing aircraft fire and explosion detection equipment and specialized test equipment for infrared-sensitive devices. Since joining RCA in 1955, Mr. Joyce designed a variety of transistor circuits for airborne fire control systems and checkout equipment. Appointed Manager, Subsystem Development, in 1959, he was given responsibility for the electrical and mechanical design of the automatic programmed checkout equipment (APCHE) for the ATLAS missile. He supervised the development of the RCA AM1100 digital differential analyzer and two general purpose digital computers, the AM3100 and the AM3220. His association with the design and development of multisystem test equipment (MTE) for the Army led to his current assignment as Project Engineer for MTE test-programming.

EUGENE M. STOCKTON graduated from Michigan State University with a BSEE in 1955, and received his MSEE from Drexel Institute of Technology in 1959. Upon completion of the RCA Specialized Training Program in 1955, he joined Defense Electronic Products, Airborne Systems Division. Here he was assigned to the design and development of the Air Force ASG 14 fire control system. In the following four years he gained additional design experience in power supplies, receivers, transmitters, and synchronizers for radar devices. Since 1959 when the nucleus of the automatic test equipment product line was established at RCA, he has gained experience in every facet of the activity with particular emphasis in system design, computer-controller design, and system integration and test. As design leader, he was responsible for the design of the computer used in the multisystem test equipment developed for the Army Missile Command.

test programming techniques are improving and equipment is becoming more readily tested as industry becomes more conscious of maintenance needs, such as the need for carefully selected test points. The unit-under-test itself varies widely in complexity. The following data at least may be useful in helping to indicate the general magnitude of the diagnostic type test program as we see it today.

The "typical" diagnostic test program consists of 100 tests with an average of 750 bits for each test. The total program uses about 75,000 bits of storage. Within this program there are some 3,600 print characters (or 22,000 bits) used for messages. These messages identify the tests and the unit under test, give special instructions to the operator, and direct the necessary repairs. Significant reduction in the total amount of storage used for messages can be anticipated through more efficient use of the computer in handling repetitive commentary and by more careful planning of the message content and vocabulary.

The storage information was deliberately given in bits. These numbers can be juggled to reflect the number of computer words of different word lengths or the number of characters, according to the way you may like to express this information. To make the information more useful, we need to define the word *test*. This, surprisingly enough, is somewhat difficult to do in simple terms. The very fact that a computer is used to control the test operations creates such a flexible situation that one test may include the analysis of many measurements to lead to several diagnostic conclusions. Let us try the following definition as being totally applicable to the word *test* as used here: *A test is that process of making one or more directly related measurements of a specific function to arrive at one or more diagnostic conclusions.*

EXAMPLES OF COMPUTER UTILIZATION

Certainly many examples of computer utilization in diagnostic testing could be picked. Those examples that have been chosen are common to many test problems and punctuate the importance of computer-control.

Digital Equipment Evaluations

The advantage of a computer-controlled test set is vividly revealed when testing a digital type unit-under-test (UUT). A multibit digital word can be inserted into the computer memory from the UUT with a single interrogation. Once the UUT message is in the memory, the full computer flexibility is utilized. As with the programmer-comparator a direct comparison with the desired results can be made. The advantage of the computer comes into play if the UUT does not behave properly. With a comparator only a greater or less-than result can be accomplished. With a computer, depending on the type of digital function being observed, there are alternatives that can be programmed.

If a straight transfer-type digital function is being examined, a shifting routine (Fig. 1) can find all false channels and print out the total failure upon examination of all channels. Knowing what message should have been fetched into the computer, the program can successively shift the data, one bit at a time in the accumulator. Each bit, as it is transferred into the sign position, is examined by the logic decision instructions, transfer on positive, or transfer on negative depending on the desired results. Each time a malfunction is detected the shift number can be stored in a predestined position in memory. In this manner, the whole word is examined and the results can be printed out with one message listing all malfunctioning channels.

Another method that may be programmed is taking a numerical difference (Fig. 2). This method is used to best advantage on a digital assembly that does some manipulation, and not a straight data transfer. Again, the programmer knows what result should be derived from the specific problem fed to the UUT. The actual test result is subtracted from the desired result, and a numerical difference is determined. Utilizing the transfer on zero logic decision, a correct result can be ascertained. If the result is not zero, its absolute magnitude can be established. Knowing the operation of the UUT the test designer can predict a large portion of the faults in this manner. Specifically assume that the tested device is an arithmetic unit from another computer. A series of addition problems could be inserted and the results, or difference of results, from correct responses would be stored in memory. The results could then be analyzed to determine the cause of incorrect bits. A feature mentioned before which comes into action when testing digital units is the ability of the program to modify itself. The series of addition problems to be inserted into the arithmetic unit mentioned above could well depend on the results of the previous comparison in the series.

Depending on the sophistication of the computer in the test set, the implementation of a masking function (Fig. 3) could greatly aid digital type tests. By performing a masking function between

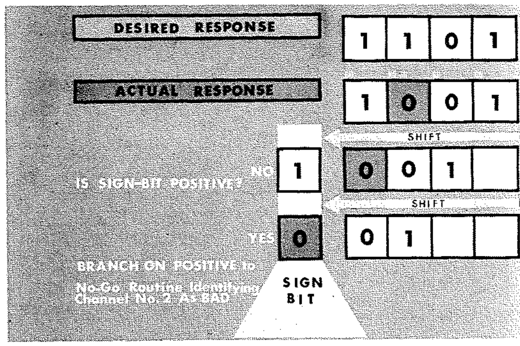


Fig. 1—Shifting routine.

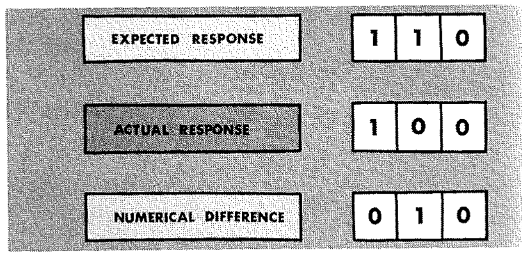


Fig. 2—Numerical difference.

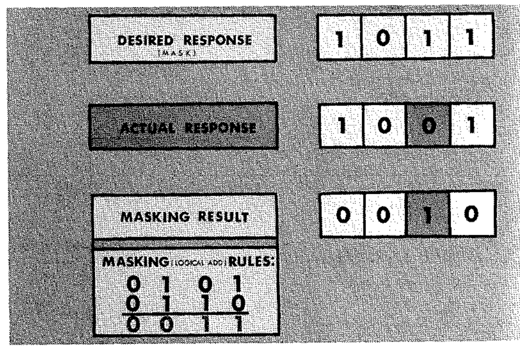


Fig. 3—Masking function.

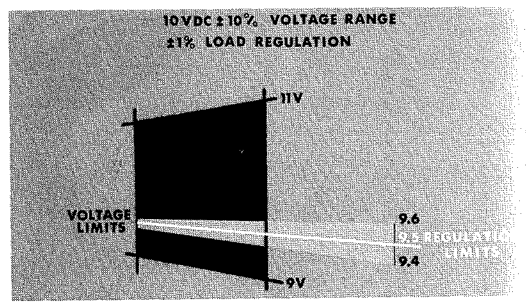


Fig. 4—Power-supply load regulation.

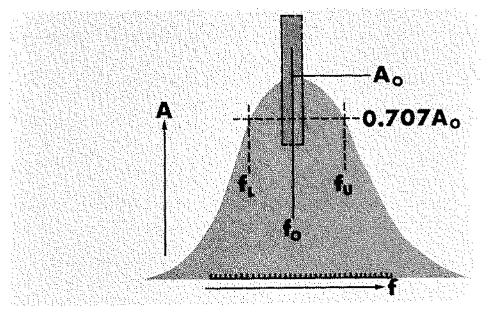


Fig. 5—Amplifier bandwidth.

the desired results and the actual results, the actual bits that are different from the expected results are what remain. The masked result could then be operated on with the methods mentioned. By shifting and examining the masked results and storing the shift count, the exact channel discrepancies are isolated.

By taking advantage of a high-speed computer as the source for digital messages to a UUT, more-accurate real time testing can be performed. The computer does not have to compare each message as it is generated, but instead store each response in the memory at a speed limited only by the memory cycle time. Thus a series of digital stimuli could be sent to the test device, with a series of results coming back for immediate storage. These results could be analyzed after completion of the high speed data collection.

Analog Circuit Evaluation

It is very apparent that the general purpose computer has considerable flexibility for manipulating multi-bit responses from digital type devices to localize failure modes indicated by the various bit combinations. In such operations, the logic-, shift-, and transfer-type instruction dominate the diagnostic program, although some add and subtract instructions also appear. The computational, or arithmetic, capability of the computer really comes into play in the examination of analog circuits where detailed fault diagnosis requires calculations on response data. Many important circuit performance-characteristics that provide clues to finding troubles can be obtained only indirectly.

Let us examine two typical examples that illustrate this important use of the computer: 1) *a test of power supply load regulation*, and 2) *an amplifier bandwidth measurement*. These examples are particularly appropriate in that they are likely to be found in many major subsystems requiring fault isolation.

Power Supply Load Regulation (Fig. 4)

A regulated power supply normally has an allowable range for its nominal output voltage that may or may not be adjustable. Even when adjustable, the absolute voltage setting is not critical. But, very critical to the performance of the supply is the specified regulation it must provide against load-current change. Load regulation is a direct measure of output resistance, a characteristic very important to the circuits that load the power supply. If this resistance is excessively high, even though the voltage is still within its specified limits, amplifier circuits can become oscillatory, flip-flops can trigger falsely on noise, and for that matter, the performance of a whole system can be degraded by the undesired noise on the power supply lines.

How is output resistance measured in the computer-controlled test system? First, the computer directs the measurement of the power supply voltage under one condition of load (perhaps no load) and records the answer in digital form in memory. Then it makes another measurement of the voltage under a different condition of load (perhaps full load). The computer calculates the difference between these two voltages and divides this difference by the change in load current. Thus, it has a measure of the power supply output resistance. The value of output resistance can then be evaluated against the programmed limits determined from the performance specification. It should be noted here that an element of sophistication in these measurements is possibly desirable. The nominal power supply voltage setting may lie between rather wide acceptable limits and the loading may be accomplished with resistors rather than with constant current loads. For these reasons, intermediate calculations may be required to determine more exactly the currents involved in the two load measurements and in order to find accurately the current difference.

Amplifier Bandwidth (Fig. 5)

There is a broad spectrum of linear amplifier performance-characteristics associated fundamentally with measurements of gain and bandwidth. In the example to be illustrated, we have the case of a relatively narrow band amplifier where the nominal gain is quite variable and we have the problem of finding out what the bandwidth is. The computer goes through an incrementing process to generate a series of signals at different frequencies and stores the resulting responses in memory. It then examines this accumulated data in a sequence of comparisons to find the maximum response.

The computer can at this point make a check of the signal amplitude against predetermined programmed upper and lower limits or calculate the gain by dividing the output signal by the measured input signal and make the comparison against the normalized limits of gain. Now that the maximum point of the response curve of the amplifier is known, the computer is used to calculate the signal amplitude at the half-power points (0.707 times the maximum signal) and determines the signal frequency at these points. Here it is practicable for the computer to interpolate in order to find the frequencies more exactly. The difference between the upper frequency f_2 and the lower frequency f_1 is computed to obtain an accurate measure of bandwidth—a performance characteristic that could not have been obtained without computer-controlled test equipment.

Minimization of Program Storage Required for Print-Out Messages

In a programmer-comparator a large portion of the file storage is used for storing print-out characters. Due to the serial sequencing of the paper tape each message must be programmed in total. A careful study of the types of print-outs show that messages fall into several patterns.

One typical message pattern (Fig. 6) consists of instructions to the repairman to replace a faulty part or subassembly; another typical message consists of instructions to the operator to make some adjustment on the unit under test. By utilizing the addressable memory and program modification capabilities of the computer, common messages can be stored in specific memory locations. During the test, the results of previous measurements and analysis will dictate which of the names or identifications will get inserted into the canned message. In this manner, the basic prose for each pattern of messages has only to be stored once. This utilization of the computer flexibility not only reduces the amount of program storage required but also dictates a common format for messages to be printed out, so that there is less likelihood of confusion in the message content.

SIMPLIFICATION OF AUTOMATIC TEST EQUIPMENT THROUGH COMPUTER CONTROL

We have come to appreciate that computer-control leads to simpler and more flexible test programs and permits more penetrating and revealing tests. We are really working in a relatively new engineering specialty field—*automatic test engineering* could be its name. The test engineer is being married with the computer engineer, even though by training and by instincts these people have been separated. *As yet, neither fully appreciates the technology of the other.* They differ from each other like analog differs from digital, like "maybe" differs from "yes" or "no." As we watch automatic test equipment evolve, we will see the rewards of a happy union of the two engineering disciplines. When a general-purpose digital computer is part of an automatic test system, it makes sense to take a hard look at the variety of special test equipment contemplated for inclusion to see what can be eliminated or simplified by taking advantage of computer-directed "intelligence."

In the modern engineering laboratory we find all kinds of test equipment to suit every peculiar technical need. It is well to reflect that many of the measurements made today with sophisticated, complex equipment were made and still can be made with relatively crude devices by classical testing techniques. Take an amplifier gain measurement, for example (Fig. 7). The amplifier can be driven from a signal generator designed to deliver accurate signals scaled to the appropriate required input level; and then the output signal can be measured absolutely with another accurate piece of test equipment. Gain is calculated by dividing output by input. This same measurement can be made with cruder equipment and yet be made more accurately. It is really not important that the signal generator be accurate but rather that it have good short term stability. Let a crude signal generator (Fig. 8) drive a precision attenuator which in turn feeds the amplifier. The attenuation is selected to yield an output voltage from the amplifier that closely approximates the input voltage to the attenuator. A piece of test equipment is used which makes a relatively crude measurement of the signal difference. A calculation involving the output signal, the difference signal, and the attenuator setting leads to a highly accurate measurement of gain. A review of basic test techniques and incorporation of these techniques into real hardware and test programs in computer-controller test equipment will bring to the user hardware simplifications, better test results, and improved system reliability.

Let us look at another example where computer-controlled test equipment can be simplified (Fig. 9). Servomechanisms often require very low frequency signals for stimuli either directly or for modulating higher carrier frequencies. With computer-control it becomes practical to eliminate any need for having as part of the test equipment complement an identifiable signal generator for these frequencies. The digital-to-analog converter (DACON) for delivering DC signals is a fundamental element of any comprehensive automatic test system. The computer can be programmed to change the digital words that control the DACON continually in a quantized fashion to synthesize a sine wave of the desired frequency and amplitude. There are several forms that the program may take to do the job of controlling the DACON. One method can be examined superficially to illustrate the principles involved. First, a normalized set of digital words would be stored in memory. It would take 400 data words (of 8 bits each) to generate one cycle of a sinusoid generated from a DACON controlled by the states of two BCD characters. If the normalized set of words were sent out sequentially to the DACON, the peak value of the sine wave generated would be equal to the maximum voltage that could be delivered. For any other voltage lower than the maximum, the computer would modify this list by multiplying each value by the appropriate factor. The speed for outputing the data words would be established by a simple subroutine using index registers. It is quite reasonable with a good medium speed computer to control the DACON output to provide a 1% sine wave stimulus up to 100 cps.

In a similar fashion, the computer can, by control of the DACON, generate low-frequency saw-tooth, square-wave, or triangular waveforms. For that matter, it can be used to produce any complex repetive pattern or profile within the limitations of its processing speed.

SUMMARY

The digital computer assumes a very active and powerful role in controlling automatic test equipment. It is a vital component of the test system because it can, through its ability to calculate, through its capacity to remember, and through its faculty to make decisions, isolate faults to a level normally attainable only by the skilled engineer. The computer provides the test designer with a flexibility that eases the programming problem and permits a reduction in the size of the total program. It readily accommodates mathematical diagnostic techniques as they are perfected and opens the door to simplifications in the stimuli and measurement equipment that it controls.

BIBLIOGRAPHY

1. For many papers on RCA work in automatic testing, see RCA ENGINEER 8-2 Aug.-Sept. 1962. A reprint therefrom, entitled *Systems Support*, which also includes papers on the subject both from that issue of the RCA ENGINEER and from several other journals (total of 26 papers), is available from D. B. Dobson, Systems Support Engineering, RCA Aerospace Systems Division, Burlington, Mass.
2. The August 1963 *IEEE Transactions on Aerospace, AS-1-2*, is a 1,500-page compilation of the papers presented at the International Conference and Exhibit on Aerospace Support, (IEEE) which was held at the Sheraton Park Hotel, Washington, D. C., Aug. 4-9, 1963. For information on obtaining copies of that *Transactions*, contact D. B. Dobson (address as above in Ref. 1).

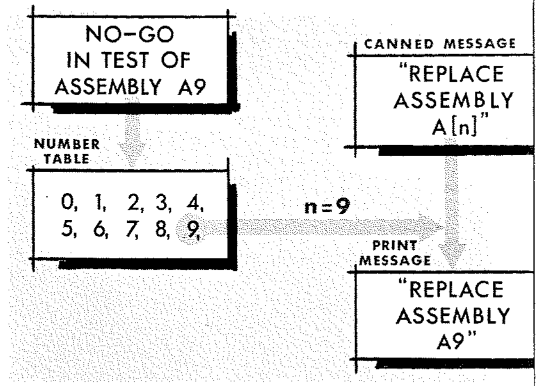


Fig. 6—Typical message pattern.

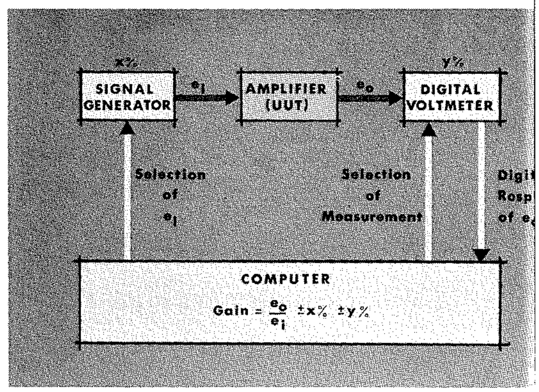


Fig. 7—Amplifier gain measurement.

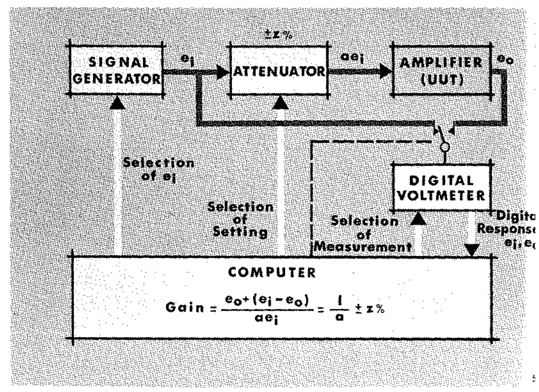


Fig. 8—Amplifier gain measurement (cruder equipment than Fig. 7).

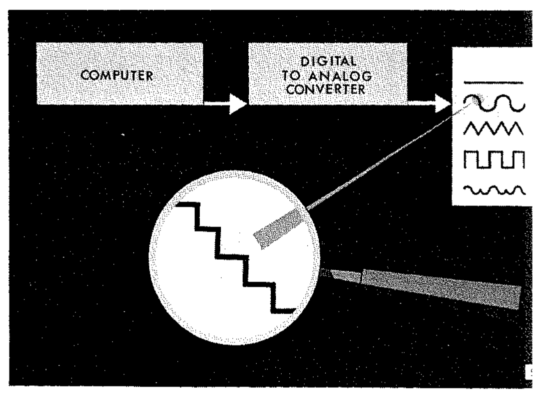


Fig. 9—Synthesized waveforms.

OPTIMIZING SQUARE-ROOT COMPUTATIONS ON A DIGITAL COMPUTER

F. H. FOWLER, JR.

Communications Systems Division, DEP, Camden, N. J.

THE Newton-Raphson method is usually used when square root is calculated on a digital computer. This method makes use of a relatively simple calculation for refining an estimate of the desired square root to obtain a more accurate estimate. The calculation may be repeated as many times as desired, each time refining the result of the previous calculation. If the initial estimate is positive, the final estimate can be made as accurate as desired by repeating the calculation enough times.

This paper develops a procedure for making the initial estimate. The number whose square root is desired is normalized, and an initial estimate is obtained by a table look-up. For each of several intervals, the table gives the initial estimate for a normalized number within that interval. These initial estimates are chosen to minimize the maximum possible error after the first iteration. The paper also treats the relationship between the desired final accuracy, the number of iterations required and the number of words in the table of initial estimates. Rates of convergence are formulated.

In this paper, it is assumed that the time for an *add* type instruction is substantially less than the time for a *multiplication* and that the instruction complement includes a *normalize* instruction, logical operations and shift operations. The details have been developed for binary arithmetic, although they could have been developed similarly for a computer using decimal arithmetic.

BASIC ITERATIVE PROCEDURE

The formula for obtaining an improved estimate x_{n+1} of the desired square root of the given number B^2 from the estimate x_n is:

$$x_{n+1} = \frac{1}{2}\left(x_n + \frac{B^2}{x_n}\right) \qquad (1)$$

To apply this, some initial estimate x_o is obtained. From this, $x_1, x_2, x_3, \ldots$, are successively computed by Eq. 1. The computation may be terminated when either of two conditions is satisfied: completion of a specified number of iterations; *or*, for some unspecified n, that $|x_{n+1} - x_n| < \varepsilon$, where ε is a specified positive number.

RATE OF CONVERGENCE

To study the rate of convergence, we will see how the relative error decreases with each successive approximation. The relative error y_n of the nth successive approximation x_n is, by definition:

$$y_n = \frac{x_n - B}{B} = \frac{x_n}{B} - 1. \qquad (2)$$

Final manuscript received November 17, 1964

This may also be expressed in the form:

$$\left.\begin{aligned} x_n &= B(1 + y_n) \\ x_{n+1} &= B(1 + y_{n+1}) \end{aligned}\right\} \qquad (3)$$

Substitution of Eqs. 3 into Eq. 1 and simplification of the results gives:

$$y_{n+1} = \frac{y_n^2}{2(1 + y_n)} \qquad (4)$$

From Eq. 2, if x_o is positive, $y_o > -1$. tive. Furthermore, if any relative error is Eq. 4 also shows that if y_n is positive, From Eq. 4, if $y_o > -1$, then y_1 is positive, then the error after the next iteration, and hence all subsequent relative errors, are also positive. then:

$$0 < y_{n+1} < \frac{y_n}{2} < \left(\frac{1}{2}\right)^{n+1} y_o \qquad (5)$$

And, if $y_n < 1$:

$$0 < y_{n+1} < \frac{y_n^2}{2}. \qquad (6)$$

Eq. 5 shows that, if the initial estimate is positive, the error will indeed approach zero eventually. Eq. 6 provides a more realistic indication of the rapidity of convergence, once a reasonably accurate estimate is obtained. For example, from Eq. 6 it can be seen that:

$$\left.\begin{aligned} &\text{If: } & y_o &= 1/8 = 2^{-3} \\ &\text{Then: } & y_1 &< 2^{-7} \\ &\text{And: } & y_2 &< 2^{-15} \end{aligned}\right\}. \qquad (7)$$

The relationship between y_n and y_{n-1} is plotted in Fig. 1, which also traces the effect of three iterations upon the relative error. In the example, the computation began with a rather large negative relative error. Three iterations have reduced this error substantially.

A good procedure for making the initial estimate would render the first two or three iterations of this example unnecessary. Such a procedure will now be demonstrated.

PROCEDURE FOR THE INITIAL ESTIMATE

A satisfactory procedure for obtaining the initial estimate must comply with three conditions: *first*, it must be sufficiently accurate such that the desired final accuracy can be obtained without performing too many iterations; *second*, the computation time for this estimate should not be too long; and *third*, the number of memory locations required must not be excessive.

In scientific and real-time problems, the computations made are often repeated many times with slightly different numbers. Therefore, the square root of the number in the current computation may not differ greatly from the square root of the corresponding number in a previous computation. When this is so, the initial estimate for the current computation can be the result from the previous computation.

When this method is used, there may not be a good initial estimate of the square root the first time the computation is performed. Thus, in the first calculation of the square root, either reduced accuracy is obtained or extra iterations are performed. If the reduced accuracy alternative is accepted, this reduced accuracy may apply to the first few calculations, not just the first calculation.

When the initial estimate cannot be obtained from the results of a previous calculation, some other procedure for obtaining the initial estimate is required. The first step in such a procedure is to multiply the original number by a normalizing factor. The normalized number thus obtained will fall within a restricted interval. This makes it easier to obtain a good initial estimate.

In binary computers, it is easy to normalize a number A^2 by multiplying it by an appropriate power k of 4, so that

$$0.25 \leq 4^k A < 1. \qquad (8)$$

Then, to simplify the notation, let:

$$B^2 = 4^k A^2, \qquad (9a)$$

So that:

$$B = 2^k A \qquad (9b)$$

Eq. 9b shows that $\sqrt{A^2}$ can be obtained from $\sqrt{B^2}$ by multiplying B by 2^{-k}. Also, from Eqs. 8 and 9:

$$0.25 \leq B^2 < 1 \qquad (10a)$$

$$0.5 \leq B < 1. \qquad (10b)$$

Thus, a procedure for calculating the square root of numbers in the range specified by Eq. 10a can be made applicable by Eq. 9a to all positive numbers.

The range specified by Eq. 10a can be subdivided into several smaller ranges. If this is done, the typical lower limit of B will be $\alpha_i\beta_i$ and the typical upper limit will be β_i. Then, within this ith range, let $\beta_i C_i = B$, so that, within the typical range $(\alpha_i\beta_i \leq \beta_i C_i < \beta_i)$:

$$\left.\begin{aligned} \alpha^2 &\leq C^2 < 1 \\ \alpha &\leq C < 1 \end{aligned}\right\} \qquad (11)$$

In the special case in which $\alpha = 0.5$, $\beta = 1$, Eqs. 11 and 10 are the same.

If the procedure for obtaining the initial estimate complies with the second condition, then, within any interval, the formula for the initial estimate should be simple. In response to this requirement, the operations performed will be restricted to addition or subtraction and to multiplication or division by small integral powers of 2. Thus:

$$x_o = pB^2 + q\beta, \qquad (12)$$

where: $p = 1/2$, 1, or 2 and q is a constant. Then, if $z_o = x_o/\beta$, then:

$$z_o = pC^2 + q \qquad (13)$$

And:

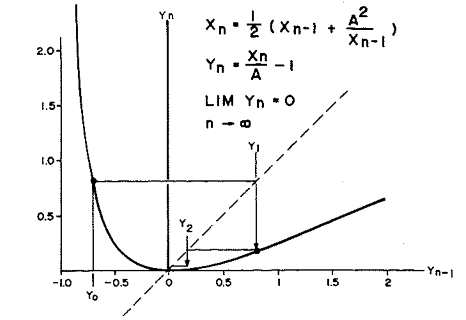


Fig. 1—Convergence of Newton-Raphson method of calculating the square-root A^2. If the estimate X_0 of A is positive, the relative error Y_0 will exceed —1. If the relative error is greater than —1, the next relative error will be positive. Thus all relative errors (except possibly the first) are positive. Furthermore, the limiting value of the relative error is zero.

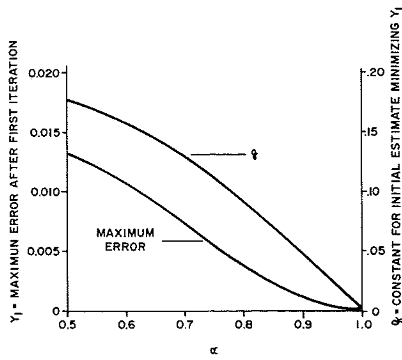


Fig. 2—Initial estimate and error for the square-root of a number between α and 1.

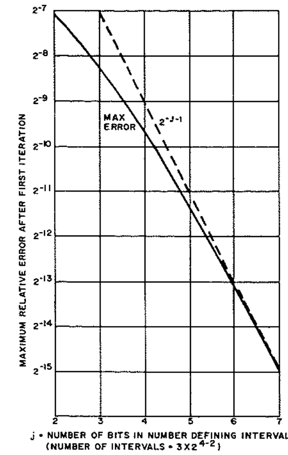


Fig. 3—Maximum relative error after the first iteration for calculating the square-root of B^2 within the range

$$y_0 = \frac{z_0 - C}{C} = \frac{pC^2 - C + q}{C} \tag{14}$$

Furthermore, the relative error after the first iteration is

$$y_1 = \frac{y_0^2}{2(1 + y_0)} = \frac{(pC^2 - C + q)^2}{2C(pC^2 + q)} \tag{15}$$

Within the range specified by Eq. 11, y_1 will have its greatest value when $C = \alpha$, $C = 1$, or $C = C_{max}$, the abscissa of a maximum point. This maximum point exists within the practical range only if:

$$0 \leq pq < 0.25 \tag{16}$$

$$\alpha \leq C_{\max} = \sqrt{q/p} < 1 \tag{17}$$

In this case:

$$y_1(C_{\max}) = \frac{(2\sqrt{pq} - 1)^2}{4\sqrt{pq}} \tag{18}$$

We wish to find the value of q which will make the greatest value of y as small as possible. When this value is either $y_1(1)$ or $y_1(\alpha)$, decreasing $y_1(1)$ will increase $y_1(\alpha)$ and vice versa. Therefore, the best compromise can be achieved by making $y_1(1) = y_1(\alpha)$. When this condition is used with Eq. 15, the following is obtained:

$$\frac{(p\alpha^2 - \alpha + q)^2}{2\alpha(p\alpha^2 + q)} = \frac{(p - 1 + q)^2}{2(p + q)} \tag{19}$$

This is a cubic whose roots are:

$$q_1 = \frac{p}{2}\left[\sqrt{(1 - \alpha^2)^2 + 4(\alpha/p^2)} - (1 + \alpha^2)\right] \tag{20a}$$

$$q_2 = \frac{p}{2}\left[-\sqrt{(1 + \alpha^2)^2 + 4(\alpha/p^2)} - (1 + \alpha^2)\right] \tag{20b}$$

$$q_3 = p\alpha. \tag{20c}$$

Of these roots, only the first, with $p = 1$, is of practical importance. From Eqs. 16 and 17, for $p = 1$ and $\alpha \geq 0.5$, there is no maximum point within the practical range. Therefore:

$$y_{0\max} = q_1 \Big|^{p=1} \qquad y_{1\max} = \frac{q_1^2}{2(1 + q_1)} \tag{21}$$

Values of y_{1max} and q are plotted against α in Fig. 2.

Two methods of dividing the range from 0.25 to 1 into several smaller ranges can be considered. In the first method, α_i would be the same for every range. This method would minimize, for a given number of ranges, the error after the first iteration. However, with this method, it is not easy to determine range within which lies the number whose square root is desired.

A simple method of dividing the range is to let:

$$\beta_i^2 = i2^{-j} \qquad i = 2^{j-2}, 2^{j-2} + 1, \ldots, 2^j \tag{22}$$

When the range is thus divided, the value of $(i - 1)$ associated with the range in question can be obtained from the j most significant bits of B^2. Thus:

$$\beta_{i-1}^2 = (i - 1)\, 2^{-j} \leq B^2 < i2^{-j} = \beta_i^2 \tag{23}$$

$$\alpha_i^2 = \frac{i - 1}{i} \tag{24}$$

The smallest value of α_i is that for which $\beta_{i-1}^2 = 0.25$; and hence, $i - 1 = 2^{j-2}$. For this interval,

$$\alpha^2 = \frac{2^{j-2}}{2^{j-2} + 1} \tag{25}$$

When j is large, the maximum relative error after the first iteration can be approximated by:

$$y_{1max} \approx 2^{-2j-1} \quad (j \text{ large}) \tag{26}$$

Values of the maximum relative error computed by Eqs. 20 and 21 for values of α given in Eq. 25 are plotted on a logarithmic scale against j in Fig. 3. In Fig. 3, the approximation of Eq. 26 is also plotted as a dotted line, and the maximum relative errors for one and two intervals are stated for comparison. (With a computer having a *normalize* instruction, two intervals can be used almost as easily as a single interval.)

After deciding the number of intervals desired, the constants β_i and q_i can be computed by Eqs. 20c, 23, and 24. From these, values of $\beta_i q_i$ can be calculated and stored in a table prior to the production calculations to obtain the initial estimate from the formula:

$$x_o = B^2 + \beta_i q_i \tag{27}$$

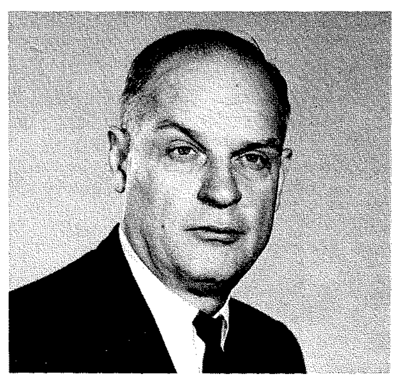
To determine the number of intervals desired, use should be made of Eqs. 6, 20a, 21, and 25. From the specified final accuracy (after the last iteration), the required accuracy after the next to last iteration can be obtained from the following form of Eq. 6, assuming that there are $n + 1$ iterations:

$$y_n \sim \sqrt{2y_{n+1}} \tag{28}$$

The required accuracy after all previous iterations can similarly be calculated.

Then, from Eqs. 20a, 21, and 23, it is possible to determine: *first,* a value of j, say $j(1)$, such that $y_{1max} \leq y_{n+1}$; then, another value of j, or $j(2)$, such that $y_{1max} \leq y_n$, etc.; *and* a j (k) such that $y_{1max} \leq y_{n+2-k}$. Now, a table composed of $3 \times 2^{j(k)-2}$ values of $\beta_i q_i$ will be required if there must be relative error of less than y_{n+2-k} after the first iteration, hence less than y_{n+1} after the kth iteration.

The programmer is now able to trade memory locations for time. The number of iterations k can be reduced by increasing the size of the table, whose size was computed numerically from y_{n+1}, the specified final error. On the basis of the value of space in the computer memory as compared to the value of operating time, a decision as to the number of intervals desired can be reached.



FRANKLIN H. FOWLER, JR. graduated from Yale University in 1938. Until 1950, he was a mechanical engineer specializing in theoretical applied mechanics. From 1950-1953 he was Staff Mathematician, Engineering Research Associates, a division of Sperry-Rand; he engaged principally in the design of special purpose digital computers. In 1953 he became Research Analyst for Jacobs Instrument Company and was a consultant on the design of computers and high-speed printers. Mr. Fowler joined RCA in 1954 to work on engineering tasks involving the design and application of digital computers. He has been awarded two patents, one on a serial coincidence detector and one on a high-speed printer. He has published and presented several professional technical papers. Mr. Fowler is listed in "American Men of Science."

VE-DET is an electronic system now being marketed commercially by RCA for the detection of standing or moving vehicles. It is an outgrowth of earlier development work of RCA Laboratories on automated highway systems, and represents a significant step in instrumentation techniques for the automatic control of highway, railroad, or other traffic. Potential applications include traffic counting, signal control based on number and speed of vehicles, monitoring of parking facilities, various types of indicators that depend up detection of speed or presence of vehicles, and sophisticated warning light systems that automatically adjust to traffic situations. The designs of the original VE-DET and the second-generation VE-DET 4-PAK equipment are described, as are various optional features and modes of operation.

E. C. DONALD
Design and Development Engineering
New Business Programs
Plymouth, Michigan

VE-DET

Electronic Vehicle Detector for Automated Traffic Control

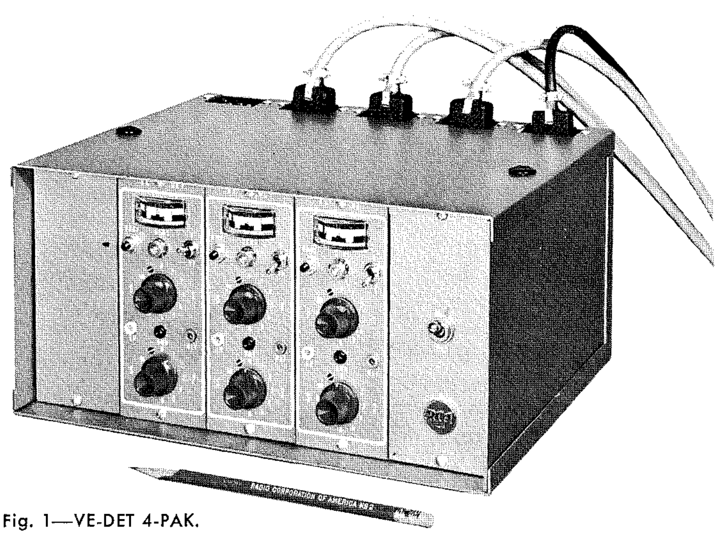


Fig. 1—VE-DET 4-PAK.

EACH day sees the development of new concepts and better circuit designs calling for more highly refined, advanced components. One such concept is RCA's Vehicle Detection System, which now provides commercially available equipment that forms a basis for sophisticated traffic control as a step toward a future concept of automated highways.

Both the early model of VE-DET, and the present VE-DET, 4-PAK, are commercial versions of the electronic vehicle detection system originally proposed by RCA Laboratories. In 1953, Dr. Zworykin demonstrated the basic principles of an electronic highway system using 1/5 scale models. In 1957, a demonstration was given in Nebraska in which full-size cars were used to demonstrate improved control techniques. Shortly thereafter, a quarter-mile oval track was built at the RCA Laboratories and equipped with the necessary electronic installations to apply these techniques to fully automatic control of suitably equipped cars. In 1960, in conjunction with General Motors Corporation which furnished cars with the necessary servo systems, a demonstration was made to the press and interested highway officials.

THE FUTURE AUTOMATED HIGHWAY

Any electronic highway system must be immediately useful to all drivers whether or not their vehicles are electronically equipped. It must provide additional benefits to drivers of equipped vehicles and be applicable to existing roads. It must permit expansion, without premature obsolescence, into the "fully-automated" highway. Since it is virtually impossible to convert many thousands of miles of highway and tens of millions of vehicles to an automatic control system, equipped and unequipped traffic will be intermixed on highways for years to come. Within the framework of the proposed detection system, a measure of control of unequipped vehicles is now available in the form of vehicle counters, and traffic-actuated warning signals which will benefit vehicles with no special equipment.

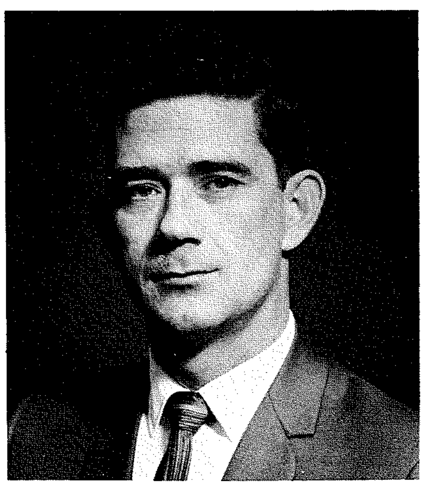
VE-DET—HOW USED

As a result of these applications, a commercial vehicle detector has been developed for highway use, and is currently being marketed by RCA in Plymouth, Michigan, under the name of VE-DET. The transistorized VE-DET detects standing or moving vehicles, such as bicycles, motorcycles, automobiles, trucks, airplanes, and even those used by the railroad industry.

For highways, a rectangular wire-loop, comparable to a car in size, is em-

Final manuscript received November 13, 1964

EDWARD C. DONALD, prior to attending Lawrence Institute of Technology (1956-1958), served a four year U. S. Naval enlistment as an electronic technician. His background includes a 2 year employment with Bethlehem Steel Co. as a machinist apprentice before the Korean Conflict. Employed with Efficient Engineering, Inc. he designed and developed electronic packaging for various portions of the DART, THOR, TITAN and MACE Missiles. In 1959, he was contracted to the Atomic Energy Commission in Albuquerque, New Mexico, where he led a team of electromechanical designers and draftsmen in electronic packaging of an automatic program and recording project. Since joining the Industrial Products group of RCA New Business Programs in Plymouth, Michigan, he has been responsible for printed circuit and electronic packaging of various electronic inspection equipment and industrial products, and also, has been instrumental in circuit designing and packaging of high speed automatic industrial and automotive post process inspection machines.



bedded in or near the surface of the road and connected to the VE-DET normally placed at the side of the road. For railroads, a section of the rails is shorted together to replace the embedded wire-loop. Electronic detection is based on the phase characteristic of a parallel-tuned, resonant circuit composed of a lumped capacitance, and the inductance provided by the wire-loop. By driving this tuned circuit with a radio-frequency current constant in amplitude and phase, the total voltage across the combination reflects any change in the impedance of the resonant circuit.

A crystal controlled oscillator (94 to 110 kc) is coupled to a buffer stage which drives the embedded road-loop and one of the inputs of the phase detector. The road-loop is resonated by two sets of capacitors (fine and coarse) so that the phase of the loop current relates to the current injected into the phase detector is a function of the phase relationship between the loop and buffer currents.

When a metallic object, such as a vehicle, enters the loop, the current phase is altered and the phase detector indicates this by a shift in its DC output voltage.

The phase detector output is amplified and used to excite and energize a mercury-wetted contact relay. When the loop's phase characteristics are upset by a vehicle driven onto the road-loop, or a temporary loss of power, the relay is de-energized, thereby retaining an important fail-safe feature. Once a vehicle is over the loop, the relay will remain de-energized for 30 to 180 seconds and then return to its original energized state. In special applications this time can be extended to 13 minutes.

EARLY REFINEMENTS

Although satisfactory for numerous applications, the need for a second mode arose; a *true presence mode*, one that could detect a vehicle as long as it remained over the loop. This was done by inserting a slow-acting servo-loop which doubles back to the junction of the buffer stage and phase detector. The closing of the servo-loop is accomplished by means of a slow-speed electromechanical adaptive element which has become known as a *magnaptor*. The magnaptor receives an input signal from the system, and simultaneously feeds a reference signal back into the system. The value of the adaptive element automatically adjusts until the phase detector output matches the reference, thereby establishing a required transfer function for the system.

When a vehicle enters the road-loop, one side of the phase detector is acted upon and its DC output voltage is changed accordingly. This change occurs at a rapid rate providing large signals in the relay circuit without affecting the magnaptor tuning. Once the relay is de-energized, the magnaptor is removed from the circuit electrically. Since the slow-speed magnaptor cannot tune out the voltage differential, the vehicle remains detected until it leaves the loop.

In the standard mode of vehicle detection, the loop inductance changes are obviated by AC coupling of the DC amplifiers. It is general knowledge that detection of a vehicle under such a condition can only be momentary and detection is lost when the vehicle remains in the road-loop long enough to allow the capacitors to reach their quiescent levels.

As a result we now have two distinct modes of operation, *moving vehicle detection* and *true presence detection*. The need for a compatible enclosure to accept either or both modes resulted in the second generation of VE-DET, called VE-DET 4-PAK.

PACKAGING

A versatile, reliable, and rugged model was required which could be expanded to meet all present and future applications. While retaining reliability, accuracy, and ease of maintenance, an inexpensive in-road installation of VE-DET 4-PAK includes the use of plug-in planar styled printed circuit cards with plug-in transistors, a printed circuit interconnecting board and an anodized aluminum shelf assembly.

Each detection module consists of two separate printed circuit cards. The standard mode of operation (*moving vehicle detection*) requires: 1) a tuning board plug-in card, and 2) a vehicle board plug-in card.

For the true presence mode of operation, the vehicle board is replaced by a true-presence plug-in card. Fourteen different modes of operation are attained when using the 4-PAK. When special applications are desired, any of the 14 combinations can be expanded to meet exact requirements.

Planar style printed circuit cards were chosen for their proven reliability, immediate availability, and low cost.

All four printed circuit plug-in cards are 6 x 4¾ inches. Because the power supply contains the heaviest and largest components, 3/32-inch-thick glass epoxy material was used for the circuit card. All other detection modules are etched from 1/16-inch material.

Because of the extremely high gain of the VE-DET 4-PAK circuits, extreme caution was taken in selection of all component parts. After the assembly of components to their respective printed circuit cards, both sides of the boards

Fig. 2—Moving vehicle detection.

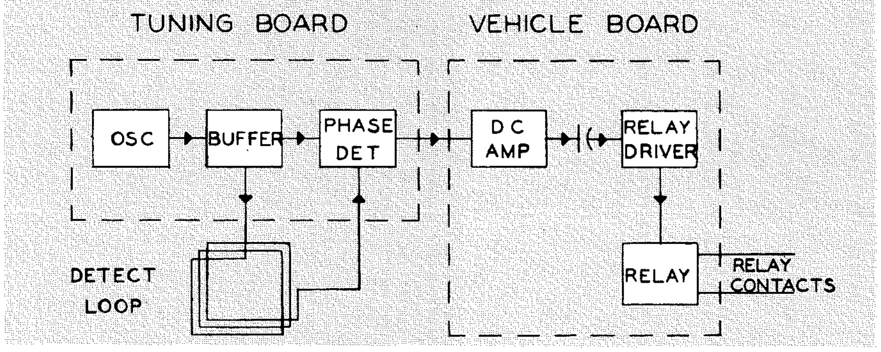
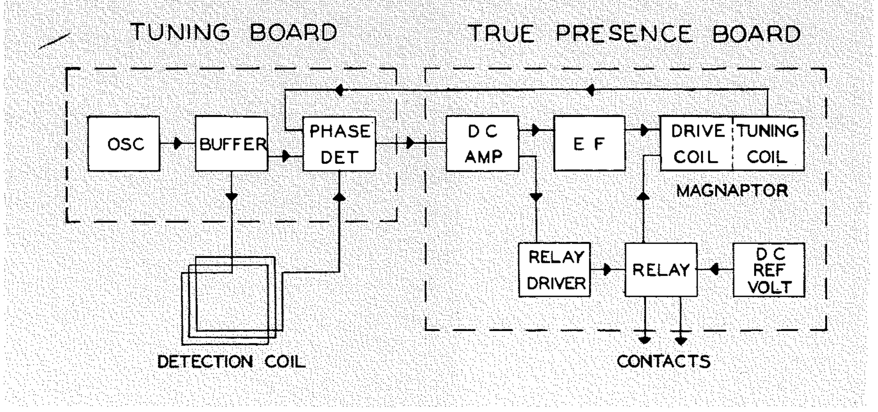


Fig. 3—True presence detection.



are treated with a fungicidal protective coating. Two coats of a sprayed solvent containing a phenolic spar varnish provides moisture, corrosion, and fungus proofing.

The shelf assembly consists of a frame enclosure with top- and bottom-rear covers. The exposed portions of this assembly employ a protective and decorative etched, light blue anodized finish for the wrought aluminum alloy. This finish has a smooth sheen of low reflectivity and good resistance to fading under light exposure.

A chemical (nickel acetate) seal closes the pores and retains the color of the coating. The oxide coating produced by this finish renders the aluminum alloy surface passive and highly resistant to corrosion when subjected to mild atmospheric exposures. A continuous or unbroken coating offers substantial protection against corrosion when the shelf assembly parts are associated with dissimilar metals.

Space for any four detection modules and one power supply is available, with the power supply being inserted into the extreme right position. When less than four detection modules are desired, anodized front spacer panels are provided. Into one detection module space, a tuning board is placed to the left and to the right either a vehicle board or a true presence board is installed. Aluminum sheet spacers are used between modules to reduce interaction. All plug-in cards are properly keyed to prevent any misplacement.

The printed circuit interconnecting board is attached to the rear of the enclosure. Loop and relay contact wires, separately sleeved, extend from the connector board to loose six-pin connectors. Three sleeved wires (AC input) extend from the power supply via the connecting board to a loose three-pin connector. Use of the clear, heat-shrinkable tubing provides insulation for connecting wires and terminals and allows visual check of each soldered connection.

All connectors are riveted to the top cover. Both the top and bottom-rear covers are then snapped into position on the frame enclosure by means of snap-button retainer studs; the top cover is made easily removable (see Fig. 4) allowing a visual check when inserting the printed circuit plug-in cards. Snap-buttons are treated with a polyvinyl chloride coating which provides non-skidding and avoids scratching when shelf assemblies are stacked. With the use of keyed quick-disconnect connectors, the complete assembly is easily removable from one location and transported to another.

POWER SUPPLY

The power supply includes a front panel, a printed circuit card assembly, and a cable assembly. The front panel is anodized to the same specifications as the shelf assembly. The front panel is connected to the printed circuit card by the two power wires coming from the switch. This allows the card to be firmly inserted before positioning the panel to the shelf assembly.

For a temporary installation, the power supply is removed and a circuit card containing the proper wire jumpers is inserted into its position. The power supply cable is connected to an external battery which has an operating life of approximately 20 days.

TUNING BOARD

The tuning board, adaptable to both modes of operation, (*moving vehicle detection* and *true presence detection*) serves two purposes. First, it contains the crystal controlled oscillator, buffer, and phase detector stages. Second, the card transmits the selection and tuning information from the front panel to either the vehicle board or true presence board.

A right-angle printed circuit crystal socket is provided for a selected crystal. For a single detection application, a 100-kc crystal is recommended. When two or more detection modules are required in one application, crystals 2 kc apart are selected from the 94-to-110-kc range. By using different frequency crystals, spurious oscillations between any two detection modules are eliminated.

The front panel is separated from the circuit card and considered as a separate subassembly. The electrical information is transmitted between the two via two flat multiconductor cables. These two cables are twisted two turns at assembly and coil into place when the tuning board is properly positioned. By using these cables, the front panel may be removed from the shelf assembly while the circuit card is still in place. The front panel contains all the components necessary for any tuning procedure or inspection.

Resonating capacitors are mounted to the two rotary decade switches located on the front panel. A 0-to-500μa microampere meter provides a visual means of all operational or functional inspections required. The system gain may be increased or decreased by the panel mounted potentiometer without affecting the tuned circuit. Three test points (loop, relay, and ground) are present for more accurate tuning and inspection.

VEHICLE BOARD

The vehicle board is supplied only when the moving vehicle detection mode is desired. It contains the DC amplifiers, the relay driving stage and the SPDT mercury-wetted relay. When a special application requires the use of an additional set of contacts, a second SPDT mercury-wetted relay is mounted to the circuit card. To extend the memory of a detected vehicle from its normal time (30 to 180 seconds) to 13 minutes, a 500-μf electrolytic capacitor is added to the vehicle printed circuit card.

Since the vehicle board is not used without a tuning board, the four relay contacts are transferred to the tuning board cable via the shelf assembly interconnecting board. To meet all standard and special applications, four models of the vehicle board are available.

TRUE PRESENCE

The need to detect a vehicle for an indefinite period of time is filled by the true presence board. A vehicle once detected de-energizes a DPDT mercury-wetted relay. The relay must remain de-energized until the vehicle leaves the detection area. How long the vehicle remains in the loop is unimportant. What is important is that the vehicle must continually be detected; the detector, once the vehicle has passed, must recover in time to detect a vehicle immediately following. The true presence board accomplishes this.

The true presence board is comprised of a DC amplifier and relay driving stages, stabilizing and fail-safe circuits, a DPDT mercury-wetting relay, and the magnaptor. A thermistor is employed to stabilize the circuits once the relay is de-energized and the magnaptor is removed electrically. After a vehicle has remained over the road-loop for a period of time, the circuits would drift with ambient weather conditions, without the aid of the thermistor. This would cause the magnaptor, even though not electrically involved, to appear to be detuned, If this occurred, after the vehicle departed the relay would remain de-energized and continue to report a vehicle present. The true presence detection would then require external resetting.

Fail-safe circuits prevent the magnaptor from detuning with a temporary loss of power; without such circuits, the relay would de-energize upon return of power, indicating a vehicle present; again, external resetting would be required.

One set of contacts of the DPDT mercury-wetted relay is provided, in like manner as the vehicle board, for the customer's application. The second set of contacts is in series with the drive coil of the magnaptor, thereby electrically removing the magnaptor from the circuit when a vehicle is detected.

When true presence detection is desired in an established circuit, the vehicle board is replaced by a true presence board and the tuning board front panel toggle switch is placed into the *TP* position. After allowing several minutes for the magnaptor to seek its null position, the true presence detection is established and available for its application. To further increase the versatility of the VE-DET 4-PAK, the true presence board was designed to function in either mode of operation. When the tuning board front panel toggle switch is in the *V* position, the magnaptor remains in the circuit and slowly tunes out the presence of a vehicle. Thus either mode of operation can be selected by the position of the toggle switch.

MAGNAPTOR

The inductive readout magnaptor is a slow-speed electromechanical adaptive element. (An *adaptive* element has a value which may be automatically varied to suit the requirements of the system.) Because the magnaptor has a memory, the VE-DET 4-PAK may be turned off and the system will thereafter retain the exact transfer tuning function.

The magnaptor may be operated so that it varies over its entire range in a few seconds, or several hours, and it has a memory with an indefinitely long-time stability.

The magnaptor consists of a piston positioned into an oil-filled cylinder. Onto one end of the cylinder, the drive coil is directly wound between two positioned spacers. The end opposite the drive coil is sealed with a phenolic plug. Prior to sealing, the inside surface of the cylinder must be free of all foreign matter. The cylinder is then partially filled with a measured amount of silicon oil. The piston, also free from contamination, is now properly placed into the oil filled cylinder. After the piston has settled into position and all air pockets have been removed, the open end is sealed with a second phenolic plug. When inserting the final end plug any excess oil will overflow thereby removing any remaining air pockets. The magnaptor must be assembled in a white-room atmosphere by using extreme caution during assembly, the cycling time of all magnaptors will be within 10% of being the same.

APPLICATIONS

The VE-DET 4-PAK with its important characteristics of an embedded wire-loop and its compatibility with the long range concept of a gradually-evolving, fully-automated highway, is now being successfully utilized. Listed here are some of the diversified applications of VE-DET:

1) *Traffic Counter*—One detection module will cover any single, selected road lane, and provide mass detection across as many as eight lanes; numerous other system configurations are possible.
2) *Signal Controller*—This installation includes sufficient detectors to provide a traffic signal with the maximum amount of intelligence to know the actual situation regarding speed and number of vehicles approaching an intersection from all directions. It also provides the necessary information to know whether or not and when the vehicles have cleared the intersection.
3) *Parking Facility Control*—The VE-DET is especially versatile inside buildings, since it can be mounted on walls or ceilings to detect passing vehicles. When connected to counters, the detectors enable parking facility operators to maintain accurate counts of vehicles parked on individual levels. It can be utilized as an expired meter control, registering when a vehicle enters or leaves a parking area.
4) *Indicators*—The detectors may be applied to door openers, toll booth vehicle indicators, air field instrumentation, unlimited use within a railroad system and other apparatus such as a concealed vehicle-speed indicator.
5) *Warning Light*—Another application is the traffic warning light. This provides a visible warning with the "flying tail" (a series of multicolor lights) flush mounted in the pavement at 25-foot intervals. Lights are coded to indicate to following cars the distance and closing speed. As a vehicle moves forward, the three lights directly behind it glow red. The next three are amber, the following three green, and all remaining lights will glow white; therefore, not only providing a flying tail but also a "leading tail" of traffic warning lights to a second vehicle. While the flying tail of lights would be of valuable assistance in rain or fog, the leading tail of warning lights could be instrumental in warning drivers approaching a hazard location such as a blind intersection, road curve, or hill, that another vehicle is also approaching.

CONCLUSION

The commercial version, VE-DET 4-PAK is now available for any immediate application. With its versatility it can easily become the foundation of the future fully automated highway system.

ACKNOWLEDGEMENTS

N. R. Amberg, General Manager, who made himself readily available for consultation; G. A. McAlpine, Marketing Manager, whose efforts produced research and reference material needed for the project; R. G. Walz, Engineering Manager, whose perseverance stimulated progress in the program; E. J. Marcinkiewicz, Project Engineer, who served as liaison officer between the RCA Laboratories and the design effort, and W. L. Ferris, Development Engineer, whose efforts contributed to the production development of the magnaptor.

The developments reported herein represent the results of the Research and Development Program of the original vehicle detection system initiated at the RCA Laboratories in Princeton, N. J. Without the continued knowledge, interest, and support of Leslie E. Flory, George W. Gray, and their associates, the VE-DET 4-PAK would never have become a reality.

BIBLIOGRAPHY

1. A. I. Stoller, "A Slow Speed Electromechanical Adaptive Element," *Private Communication*, RCA Laboratories, Sept. 20, 1963.
2. *Sensing and Communication Between Vehicles*, Sept. 1962. (This reference contains biographical sketches on Dr. Valdimir K. Zworykin, Leslie E. Flory, George W. Gray, Winthrop S. Pike, C. O. Caulton, and Dr. Edward G. Ramberg; the originators of the Electronic Vehicle Detection System).
3. Keith Gardels, *Automatic Car Controls for Electronic Highways*, General Motors Research Laboratories, GMR-276 June 1960.
4. *An Electronic Control System for Vehicles on the Highway*, RCA Laboratories, Apr. 1960.
5. *Improving Safety and Efficiency on the Nation's Highways Through the Use of an Advanced Electronic System*, RCA Broadcast and Communications Division, Camden, N. J., (date unknown).

Fig. 4—VE-DET 4-PAK. Shelf assembly, top cover removed.

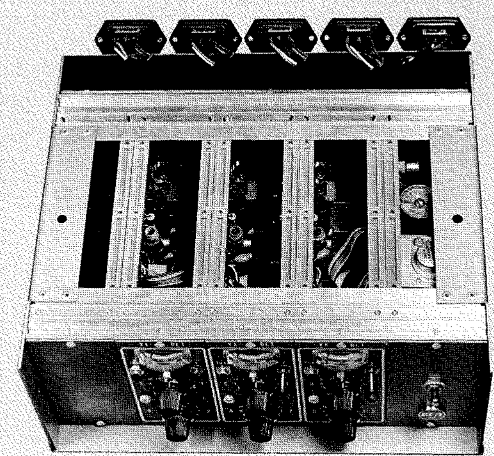
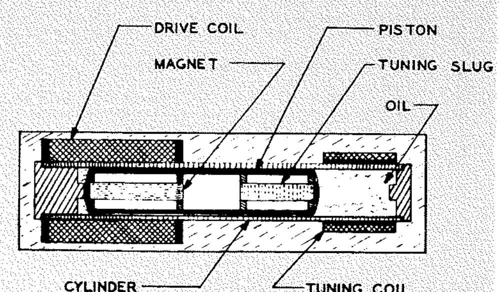
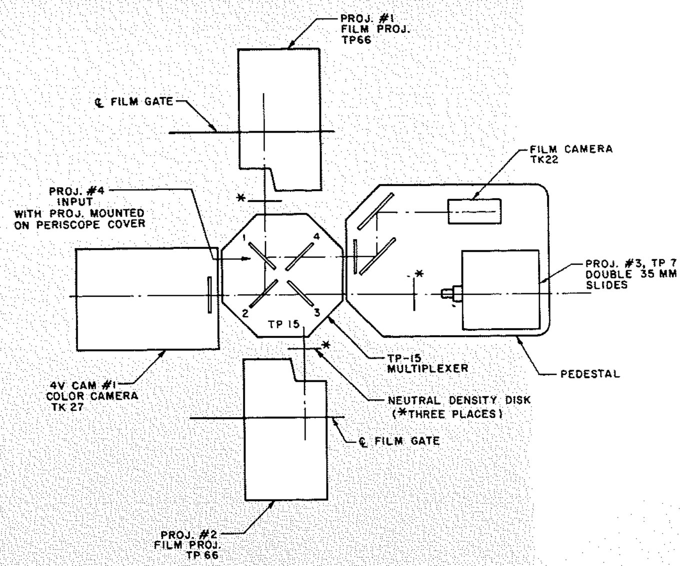


Fig. 5—Magnaptor.





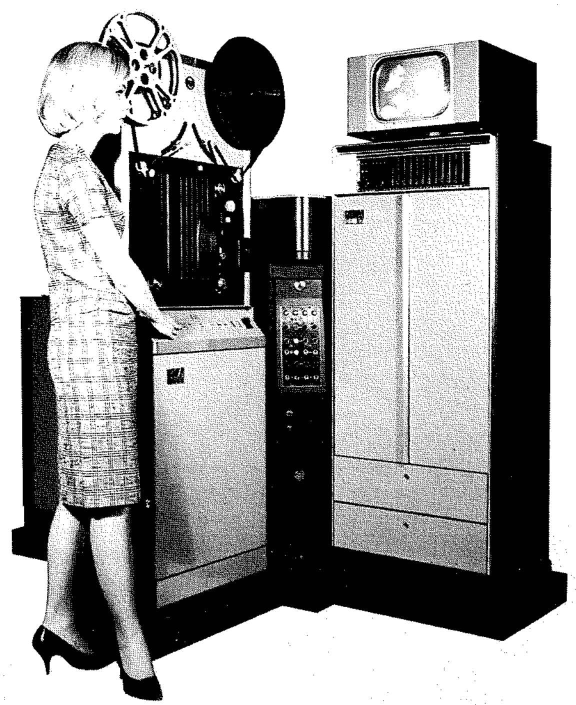


Fig. 1—The TK-27 color film camera. Diagram shows a typical multiplexing arrangement for handling three film sources (two-film projectors and a slide projector) which may be optically selected for projection onto the TK-27 color film camera (or TK-22 monochrome film camera).

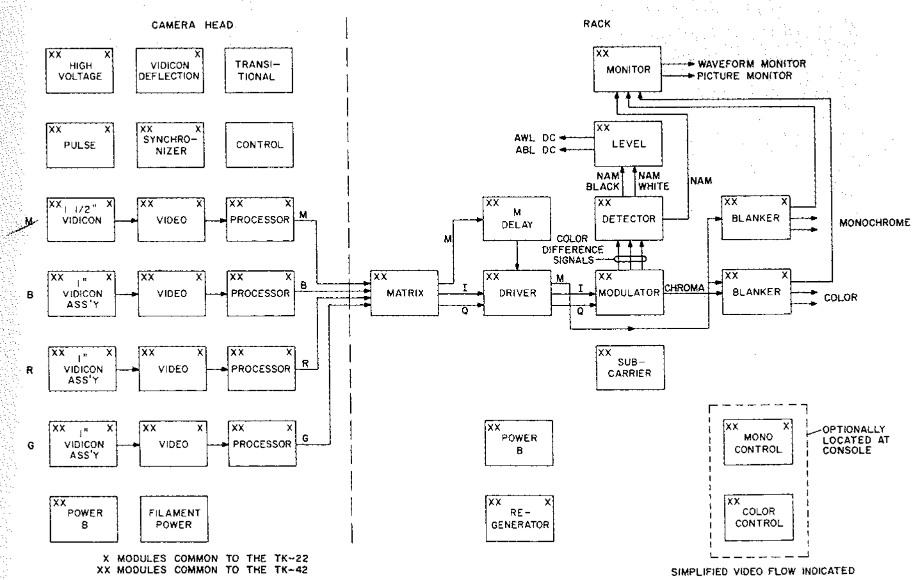
THE NEW TRANSISTORIZED TK-27 COLOR TV FILM CAMERA

RCA's latest color film camera, the TK-27, is the second of a series of cameras employing standard transistorized modules. It has been designed to provide better stability, reliability and picture quality than present tube equipments. The similarity of circuits used in the various broadcast equipments has enhanced the "common-module" approach; such concepts are included in the TK-27. Considerations in design such as monitoring, automatic operation, ease of mantenance, and overall operating flexibility are discussed in this paper.

D. M. TAYLOR, Ldr.
Television Camera Equipment Engineering
Broadcast and Communications Products Division
Camden, N. J.

DAVID M. TAYLOR received his BEE from Rensselaer Polytechnic Institute in 1951 and his MSEE from the University of Pennsylvania in 1959. After two years with Hazeltine Electronics Corporation, he joined the Broadcast Engineering Section of RCA in 1953 where he has worked on a broad gamut of color and monochrome television equipment including; monitors, cameras and automation systems. Since becoming a Leader in 1962, he has been associated with the Television Camera Group with design responsibility for the TK-27 Color Film Camera in addition to factory follow and maintenance of line responsibility for both live and film color cameras. He is a member of IEEE, SMPTE and is a Registered Professional Engineer in New Jersey. He also holds a First Class Radio Telephone License and Amateur Radio License.

Fig. 2—TK-27 modules.



In color television broadcasting, a color film camera is used to convert existing color film (double-frame 35-mm slides, and 16-mm and 35-mm movies) into a high-quality color video signal. The most common television film installation (Fig. 1) optically multiplexes a number of picture sources including both color and monochrome picture information. Therefore, the TK-27 color film camera must produce high-definition pictures for transmission and ultimate reception on any color television receiver or on any monochrome receiver using the same signal.

An earlier paper[1] discussed the development during the past four years of RCA's four-tube color television studio camera. As a part of this total activity, a development model of a companion four-vidicon color film camera was designed and displayed at the 1963 National Association of Broadcasters Convention. The development goals for this early film camera were:

1) Obtain the best possible monochrome picture.
2) Make no sacrifice in color performance.
3) Provide competitive sensitivity.
4) Allow latitude in operating conditions.
5) Provide greater ease of operating.

ESTABLISHING THE TK-27 DESIGN GOALS

Based on the endorsement of the four-tube approach by both Broadcast and Communications Products engineers and RCA's customers, a product design cycle was initiated in the middle of 1963. (Systems planning had started much earlier in anticipation of the product design cycle.) As discussed in a previous article[2], the TK-27 became a part of the standard module, or identical circuit, philosophy of camera design. A reiteration of the main goals of this program is as follows:

1) Transistorization.
2) Maximum use of identical circuitry.
3) Use of standard modules.
4) Greater reliability.
5) Simplified operation.
6) Automatic camera cable and encoder delay compensation.
7) Built-in signal-level test.
8) New look.

To establish the objectives of the standard-module program, several important engineering decisions were reached during the planning stages; some of these were:

1) 1½-inch hybrid (magnetic deflection, eletrostatic focus) vidicon[3] for the monochrome channel to give high definition both vertically and horizontally along with excellent signal-to-noise performance.
2) 1-inch hybrid vidicon[3] to be used in the blue, red, and green color channels.
3) Vertical mounting of the optics to conserve floor space.
4) No active circuits at the control panels.
5) All of the automatic features of the TK-22 monochrome film camera[4] extended for color operation of the TK-27.
6) Setup similar to the TK-22.
7) Inclusion of the encoder at the rack location.

THE TK-27 ELECTRICAL SYSTEM

Although a detailed description is beyond the scope of this paper, several intriguing design problems required solution during the planning and design of the TK-27 color film system. Some of these considerations included the monitoring and setup techniques, as well as the adaptation for color film of the TK-22 automatic modes of operation (e.g., gain, black level, and sensitivity).

Equally as challenging was the need to use standard modules to solve these problems. For example, it was not apparent just how extensively the standard-module approach could be applied to the TK-27 color-film camera and to companion broadcast and television equipments. As the design program progressed, the number of basic circuits which could be treated from the standard-module concept increased; the total number of modules, including the standard modules in the TK-27 color film camera, is shown in Fig. 2. The monitoring, setup techniques, automatic modes of operation, and the extension of automatic operation to the TK-27 color film camera operation, are discussed in the remainder of this paper.

MONITORING

Several design innovations have been incorporated in the new TK-27 color film camera to assure greater ease and accuracy of monitoring by the television station film operator; such new methods were necessary to overcome the greater complexity of monitoring a four-tube color film camera involving B, R, G, and M signals instead of the conventional three-tube color film camera previously used. Another factor was that the TK-27 monitoring system was to be used for the new four-tube TK-42 live color television camera.

Before describing how these requirements were met, it will be helpful for the reader to consider how the television

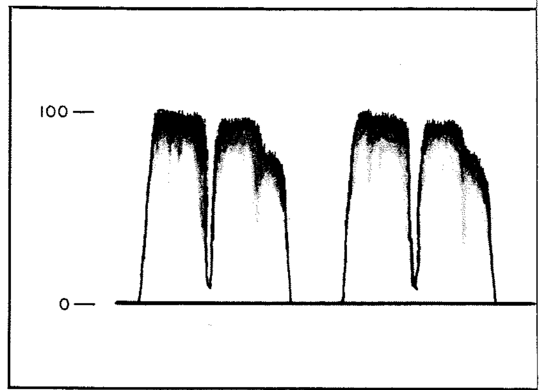


Fig. 3—Waveform monitor display of monochrome signal.

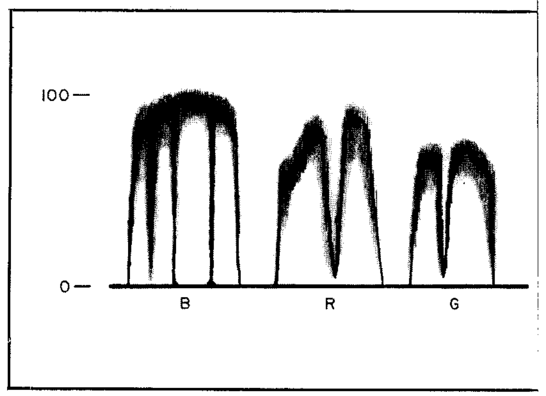
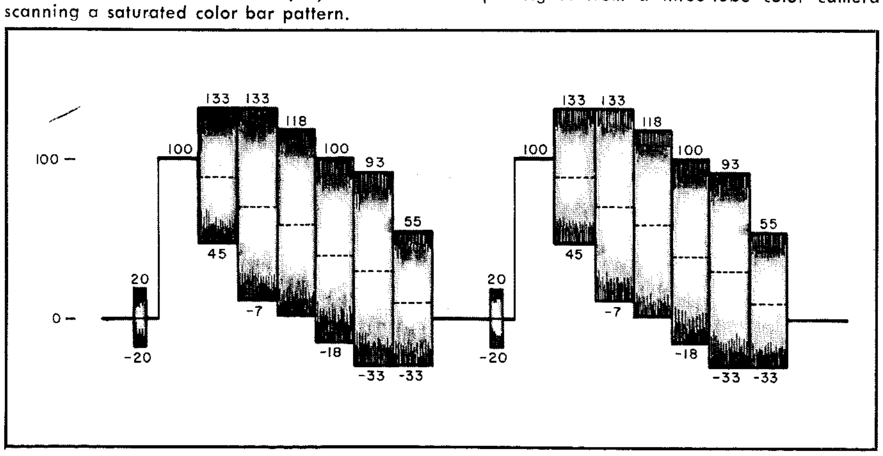


Fig. 4—Waveform monitor display of signals into the encoder from a three-tube color camera.

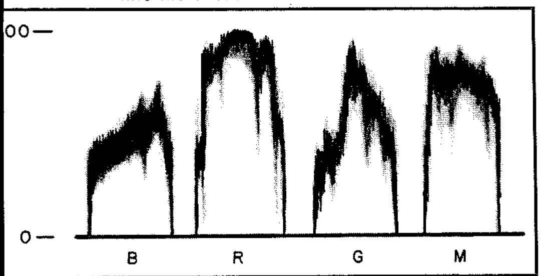
Fig. 5—Waveform monitor display of encoded output signal from a three-tube color camera scanning a saturated color bar pattern.



Final manuscript received November 16, 1964

station operator must adjust, calibrate and monitor the amount of light striking the pickup tube so that the electrical signal generated from the pickup tube has the prescribed amplitude (Fig. 3). This level is constantly monitored by the operator on a waveform monitor (CRO) on which the height or amplitude is calibrated. Using this as a guide, the operator is able to remotely adjust the light

Fig. 6—Waveform monitor display of signals into the encoder from a four-tube color camera.



reaching the pickup tube in the live or film camera and in effect also regulate the amplitude of the signal on the waveform monitor.

In any film camera, a variable neutral-density disk may perform the same function as the iris of the studio camera; Fig. 3 shows the standard waveform monitored for monochrome operation.

In past color operation, the three color signals—blue, red, and green were simultaneously displayed and monitored on the waveform monitor. The camera operator adjusts a control until the highest amplitude of the three waveforms (B, R, G of Fig. 4) touches the 100% level. The three color signals are cabled into the colorplexer which encodes these individual signals into the single composite color signal prescribed by the FCC. When the three-tube camera scans a scene containing a vertical bar pattern comprising a white bar and fully saturated yellow, cyan, green, magenta, red, and blue bars, the composite electrical signal fed to the transmitter would be as shown in Fig. 5.

If a four-tube system were monitored in the same manner as was done for the three-tube camera, the M (monochrome) signal would be displayed simultaneously with the B, R, and G signals (Fig. 6); in this case, the video operator would adjust the neutral density control until the highest amplitude of the four signals reached the 100% value shown on the waveform monitor. A four-tube color film camera adjusted in this way and scanning the previously mentioned color bar pattern would produce the encoded color signal of Fig. 7.

The difference in amplitudes between the Fig. 5 and Fig. 7 waveforms result from the *gamma*, or transfer characteristic, of the monochrome pickup tube. The consequences of this change in the video signal are: 1) normal distortions produced by the transmitter are increased for the yellow and cyan saturated colors as seen on a color receiver; 2) the electrical signal at the kinescope of the receiver can be as much as 25% over the normal level of a three-tube camera viewing a saturated blue scene, and 3) in wideband monochrome receivers, the visibility of the color subcarrier will increase because of the rectification effects occurring at the kinescope.

Such undesirable monitoring effects could occur in the TK-27 system if the B, R, G, and M signals were each monitored separately for amplitude on the scope. To avoid these effects in the TK-27 camera, the four channels are converted as shown in Fig. 8 to three channels (B_r, G_r, R_r) identical to those in the color receiver. These three signals are then monitored for amplitude and the effect of the fourth channel signal, the M signal, is truly represented and monitored. The three channels are also combined into a single waveform display as described in detail below. This system takes advantage of the fact that the peak amplitude height (100%) and the base position (zero level) are the primary considerations in level monitoring.

Although the film operator observes a single waveform, he is, in effect, monitoring the peaks of the three derived B_r, R_r, G_r signals; he also observes and maintains zero black level which is represented by the lowest portion of the composite waveform containing the lowest amplitude of the three derived B_r, R_r, G_r waveforms.

To further explain the single waveform monitoring: The three signals (B_r, R_r, G_r) are processed by nonaddi-

Fig. 7—Waveform monitor display of encoded output signal from a four-tube color camera scanning a saturated color bar pattern.

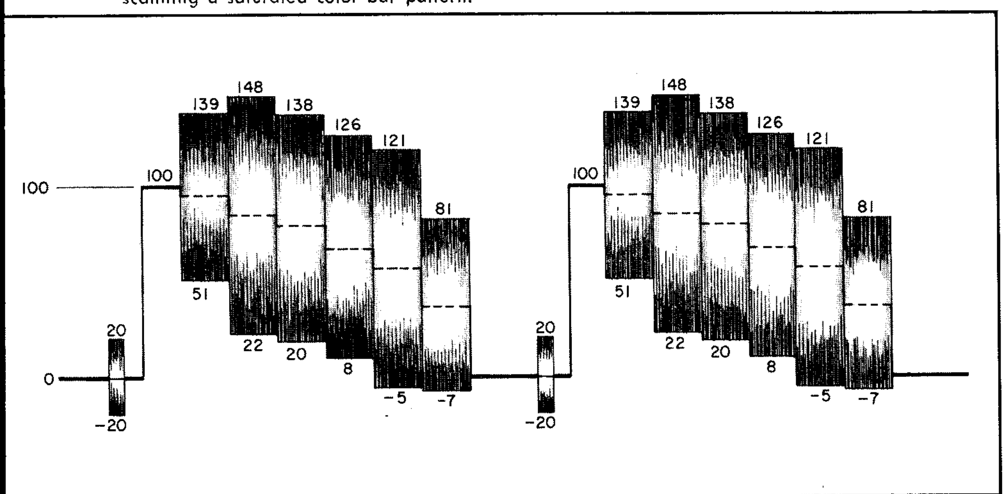
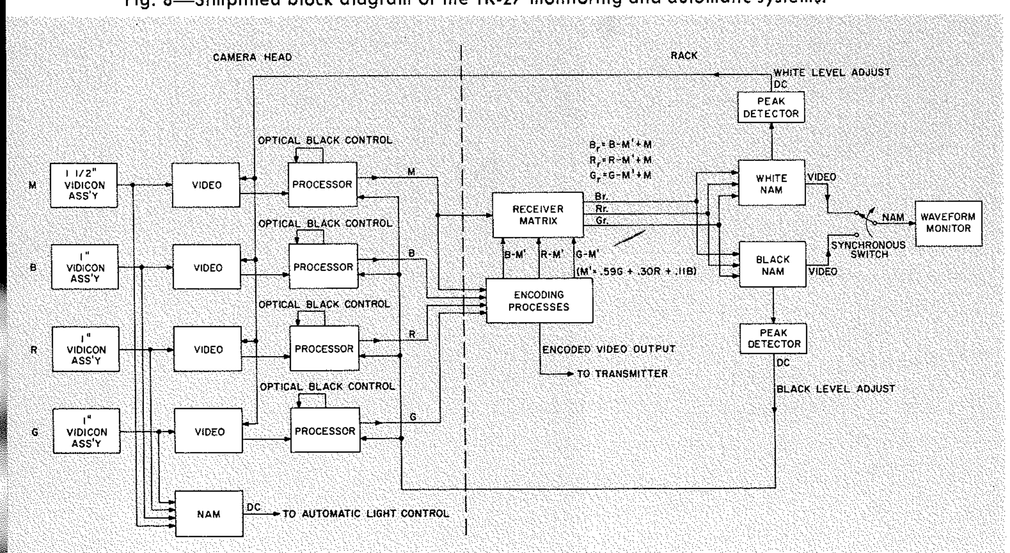


Fig. 8—Simplified block diagram of the TK-27 monitoring and automatic systems.



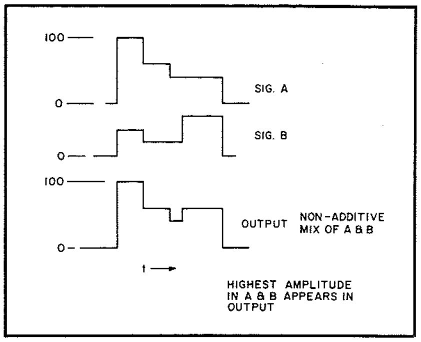


Fig. 9—Principle of nonadditive mixing.

tive mixing. (When two or more waveforms are mixed in a nonadditive manner, the resultant waveform represents at any instant of time the greatest amplitude of any of the waveshapes). As shown in Fig. 8, the single signal resulting from the nonadditive mixing for white and black levels may be selected for display on the waveform monitor by a synchronously operated switch. The electronic switch commutates continuously between the two nonadditively mixed (NAM) signals, taking two lines of NAM white and two lines of NAM black. The output of the switch is then taken to the waveform monitor sweeping at a standard ½ horizontal rate. The effect is seen on the waveform monitor as a superposition of these two signals. To the video operator, these signals appear exactly the same as the signals from a monochrome camera (Fig. 3); thus, the operator adjusts the color film camera controls in exactly the same way that he would for his monochrome camera.

AUTOMATIC OPERATION

Automatic White Level (AWL)

In a color system having AWL, it is necessary to control all four channels proportionately and simultaneously. To control the channels independently of each other, would completely destroy the colorimetry of the pictures. The same NAM white signal (Fig. 8) used in waveform monitoring is the correct signal to use in an automatic loop providing AWL control. This NAM signal is peak-detected to give a DC voltage to be used as a control signal for AWL. The DC voltage is used to control simultaneously the gain of all the channels until the highest peak amplitude in the receiver-matrixed B_r, R_r, G_r signals is brought to the 100% level.

The AWL maintains constant output signals for input signal variations ranging to ± 6db; such variations are a function of light input and density changes in slides or motion picture film material.

Automatic Black Level (ABL)

The ABL is accomplished in much the same manner as AWL (Fig. 8). However, in this case, the output of the NAM black signal for waveform monitoring is used in conjunction with a peak detector to give a DC voltage to control black level proportionately in each of the channels; for establishing ABL, the lowest point in the B_r, R_r, G_r receiver matrixed signals are brought down to the zero level. Because of the way in which the black level control is implemented in each of the channels (described in an earlier paper[4]) the gain of each channel is changed in direct proportion to the amount of black level shift; thus, a balance for white level is always maintained between the channels.

Optical Black

One of the problems in using vidicons as pick-up tubes in color television is that the dark current (the signal current from the tube when no light is impinging on the tube) is a function of temperature and target voltage. Since the dark currents from the vidicons vary independently for each tube, a change in the critical black balance of the color picture could result. For example, if a scene fades to black, the picture might become green because of the difference or drift in the dark currents from the vidicons. To overcome this problem, a portion of the picture picked up by the vidicons is made black by opaquing the corners of the image. This is not visible in the receiver because the raster of the receiver normally extends about 10% over the edge of the picture tube frame. By using suitable keying circuits, the TK-27 samples the masked areas, generates a correction voltage in each channel to correct black level and thus maintains the proper black level balance.

Automatic Sensitivity Control (ASC)

The variations of highlight brightness from film to film is a situation which must be handled in a television color film camera. Such variations can be as much as 30:1. In a color system, it is not possible to compensate for the film density by changing the brightness of the projection bulb by varying the voltage applied to it because the color temperature of the incandescent lamp changes as a function of the brilliance of the lamp.

To overcome the color temperature problem, the projection lamp is operated at constant input voltage thus also maintaining constant brilliance. Since lamp brightness can not be varied, another method must be used to control the effects of variations in film densities so that a constant highlight value always strikes the vidicon pickup tubes. Such control is effectively accomplished by a neutral-density disk placed between the color film and the vidicon pickup tubes. For manual control, the camera operator remotely adjusts the neutral disk to maintain the light output from the film projection system at a constant level. For automatic control, the TK-27 does not in itself contain the amplifiers and servo drivers to operate the neutral density disk in a feedback system; however, it does supply a control voltage to an external unit used for this purpose; this control voltage is derived from nonadditively mixing the individual, R, B, G, and M camera signals (Fig. 9). Since the mixed signals are taken ahead of any video gain control, they truly represent the light levels on the faces of the vidicons which act as peak-reading light meters.

Fully Automatic Operation

In summary of automatic operation, design of the TK-27 allows the use of all automatic controls in any desired combination. To be more explicit, it is possible and often desirable to have automatic sensitivity, automatic gain, automatic black, and optical black all working at the same time. Since there are certain situations, primarily those concerned with special effects, when an operator must control the signal manually, all or any of these automatic controls can be turned off.

Thus, the TK-27 color film camera design provides, as do the other RCA "new look" camera designs, simultaneous operation of automatic sensitivity, automatic white level and automatic black level functions.

Ease of Test, Setup and Maintenance

The features of automatic operation, together with built-in signal level test circuits combine to provide a more reliable setup and test procedure. Contributing to simplified operation, is the incorporation of the test pulses to speed up the initial adjustment of camera signal levels. Such pulses determine that the pickup tube and amplifiers are operating at their proper levels. Circuits are arranged within the camera system so that one man (formerly two) can now set up and adjust the camera by use of these pulse techniques. By depressing a switch on the control panel, these same test pulses may be momentarily inserted into the system at any time for a test check of stability.

MECHANICAL DESIGN

Major efforts in mechanical design were

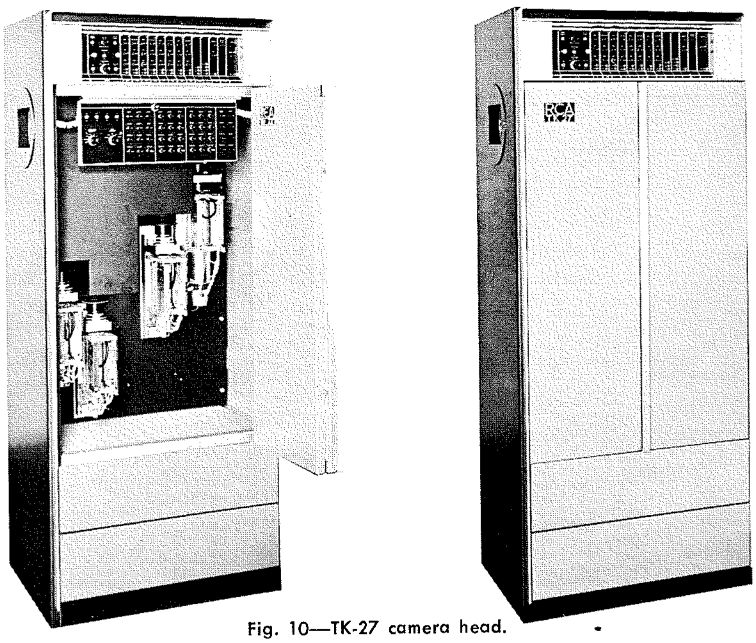


Fig. 10—TK-27 camera head.

directed toward reducing the floor space required by the color film camera (Fig. 10). By maintaining the vidicon assemblies and the optics on a vertical bedplate and allowing sufficient space for the electronics, a space saving of 2 to 1 was achieved over the earlier TK-26 color film equipment.

Another mechanical design feature of the camera head is the easy and rapid removal of the vidicon yoke assemblies to facilitate troubleshooting, tube changing, or replacement of yoke assemblies. Each vidicon camera assembly is accurately indexed to assure optical alignment, focus and registration.

Mechanical design of the modules and mountings used both at the camera head and at the rack are a part of the RCA module approach (Fig. 11). In the TK-27, only the control panels (Fig. 12) appear at the console in addition to the usual waveform and picture monitor.

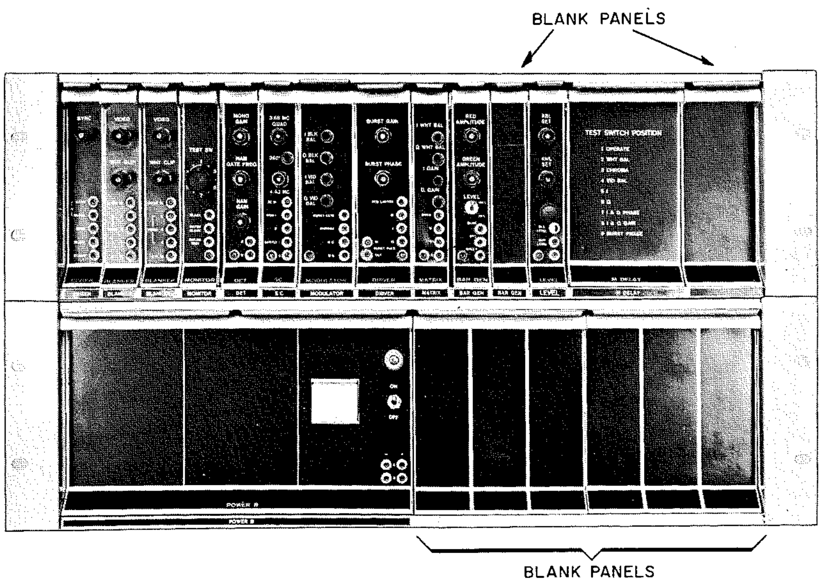
OPTICAL DESIGN

In the optical design of the TK-27, it was decided to use the dichroic prism of the TK-26 color camera because it had been highly developed and refined in its design. This optical assembly splits the light into separate red, green and blue components; with this prism as a nucleus, the rest of the optical system (Fig. 13) is new to the TK-27 design. Included in the specialized optical design is the field lens, and the neutral-beam-splitting prism and lenses for both the 1-inch and 1½-inch vidicons.

A design goal was to produce a system in which the four images from the vidicons could be accurately superimposed electrically on the face of the kinescope. Since differential image distortion due to both optical and electrical effects prevent perfect registry, a design goal was established to reduce optical misregistry to 0.044% of picture width.

To accomplish this demanding specification, it was necessary to provide adjustments on the neutral beam-splitter and the mirrors, and to develop a specialized alignment procedure using a collimated light source (light eminates in parallel rays) and an optical telescope. After the adjustments have been made, all the images now produced will be centered on the face of the vidicons with no trapezoidal effects to produce misregistry. As in any other camera, it is still necessary to make the standard electrical adjustments such as centering, size, and skew to obtain a completely registered picture.

Fig. 11—TK-27 rack mounted equipment.



ADDITIONAL TK-27 DESIGN FEATURES

In addition to the major design considerations of monitoring, automatic operation, color fidelity, and stability previously described above, there are several design features which are important to effective film camera operation and may prove interesting to other engineers. Most of these features described below were designed with full regard to the requirements of companion camera equipment for both monochrome and color operation. This applies particularly to the handling and simplification of the total number of signals and circuits required in the camera system.

Minimum Drive Signals

Formerly, the color film cameras required the following signals which were obtained from a master synchronizing generator in the television installation: *synchronizing, blanking, subcarrier, burst flag, horizontal drive,* and *vertical drive.* At the outset of the design program, it was decided to originate two of these signals (*horizontal drive* and *vertical drive*) within each of the camera chains for both monochrome and color instead of requiring that these signals be fed from the synchronizing generator. This resulted in a simplified distribution system[4] having simplified cabling and a minimum of distribution amplifiers.

Automatic Time Delay Compensation

As described in an earlier paper[4], the TK-27 design incorporates an automatic sensing circuit which compensates for time delay in the system; for example, the sensing circuit detects the time delay in the camera cable and automatically advances an internally generated horizontal-drive signal to avoid introduction

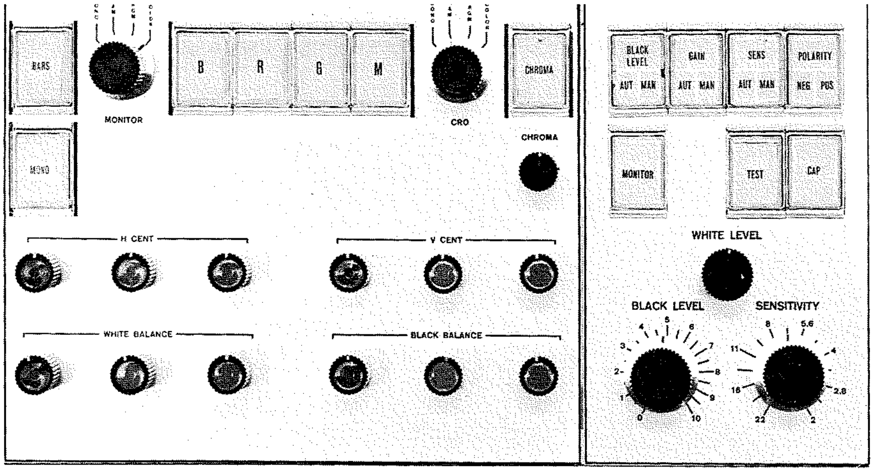


Fig. 12—TK-27 control panels.

of the delay into the outgoing video signal. This system is used in all cameras both monochrome and color so that the outgoing video signal is timed corrected with respect to synchronizing and blanking signals.

Additionally, the color film camera must take into account further time delay present in the color system occasioned by the encoding and color-filtering processes. Such compensation is done by sensing or sampling the signal information at exactly the same point as is done in the monochrome system.

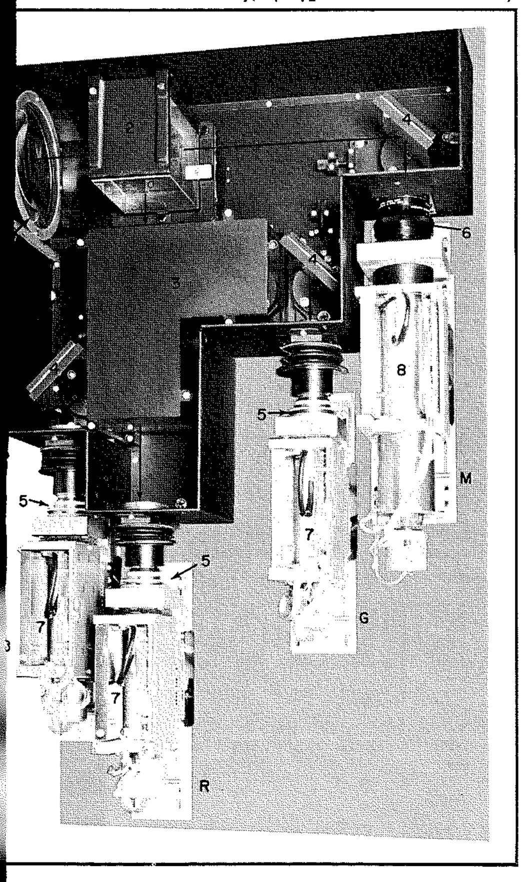


Fig. 13—TK-27 optical system: 1) field lens; 2) neutral beam splitter prism; 3) dichroic beam splitter prism; 4) mirror; 5) lens for 1-inch vidicon; 6) lens for 1½-inch vidicon; 7) 1-inch vidicon assembly; 8) 1½-inch vidicon assembly.

This is the final stage in the camera system. By sampling this signal at the last point in the system, the color film camera automatically compensates for any additional time delay such as that occasioned in the encoder. The output signal is timed correctly (for both monochrome and color operation) with respect to the incoming synchronizing signal. Moreover, there is no longer a need to provide separate pulse distribution system for both monochrome and color signals.

Monochrome Operation

The control circuitry allows push-botton selection of *monochrome only* operation of the TK-27 camera. Only those circuits required for processing the signal from the 1½-inch vidicon are used. With the camera operating in this mode, the entire operation of the camera reverts to the same operation as in the TK-22 monochrome film camera. This applies to all functions such as negative film operation and automatic target operation, and includes the operation of the monochrome control panel.

Balance Controls

Located on the color film camera control panels are two sets of balance controls; one set is for *white balance*, and the other for *black balance*. These are used to compensate for deficiencies in color film. The two sets of balance adjustments control to a limited degree ($\pm 10\%$) the amplitudes of the R, G, and B video signals.

The uniqueness of these controls is that the amplitudes of the white level signals can be adjusted while black level is still maintained, or vice versa. Thus, it can be said that white balance can be adjusted without affecting black balance, and black balance can be corrected without affecting white balance.

Chroma Control

Chroma level may also be controlled and adjusted from the color film camera control panel; thus, chroma deficiencies in color film can be compensated and adequate chroma levels maintained. Without the special monitoring provided in the TK-27; namely, that of looking at the B_r, R_r, G_r signals as the receiver sees them, it would be extremely dangerous to provide this type of control because of the possibility of overloading the system. However, no danger is encountered in the TK-27 because it is always possible to ascertain when maximum chroma levels have been reached.

European Standard (CCIR) Operation

The TK-27 is equipped so that the appropriate drive signals are available for CCIR operation of the equipment; it will produce NTSC-type encoded signals having a 50-cycle field rate, 625-line rate, and a 4.43-Mc color subcarrier. The camera chain can be transferred to this type of service by actuating a single, remotely-located switch, since relay control had been provided in all of the appropriate modules. In the case of the TK-27, we have chosen to provide a CCIR type of operation using a 4.43-Mc subcarrier and having I and Q bandwidths which are the same as those used in our domestic FCC approved transmissions.

CONCLUSIONS

The development and design of the TK-27 color film camera represents another step forward in the Broadcast and Communications Product Division program to design and produce a series of modularized, transistorized camera equipments providing increased reliability, maintainability, and flexibility for the broadcast. It is the first of the new series of color cameras to become commercially available to the market.

ACKNOWLEDGEMENT

The TK-27 color film camera design program was materially aided by the following engineers: *Systems*, R. A. Dischert; *Electrical*, A. Reisz, R. R. Brooks, L. J. Bazin, and W. J. Derenbecher; *Mechanical*, W. A. Tsien; and *Optical*, Miss G. L. Allee, and L. T. Sachtleben.

BIBLIOGRAPHY

1. K. Sadashige and Dr. H. N. Kozanowski, "A Brief Review of Color TV Camera Development," RCA ENGINEER, *10*-2, Aug.-Sept. 1964.
2. N. L. Hobson, "Product Design Philosophy for New Broadcast TV Camera Equipment," RCA ENGINEER, *10*-2, Aug.-Sept. 1964.
3. R. G. Neuhauser, "Developments in Electron Optics Produce Two New Lines of Vidicon Tubes," RCA ENGINEER, *10*-2, Aug.-Sept. 1964.
4. N. P. Kellaway, "RCA's Newest Monochrome TV Film Camera, TK-22," RCA ENGINEER, *10*-2, Aug.-Sept. 1964.

MINIATURE C-BAND SOLID-STATE FREQUENCY MULTIPLIER FOR MISSILES

A rugged, miniaturized, all-solid-state harmonic generator especially designed to operate under the adverse environmental conditions encountered in missile applications is described. The harmonic generator is a module, 26 in^3 in volume, which accepts power in the 30-to-40-mw range at 104 Mc, amplifies this power to approximately 8 watts, and then harmonically converts the frequency by a factor of 48 to 5,000 Mc. At this frequency, a power output in excess of 400 mw is obtained over the temperature range from 0° to 75°C with minimal white-noise contributions in the vicinity of the output frequency.

J. J. NAPOLEON, D. E. NELSON and C. L. CUCCIA*

Microwave Tube Operations Department
Electronic Components and Devices, Harrison, N. J.

A NEW, miniature, c-band, solid-state harmonic generator, RCA Developmental No. SS-1025, especially designed for operation in missile environments has demonstrated characteristics that are believed to be unique and to represent contributions to the state-of-the-art of such devices. Particularly significant is the ability of this miniaturized device to operate over a wide temperature range (0° to 75°C) without degradation in performance or generation of white noise at, or near, the carrier frequency.

The SS-1025 harmonic generator is a highly ruggedized device that uses varactors to achieve frequency multiplication at a high conversion efficiency. The electrical characteristics, mechanical features, and environmental capabilities of this device are generally representative of what can be achieved with a c-band harmonic generator especially designed for use in missile applications.

BACKGROUND

In 1958, disclosures by Chang[1], Uhlir[2], and others indicated the exceptional capabilities of varactors to provide frequency conversion with comparatively low conversion losses. Since that time, efforts to derive the maximum benefit from this technique have been intensive in a variety of areas, including: 1) the development of varactors having wide ranges of characteristics; 2) the development of transistors capable of handling high power in the 100-Mc range; 3) the development of harmonic-generator techniques of practical use in the range from 500 to 5,000 Mc and above (the range between the frequencies at which lumped-constant parameters can be used to advantage and those at which waveguides provide the optimum circuit performance); and 4) studies to obtain a more thorough understanding of the "idler" circuit which has made possible frequency multiplication by factors of 3 and 4 at efficiencies heretofore attainable only in frequency-doubler circuits.

By 1962, a wide variety of advances had been made in all the areas mentioned above. Evidence of these advances was provided by the development of varactors and transistors capable of producing several watts of output power in c-band,[3] the commercial availability of varactors and transistors having reproducible characteristics and capable of operation at many power levels and in various frequency ranges, and the development of high-performance frequency tripler and quadrupler circuits having efficiencies between 40 and 50%.

The development of the SS-1025 harmonic generator was a direct outgrowth of several earlier programs carried out by RCA. Pioneering research in 1958 by Dr. K. K. N. Chang[1] and C. Stocker at the RCA Laboratories provided one of the earliest disclosures of the use of varactor harmonic generation to obtain c-band frequencies. Subsequent work in RCA resulted in the development of practical devices and circuits.

At the RCA-EC&D plant in Somerville, New Jersey, parallel programs led to two developments which represented substantial advances in the art: 1) the design of power transistors[4] which could provide several watts of output at 100 Mc and 2) availability of a variety of varactors having increased power-handling capabilities at various frequencies. The development of a varactor having a breakdown voltage[5] of 200 volts and of a 50-volt, c-band pill-type gallium-arsenide varactor[6] contributed greatly to this program.

Two other programs in RCA furnished a background of key system-and-circuit design information. As early as 1959, groups at RCA Victor Co., Ltd., in Montreal[7] and RCA Industrial Electronic Products in Camden,[8] during developments of remote, unattended radio-relay stations for commercial applications, started work on chains of transistor-amplifier and varactor-harmonic-generator circuits for use in s- and c-band multichannel FDM-FM radio-relay applications. These systems were developed and placed in test and service, in both Canada and the United States, during the period from 1961 to 1963. From the standpoint of circuit performance, reliability, and reproducibility these radio-relay circuits became the proving ground for a wide spectrum of devices and circuit techniques. The experience gained from these programs formed a basic starting point for the development of the subject c-band harmonic generator.

Final manuscript received October 7, 1964
*Mr. Cuccia is no longer with RCA

J. NAPOLEON received his BSEE from Newark College of Engineering in 1958 and his MSEE from Rutgers University in 1960. He served in the U. S. Army Signal Corps from 1953 to 1954 and worked first as an Instructor of microwave theory, and later as a technician on a microwave relay station. In 1952 and in 1956 and 1957, he taught courses in radio and television at the Jersey City Technical Institute. He joined the RCA Microwave Tube Operations Department in 1957. In 1958, he was assigned to the Microwave Design and Development Engineering group and participated in the development of a number of advanced types of traveling-wave tubes for quantity production. He made valuable contributions to traveling-wave-tube technology, particularly in relation to miniaturization techniques. In 1960, he was assigned to parametric-amplifier programs and was responsible for the development of several such devices. He is currently a project engineer on several solid-state parametric-amplifier and tunnel-diode-oscillator development programs. Mr. Napoleon is a Member of the IEEE and of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

DONALD E. NELSON received the BSEE and MS from the University of Illinois, in 1941 and 1948, respectively. From 1941 to 1945, he worked as a development engineer at Westinghouse Electric Corporation, Bloomfield, New Jersey, on pulsed magnetrons. From 1945 to 1949, he was Research Assistant and Research Associate at the University of Illinois Tube Laboratory working on CW magnetrons and millimeter-wave devices. Since 1949, he has been with the RCA Microwave Tube Operations Department in Harrison and Princeton, New Jersey. From 1949 to 1959 he was concerned with magnetron development. Since 1959, he has worked on development of oscillators and amplifiers employing tunnel diodes. Mr. Nelson is a member of Eta Kappa Nu and Tau Beta Pi.

J. J. Napoleon

D. E. Nelson

TABLE I — Characteristics of Typical Unit

Electrical	
Input Frequency	104 Mc
Input Power	30 mv minimum, 40 mw maximum
Input Impedance	90 ohms
DC Input Power	18 watts at nominal input power
DC Input Voltage	56 volts nominal
Output Frequency	5,000 Mc
Output Power	400 mw
Output Impedance	50 ohms
Spurious Output	60 db below signal, minimum
Bandpass (3-db points)	20 Mc minimum
Mechanical	
Orientation	Any
Dimensions	Refer to Fig. 6
Volume	26 in^3
Weight	17 oz

Environmental Capacity

Vibration—Sinusoidal vibration level of 5 g peak from 15 cps to 2,000 cps at a sweep rate of 2 minutes per octave. Random Gaussian vibration level of 0.2 g ^{2}/cps from 20 cps to 1,200 cps. The two vibration modes are applied concurrently.

Acceleration—Constant acceleration of 50 g applied along any axis.

Shock—150 g in any direction for a duration of 1.5 msec.

Temperature—Operating, 0 to 75°C case temperature; Nonoperating, —60°C to 100°C.

OPERATING CHARACTERISTICS

The SS-1025 C-band harmonic generator was designed to meet the electrical, mechanical, and environmental specifications listed in Table I. The device delivers 0.4 watt of output power at 5,000 Mc in response to an applied power of 30 to 40 mw at 104 Mc. Although this output power does not represent the maximum value for the state of the art, it is moderately high and can be maintained essentially constant for all aspects of missile environment.

The circuits of the SS-1025 are housed in a small 1-pound module, only 26 in^3 in volume, that is thoroughly capable of withstanding the shock, temperature, vibration, and acceleration conditions listed in Table I.

CIRCUIT DESCRIPTION

The SS-1025 harmonic generator consists of a three-stage transistor amplifier followed by a three-stage frequency multiplier chain. A block diagram of the basic harmonic generator circuit is shown in Fig. 1.

The three-stage transistor amplifier is operated with an RF input power of 30 to 40 mw at 104 Mc and provides 8 watts of output power at 104 Mc. Although the transistor amplifier is capable of providing greater output power, (as will be discussed later) the design value of 8 watts is consistent with the DC input power specification of 23 watts maximum over the 0°C-to-75°C temperature range under all drive conditions.

The three-stage multiplier chain, which provides a frequency multiplication factor of 48, is operated at an RF input power of 8 watts and providês in excess of 400 mw of RF output power at 5,000 Mc. The specific multiplication factors and sequence of multiplication selected for the chain were determined by the harmonic-generator performance specifications and transistor-amplifier design objectives which dictated: 1) the required multiplier output frequency and frequency multiplication factor; 2) the RF input and output power levels and, in turn, the efficiency; 3) the maximum allowable size and weight; and 4) the required environmental capability. The multiplier chain consists of a low-frequency power quadrupler (104 to 416 Mc) which drives a tripler (416 to 1,250 Mc) which, in turn, drives a high-frequency quadrupler (1,250 to 5,000 Mc). A design objective of 40% efficiency for each multiplier stage was established in order to achieve more than 400 mw of RF output power at 5,000 Mc with the 8-watt input power.

The C-band harmonic generator (Fig. 2) is required to perform many functions in addition to providing stable frequency conversion of RF power: e.g., the spurious output must be very low, 85 db below the output signal level; and because of a specific system requirement, white noise must be virtually nonexistent in a 3-Mc frequency band which is centered 52 Mc above the output frequency. Also, operating stability must be attained for all input powers between 30 and 40 mw over the entire temperature range.

The three-stage transistor amplifier, circuit *A* in Fig. 2, was specially designed to operate at the 8-watt level for a DC supply voltage of 55 to 57 volts. Pi-type matching networks provide the interstage coupling throughout the amplifier chain. This type of coupling in transistor amplifiers provides both excellent impedance matching between stages and attenuation of the higher harmonics which could be troublesome in the frequency-multiplier section.

The first stage uses a low-power, high-gain transistor capable of producing 500 mw of output at 104 Mc. This transistor increases the input power level to approximately 300 mw. The transistor used in the second stage and the paralleled transistors in the output stage are rated to provide a combined 10-watt output at 104 Mc. The second stage has an output of about 3 watts, which is applied to the pair of parallel transistors in the output stage. In response to this input,

TABLE II — Varactor Characteristics

Stage, Mc	Capacitance (at —6 volts), pf	Reverse Voltage Breakdown, volts	Cut-Off Frequency Gc
104-416	15	200	20
416-1,250	10	120	25
1,250-5,000	1	50	60

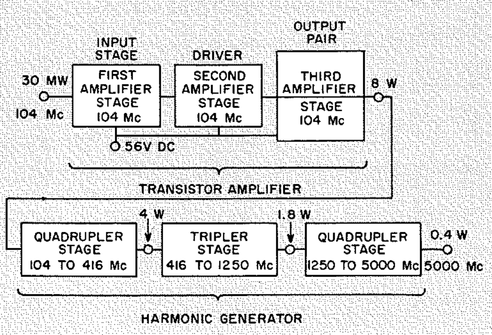


Fig. 1—Block diagram of the C-band harmonic generator.

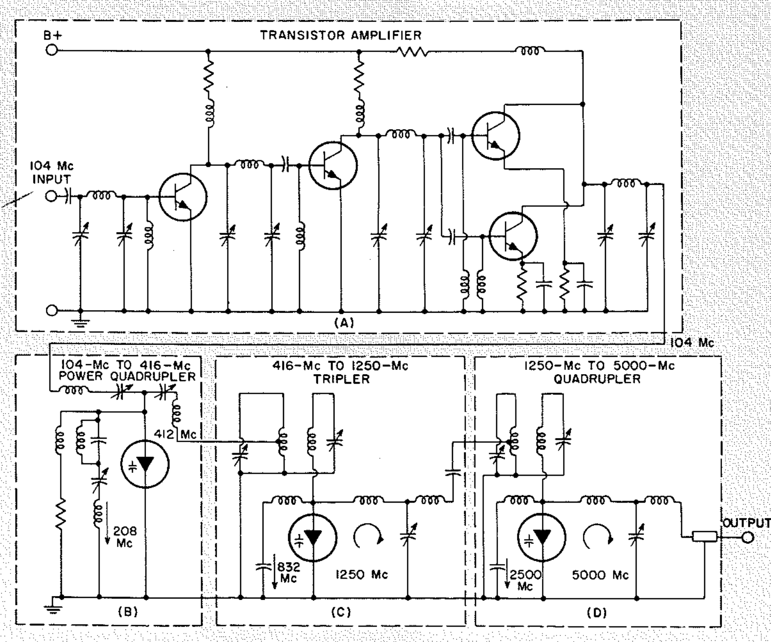


Fig. 2—Schematic diagram of the C-band harmonic generator.

the output stage provides from 8 to 10 watts of output power from the transistor chain.

The power quadrupler, circuit *B* in Fig. 2, is a shunt-type current-pumped varactor circuit, which is designed to act as the load of the transistor amplifier. The power quadrupler uses a 208-Mc idler circuit[9] and is designed to function with a 200-volt reverse-breakdown varactor having a capacitance of 20 pf at zero bias. The efficiency of this circuit is between 40 and 50%.

The two final stages of the harmonic generator, circuits *C* and *D*, are identical in their basic form. Each is a shunt-type, current-pumped frequency converter using a band-pass filter type of input coupling circuit, a single idler circuit to shunt the second harmonic of the input, and a resonant-filter type of output circuit. In each of these stages, waveguide devices are used for the output circuits.

The frequency-multiplier chain, shown by the lower section of Fig. 2, uses three varactors having the characteristics shown in Table II. The chain is an integrated circuit, designed to operate with each succeeding stage functioning as the output circuit of the state driving it. In order to achieve optimum overall circuit performance, a minimum number of varactor stages consistent with the objective overall efficiency was selected so as to minimize circuit complexity and to facilitate integrated circuit adjustments. Interstage filters and intrastage idler circuits are tunable, so as to accommodate differences in varactor characteristics, to allow for circuit adjustment to achieve optimum interstage frequency selection and impedance transformation. Because of the excellent filtering and matching throughout the chain, the generation of spurious responses is minimal.

A breadboard of the transistor amplifier and frequency-multiplier chain was built in which the circuit structures were designed to be compatible with the objective that the final harmonic generator have a volume of only 26 in.^{3} The unit was tested to obtain some verification that the performance of the individual stages would be as predicted and that the objectives of the overall chain would be accomplished.

The breadboard unit was operated to provide approximately one-half the output power required of the final harmonic generator. In this unit, two frequency doublers, which provided frequency conversions from 1,250 to 5,000 Mc, were substituted for the final quadrupler. It was found that the cascaded doublers did not permit the flexibility of operation and did not provide overall conversion losses as low as the direct frequency quadrupler.

THE PACKAGED C-BAND HARMONIC GENERATOR

Extensive breadboard tests were made before the final structure was evolved.

Fig. 3 shows a working unit of the overall C-band harmonic generator and shows the small size and the output probe of the device. Particular note should be made of the absence of protuberances and of the accurately maintained rectangularity of the housing. The box is made of aluminum, and all sections, internal and external, are formed by dip-brazing. All parts are gold-plated.

Fig. 4 shows the outline dimensions of the bottom, side, and top of the C-band harmonic generator. The maximum dimension is shown to be 4.16 inches, and the width of the unit is only 2 inches. The outline of the side view includes a diagram of the actual location of the various stages of the unit.

As shown in Fig. 4, the unit has four connections: a ground post, a DC post to which a voltage of 56 volts is applied, a 90-ohm RF input coaxial connector, and a 50-ohm RF output probe which can be used to drive a cavity circuit or a suitable coaxial receptacle.

In the transistor deck, each transistor is sealed into a well in the deck for effective heat sinking. The power quadrupler is assembled onto a small separate chassis which is then mounted next to the transistor deck and connected so that the transistor-amplifier chain and the power quadrupler can be tested as an integral unit. The tripler and the output quadrupler are housed in the harmonic generator shell. The output quadrupler is removable for separate tuning and adjustment.

All component units of the chain are assembled separately and before being mounted in place, each individual stage is checked at the power levels at which it is to operate. When the assembly is complete, nineteen controls are available to provide all final tuning adjustments which are needed to obtain optimum operation of the chain and to eliminate all spurious responses and output-frequency white noise.

MECHANICAL RUGGEDIZATION

The C-band harmonic generator is built to withstand vibrations up to 5 g from 15 cps to 2,000 cps concurrent with random Gaussian vibrations of 0.2 g^2/cps from 20 cps to 1200 cps; an acceleration of 50 g and a shock of 150 g for a duration of 1.5 msec.

The ability of the harmonic generator to withstand these vibration, acceleration, and shock conditions was demonstrated by an operating unit of the type illustrated in Fig. 3. Several features were incorporated into the harmonic generator to insure that it would withstand the required environmental conditions. Very thin aluminum walls were used throughout to obtain a low-inertia structure. Ruggedized capacitive and inductive components were employed and rugged Teflon-loaded mounts were used for the longer varactor and inductance mounts. All transistor-amplifier resistors and leads were attached to circuit-board subassemblies with a bonded coating.

Emphasis was placed on precision fitting of all component sections which were assembled together and, wherever practical, insulator bushings were used to support all members which might bend or move during vibration.

ELECTRICAL PERFORMANCE—ROOM TEMPERATURE

A series of tests of the C-band harmonic generator was conducted to evaluate its performance at room temperature. In these tests, the power outputs of individual circuit elements and of the overall unit were measured with all circuits operated at the frequencies and DC and RF input power levels specified for the device.

The transistor amplifier and power quadrupler were found to have a stable power output and a very wide frequency range at room temperature. For a DC current input of 350 ma (20 watts at 56 volts) and an RF power input at 104 Mc of 30 to 40 mw, power outputs at 416 Mc of 4 to 5 watts were repeatably measured; the overall bandwidth for these circuits was in the order of 10%. Resistive self-bias was used in the power quadrupler so that the forward conduction of the varactor would be held to a minimum during the application of the 104-Mc input power.

Fig. 5 shows the behavior of the 5,000-Mc output of the final two stages of the harmonic generator in response to a 416-Mc input at power levels up to 5 watts. The two curves in the figure compare the behavior when no tripler bias is used with that obtained when the tripler uses resistive self-bias. For an unbiased tripler, the power output (near saturation) is shown to be almost 600 mw for a power input between 4 and 5 watts; however, as the power input is reduced below this level, the power output is abruptly decreased and is very rapidly reduced to zero. When resistive self-bias is used in the tripler, the maximum power output attainable is slightly less, but the power input-versus-power output curve remains smooth and continuous as the input is reduced to negligible power levels.

Units of the overall C-band harmonic generator have provided up to 750 mw at room temperature when peaked for maximum power output. In general, the harmonic-generator units, operated with a wide variety of varactors and transistors, have demonstrated stable operation over the 30- to 40-mw input power range with outputs in the 400-to-500-mw range.

ELECTRICAL PERFORMANCE IN THE 0-TO-75° TEMPERATURE RANGE

The problem of maintaining stable electrical performance for the harmonic generator over a temperature range of 0°C to 75°C, as measured at the case, was as extensive as that of the actual design of the unit.

Several of the techniques which contributed to the achievement of stable performance characteristics over so wide a temperature range are as follows: 1) Each stage was operated slightly above saturation level; 2) The heat-sinking provisions for all heat-generating transistor and varactor elements were excellent; 3) The characteristics required of the transistors and varactors to be used in the harmonic generator were precisely specified; 4) Sufficient signal isolation was provided between stages so that small changes in varactor characteristics would not cause significant mismatches which would be accompanied by instability and a reduction in the power output; 5) Self-bias was used in all varactor stages; 6) Although thermistor compensation of all transistor bias and voltage circuits was not found to be necessary, the exact parameters of the transistor bias circuits were defined.

The most important technique used to achieve stable operation of the harmonic generator over the required temperature range was that of "hot tuning", which was applied only after the benefits to be derived from the techniques listed above had been achieved. In the hot-tuning process, the harmonic generator is detuned slightly, at some sacrifice of output power, to obtain the required uniformity in performance over the wide temperature range. This detuning is performed during a heat run at each extreme of the temperature range. The method of detuning is described below:

The unit is tuned initially at room temperature to provide an optimum level of RF output power consistent with a clean spectrum. Acceptable performance is obtained for an extended range of drive conditions; namely, 25 to 50 mw of RF input power, 50 to 60 volts DC input, and a DC power input well under 22 watts.

The ambient temperature is then raised to a level at which the case temperature of the unit stabilizes at 75°C. Typically, as the temperature rises, the DC current drawn by the transistor amplifier increases and the 5,000-Mc output power decreases. After the unit has stabilized at 75°C, the transistor amplifier is detuned so as to limit the DC input power to 22.5 watts and the multiplier chain is retuned to obtain the required 5,000-Mc output power while retaining the clean spectrum.

The ambient temperature is then reduced to 0°C and the temperature of the nonoperating unit is allowed to stabilize at 0°C. Once the unit has stabilized, the RF and DC inputs are applied to the unit and performance is observed for a period of 10 minutes after "snap-on." Typically, at snap-on, DC transistor current is low, 5,000-Mc output power is low, and considerable white noise in combination with discrete spurious signals are present at the RF output. If, within the 10-minute period after snap-on, the unit performance does not improve to meet specifications, the multiplier chain is retuned. The 0°C snap-on test is once again made, and the cycle is repeated until satisfactory performance is achieved within the 10-minute limit. The ambient temperature is then allowed to rise until the case temperature of the operating unit stabilizes at 75°C. Additional tuning is performed if necessary and the temperature cycle from 0°C snap-on to 75°C tuning is repeated until the specification is satisfied over the entire temperature range. Performance is continuously monitored during cycling to confirm proper operation at intermediate temperatures.

The snap-on problem at near-zero temperatures is due primarily to a reduction in 104-Mc output power from the transistor amplifier, caused by lower transistor amplifier gain. In this low-gain condition, the DC current drawn by the transistors operating in Class C service is reduced. The warm-up time of the amplifier is therefore increased because of the lower dissipation in the transistor junctions. At near-zero temperatures, selected circuits in the transistor amplifier can be tuned to increase the amplifier gain. It is also possible to tune the multiplier chain to reduce its low-level threshold.

Another characteristic of the harmonic generator is the drift of RF-input-power threshold with temperature. The C-band harmonic generator is required to operate at an RF input power in the range of 30 to 40 mw. Typically, the harmonic generator can be tuned to operate satisfactorily with RF input power in the range of 25 to greater than 50 mw at room temperature. The lower limit of 25 mw represents a threshold, below which insufficient power output is obtained at 5,000 Mc, or excessive noise appears in the output spectrum. As the temperature increases or decreases, the input power threshold increases may exceed 30 mw. The harmonic generator must then be tuned to maintain an adequate guard band between the RF input power threshold and the 30-mw limit over the operating temperature range.

Figs. 6 and 7 show typical characteristics of a unit in which hot tuning was used to meet the objective specifications. Fig. 6a shows the power output of the transistor amplifier and the power quadrupler subchain as a function of the input power at 104 Mc, for case temperatures of 0°, 30° and 75°C; Fig. 6b shows the DC input current to the transistors as a function of the input power. As shown, the power output of the sub-

Fig. 3—Packaged ruggedized SS-1025-C-band harmonic generator.

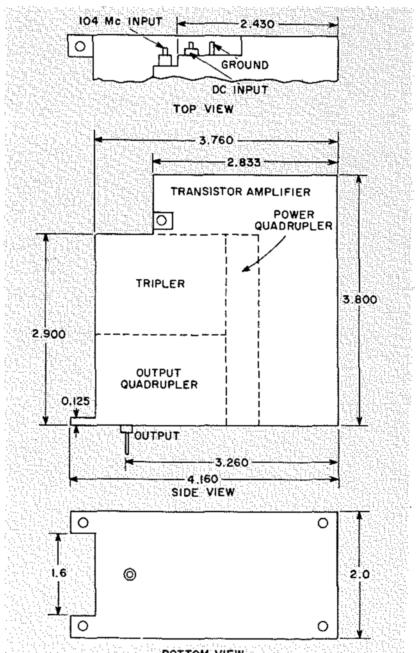


Fig. 4—Outline dimensions of the C-band harmonic generator.

chain remains above 4 watts at 75°C for all useful input powers in the 30-to-40-mw range. During this test, the transistor current did not exceed 400 ma, which represents a maximum DC power of 22.4 mw. The curves show that the power output at each temperature is a relatively constant function of input power across the 30-to-44-mw input-power range.

Fig. 7 shows the power output at 5,000 Mc for two different units, each operated with 34 mw of input power and for case temperatures from 0°C to 75°C, As shown, these units have power outputs which vary between a maximum of 500 mw and a minimum of 400 mw.

WHITE NOISE

In certain missile system applications, the 5,000-Mc output signal (carrier) of the harmonic generator serves two functions, namely, 1) transmitted carrier, and 2) local-oscillator signal. In this application, a few milliwatts of the transmitted carrier serves as a local-oscillator signal which is coupled to a mixer in the front end of a low-noise receiver. The receiver is tuned to a frequency which is displaced from the harmonic-generator output signal by the receiver intermediate frequency. The sensitivity of the receiver is determined in part by the noise figure of the mixer, which in turn depends largely on the white-noise output of the harmonic generator in the frequency band which encompasses the receiver frequency. In the case where the limiting factor on receiver sensitivity is the white-noise output of the harmonic generator, it is necessary to obtain a quantitative measure of this white noise. The level of white noise may be expressed in terms of the minimum discernible signal (MDS) in the output spectrum of a receiver where sensitivity is limited by the white-noise output of the harmonic generator.

A block diagram of the test system used to measure MDS is shown in Fig. 8. A diplexer couples a small amount of the harmonic-generator output signal to a mixer to act as a local-oscillator signal. The mixer output is fed into a low-noise IF amplifier whose undetected output is viewed on a spectrum analyzer. One port on the diplexer is common to both transmitted and received signals. The transmitted signal (harmonic-generator output) is terminated in an isolator. A simulated receiver signal, which is obtained from a calibrated signal generator, flows through the isolator into the diplexer and to the mixer. The smallest receiver signal, referenced to the transmitter-receiver port of the diplexer, which produces a discernible spike within the noise spectrum viewed on the spectrum analyzer is defined as the minimum discernible signal (MDS). The magnitude of the MDS is a measure of the white-noise output of the harmonic generator.

Alternate white-noise measurement techniques for the harmonic generator are: 1) standard noise-figure measurements, and 2) system sensitivity tests by the customer. Direct correlation has been obtained with the three measurement techniques.

The MDS of the two units used to obtain the performance curves shown in Fig. 7 was measured with the test setup shown in Fig. 8. In unit No. 1, the MDS varied from −111 dbm at the extreme temperatures to −112.6 dbm at peak power. In unit No. 2, the MDS was −110 dbm at 0°C and decreased to −113 dbm at 75°C.

The MDS figures were monitored during all temperature runs, and it was found that selected stages of the C-band harmonic generator could be tuned to provide a minimum MDS. The monitoring of MDS provided an excellent guarantee of the purity of the output-power spectrum, gave insight into controls needed for total control of harmonic-generator performance, and indicated the magnitude of the varactor biases and the reverse-breakdown voltage of each varactor required for minimum MDS.

SPURIOUS OUTPUTS

Spurious outputs (discrete frequencies as opposed to white noise) at levels of −80 dbm or greater were present only at frequencies representing integer multiples of 1,250 Mc. Typical power levels of spurious outputs are shown in Table III. As Table III shows, the spurious outputs are better than 90 db below the signal (+26 dbm at 5,000 Mc).

TABLE III — Spurious Outputs

Spurious-Response Frequency, Mc	Spurious-Response Level, dbm
1250	—75
2500	—80
3750	—65
6250	—65
7500	—75

ACCEPTANCE TEST

Table IV shows acceptance test data on important parameters, measured at room temperature, for a finished unit of the C-band harmonic generator prior to customer acceptance. Of interest is the 1-db bandwidth of 10.8 Mc, the 3-db bandwidth of 18.6 Mc, and the constancy of output power over a time interval of 21 hours.

ADVANCED ASPECTS

The C-band harmonic generator described has been designed for a specific power output consistent with low DC power and 56 volts of applied voltage. Some indication of other operating capabilities are mentioned below.

Experiments with the transistor amplifier operated at higher voltage and with an additional transistor amplifier stage as a driver to the parallel output stage have indicated that up to 15 watts of output can be obtained from the amplifier chain. With such power into the frequency-multiplier chain and with the use of varactors designed for higher-power-level operation, power outputs in excess of 1 watt are attainable at 5,000 Mc without any revision in the package.

It must be recognized that the attainment of power outputs substantially higher than those characteristic of the SS1025 will require varactors having more stringent requirements, particularly in relation to heat-sinking provisions and characteristic parameters. In addition, operation may have to be restricted to narrow temperature ranges to preserve the operating characteristics because of the necessity of operating the varactors closer to power saturation.

The operation of the harmonic-generator unit is not necessarily restricted to the conversion of 104-Mc power to 5,000-Mc power. For example, if the output quadrupler is replaced by a tripler, or by a doubler, power outputs in low S-band can be achieved. Also, the circuit components used can be retuned, with only minor modifications, to provide frequency conversions up to 133 Mc to 6,400 Mc at the same power levels. At significantly higher frequencies, however, the efficiency of the transistors is substantially reduced, and major design changes would be required

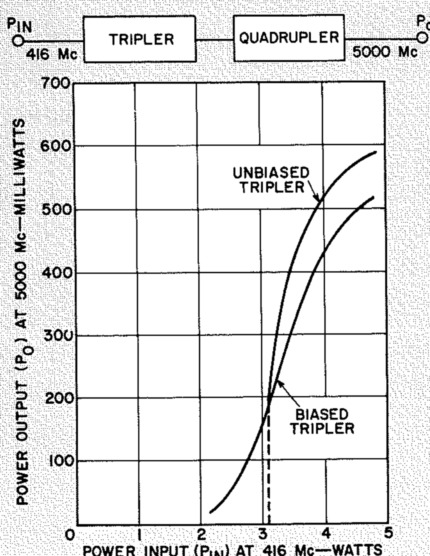


Fig. 5—Power output at 5,000 Mc of the tripler and output quadrupler combinations as a function of driving power at 416 Mc, for the conditions of bias resistor and no bias resistance in the tripler.

TABLE IV—Acceptance Test Data

Finished SS1025V7 Unit (Serial No. M-12, weight 17 oz.) tested prior to customer acceptance (at room temperature) on 1/27/64. Diplexer No. 1968.

General Data							Aging test at elapsed time: in hours, of: 0 *1st on*	4 *off*	4 *2nd on*	15 *off*	15 *3rd on*	21 *off*
Supply voltage, volts	55	55	56	56	57	57	56	56	56	56	56	56
Supply current, ma	316	360	321	373	327	383	313	318	318	317	318	318
Input signal power, mw	30	40	30	40	30	40	30	30	30	30	30	30
Output power, mw	415	460	435	485	445	500	440	430	430	420	420	420
Center freq., Gc	5	5	5	5	5	5	5	5	5	5	5	5
1.0-db bandwidth, Mc:												
total	10.9	11.4	10.8	12.0	11.2	11.9						
low side	6.7	7.1	6.7	7.6	6.9	7.8						
high side	4.2	4.3	4.1	4.4	4.3	4.1						
3.0-db bandwidth, Mc:												
total	18.7	18.2	18.6	18.4	18.6	18.3						
low side	12.3	12.1	12.3	12.3	12.2	12.4						
high side	6.4	6.1	6.3	6.1	6.4	5.9						
Spurious outputs (at 5,032 Mc), dbm	—116	—116	—116	—116	—116	—116						

Remarks:

Spurious outputs at 1,250, 2,500, 3,750, 6,250, and 7,500 Mc were not detectable.

System sensitivity:

@ Mc:	1,250	2,500	3,750	6,250	7,500
dbm:	—75	—80	—69	—68	—74

in the circuits of the frequency multiplier chain to obtain comparable conversion efficiencies.

PRODUCT IMPROVEMENT

This paper reports the first product-design cycle for the SS1025V7 harmonic generator, in which the major problems of miniaturization and ruggedization were overcome wtih relatively small sacrifice in electrical performance. Late in 1963, the SS1025V7 harmonic generator successfully completed flight certification testing. A total of fifteen units have been delivered to the customer whose missile transponder system has, in turn, passed flight certification tests.

A product improvement program is currently underway to design a second-generation device. Specific objectives are:

1) Substitution of recently-developed stud-mount transistors for the older TO-5 configuration transistor in the power amplifier. This modification will improve heat dissipation, increase the guard band between actual and rated power output, and reduce the product fabrication cost in manufacturing. A prototype amplifier has been built and is now being tested.
2) Temperature compensation of a key frequency multiplier tuner. There was need to eliminate the cycling to tune the harmonic generator for performance over the 0°C-to-75°C temperature range. The improved multiplier incorporates a tuner designed to be self-compensating over the temperature range, based on dissimilar thermal-expansion rates for the materials selected.
3) Redesign of the input section to increase conversion efficiency of the final multiplier stage.

The improvement program is still underway. However, a harmonic generator which incorporates the temperature-compensated tuner and modified input section in the final multiplier stage has demonstrated the following performance:

1) RF output power in excess of ½ watt was obtained over the entire temperature range of 0° to 75°C;
2) unit required no warm-up time at 0°C snap-on;
3) unit demonstrated acceptable performance across the 0° to 75°C temperature range after initial tuning at room ambient temperature.

It is anticipated that the improved harmonic generators will complete flight certification and be in limited production by the end of 1964.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contributions made to this development by F. Sterzer, E. Bliss, A. Presser, B. Minton, A. Solomon, F. Elliott, R. Marx, C. Hughes and E. Kuhmann.

BIBLIOGRAPHY

1 K. K. N. Chang, "Harmonic Generation with Non-linear Reactance," *RCA Review*, Sept. 1958.
2 A. Uhlir, "The Potential of Semiconductor Diodes in High-Frequency Communications," *Proc. IRE*, June, 1958.
3 B. Bossard, S. J. Mehlman, and A. Newton, "A Solid State One-Watt Tunable Exciter for the 4.5-5.0 Gigacycle Communications Band," Paper presented at WESCON, 1963.
4 R. B. Janes, "The Continuing Revolution in Semiconductors," RCA ENGINEER, April-May, 1962.
5 Klein and Kressel, "High Power Silicon Epitaxial Varactor Diodes," RCA ENGINEER, June-July, 1962.
6 Kressel and Gibbons, "New GaAs Power Varactor Diodes VD310," RCA ENGINEER, August-September, 1962.
7 Elvidge, Lopianowski, and Martin, "The MM-600 Microwave System between Rimousky and Mt. Carleton, Canada," RCA ENGINEER, February-March, 1962.
8 Privett and Forbes, "A Transcontinental Microwave System," RCA ENGINEER, October-November, 1962.
9 Kaufman and Douthett, "Harmonic Generation Using Idler Circuits," *Proc. IRE*, April, 1960.

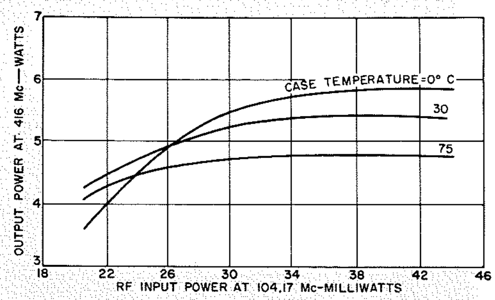


Fig. 6a—Combined output power of transistor amplifier and power quadrupler as a function of RF input power.

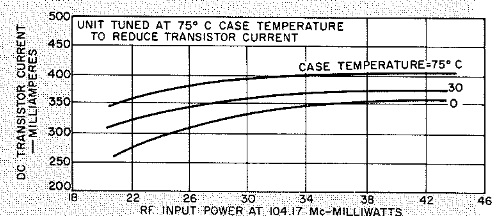


Fig. 6b—Transistor current as a function of RF input power.

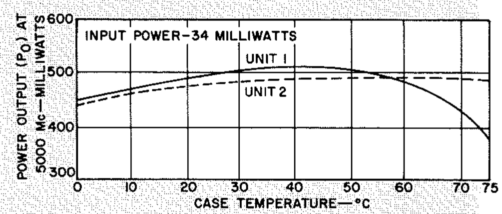


Fig. 7—Power output at 5,000 Mc for two units of the C-band harmonic generator for case temperatures from 0° to 75°C.

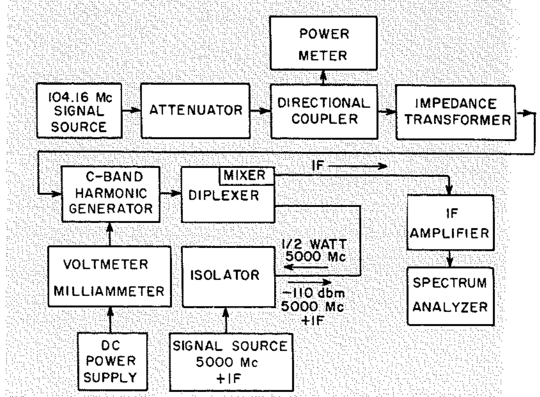


Fig. 8—Test setup used for measuring minimum discernible signal.

GEMINI SPACECRAFT PCM-FM TELEMETRY TRANSMITTERS

The GEMINI two-man spacecraft will use a pulse-code-modulated FM telemetry system operating at bit rates up to 112.6 kilobits. The RCA-designed solid-state three-transmitter system described herein provides the RF telemetry link between the spacecraft and earth. A wide range of modulation freqencies (25 cps to 150) kc) low distortion, compactness, and light weight are design features.

R. G. ERDMANN

Communications Systems Division, DEP, Camden, N.J.

The GEMINI telemetry system uses three RCA-designed solid-state transmitters in the spacecraft: one real-time unit, one for standby, and a delayed-time unit. The mid-band delayed-time unit transmits data collected by the GEMINI tape recorder[1] when the orbiting spacecraft is "between" ground stations. Figs. 1, 2, and 3 show the solid-state modulation frequencies handled, 25 cps to 150 kc, and the low distortion achieved.

The RCA transmitters have already successfully performed in the GEMINI orbital firing in April 1964 (FM-FM in this application). The special requirements of the GEMINI telemetry system, plus the destructive elements encountered in lift-off, outer space travel, re-entry and recovery imposed challenging problems, which were overcome in a design with the following characteristics.

1) Efficient operation achieved over a wide range of input voltages by a high-efficiency RF amplifier, a compact and full-regulation DC-DC power converter, and a low-loss RF output filter. The wide variation in input voltages will result from the fuel cell power supplies to be used during a projected two-week mission.
2) Thermal heat-sinking withstands thermal surges lasting one hour in a vacuum following long periods of operation at high temperatures.
3) A reactance-modulated crystal oscillator with corrected phase modulation provides maximum long- and short-term frequency stability with instant warm-up, modulation rates of up to 150 kc with 150-kc peak deviation at low distortion values, and maximum immunity from incidental FM under vibration.
4) Complete filtering of both power leads and RF output provides a "clean" output spectrum. The absence of mixers allows wideband modulation along with filtering for low spurious output.
5) Waterproof construction insures operation after extended immersion in salt water.
6) Low stress level of the components provides a long MTBF, even at high temperature: 11,000 hours at 35°C; 9,900 hours at 71°C.
7) Light weight and small size, universal requirements for aerospace equipment, are achieved.

Final manuscript received November 12, 1964

DESCRIPTION OF TRANSMITTER

Table I gives the electrical and mechanical characteristics of the transmitter.

The transmitter consists of a reactance-modulated crystal oscillator (similar to that used on the RANGER VII shot) with a corrected phase-modulated buffer amplifier and a cross-over network to yield frequency modulation over the input frequency range of 25 cps to 150 kc (Fig. 1). The high input impedance requirements of the system, along with a deviation sensitivity requirement of 100 kc/volt peak, necessitated the use of a video amplifier consisting of two stages of direct-coupled transistor amplifiers; the amplifier design employs negative feedback to minimize distortion to less than ½% over the modulation frequency range at peak deviations. The exciter, or oscillator-modulator subassembly, comprises the video amplifier, crystal oscillator, modulator circuits, and buffer amplifiers for producing a power output of 15 mw at 19 to 22 Mc. Its output is multiplied to the transmitter final frequency by 12:1.

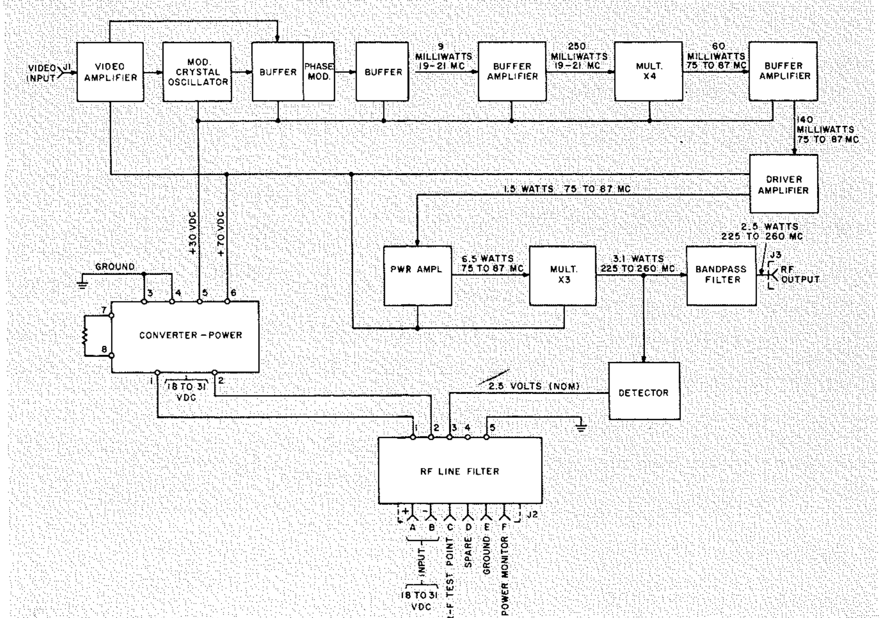


Fig. 1—GEMINI transmitter.

R. G. ERDMANN graduated from Purdue University with a BSEE (with distinction) in 1948. He did graduate work at Purdue in 1949 and University of Pennsylvania in 1952. He joined RCA in 1950, initially working on the frequency synthesizer for the AN/ARC-21 HF Transceiver. Further assignments included HF radio teletype terminal equipment, and airborne SSB receiving and transmitting circuits. In 1955, Mr. Erdmann was assigned the project of developing one of the first solid-state VHF militarized receivers (R-737 Marker Beacon Receiver). Later, his group modified the basic design of the ARR 48 data link receiver to produce the R891 receiver for the RCA DRR-1 data link system for the BOMARC-B missile. He was Leader of a group responsible for the DYNA-SOAR SHF receiver, and Search and Rescue Transceiver. He is now responsible for the GEMINI Telemetry Transmitter. He is also currently engaged in directing the group designing the LEM VHF Transceiver, to be used in the APOLLO system. Mr. Erdmann is a Member of Tau Beta Pi, Eta Kappa Nu, and IEEE.

The times-12 multiplier chain consists of a buffer amplifier driving a varactor multiplier diode which quadruples the frequency at a power level of about 60 mw. The circuit is similar to circuits developed for the DynaSoar multiplier chains for use in the SHF transmitter and receivers. Two stages of class-C transistor amplifiers follow the times-4 stage to raise the power level to about 1.5 watts. A single transistor power amplifier raises the power level to 6.5 watts and feeds four varactor diodes connected in series-parallel. The diodes convert the 80-Mc RF energy to 260-Mc output with an efficiency of almost 50%. The multiplier is matched to a bandpass filter, which has less than 1 db of insertion loss while yielding sufficient selectivity to suppress the adjacent frequency multiples by almost 70 db. This yields an antenna conducted output spectrum that is almost 83 db down.

The transmitter contains a DC-DC power converter of the regulating type to meet the requirements of wide variations in line voltages. This compact power unit weighs only 11.75 ounces and occupies about 8.5 cubic inches; it consists of an *L-C* input filter to suppress input spikes and audio frequency conducted noise, a preregulator circuit and oscillating converter, and a feedback circuit which keeps the output constant within ½% over the range of input voltages. The power converter contains a mu-metal (high-permeability) shield to suppress the magnetic field from modulating the transmitter output.

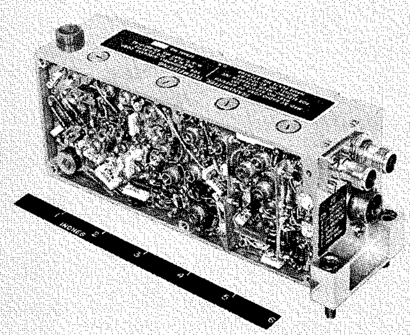


Fig. 2—Transmitter with cover removed and RF subassemblies exposed. Note that tuning adjustments are exposed. Frame is machined from solid aluminum for strength and to meet close tolerances of spacecraft mounting. When installed, transmitter is in a hermetically sealed watertight container.

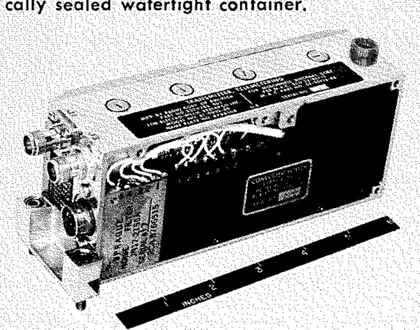


Fig. 3—Transmitter with power converter and filters exposed. An RF interference filter is built in.

DESIGN CHALLENGES

One of the more interesting design problems centered around the development of the power converter; this unit represented a challenge due to its small size and its relatively high-efficiency and low-weight requirements. The problem of weight was solved in part by potting with a filled epoxy, instead of plain epoxy.

The resultant *L-C* filter design keeps noise spikes out of the converter by integrating the spikes to a harmless value, and at the same time filters the AC ripple voltages. The converter employs a switching transistor to preregulate the input voltage to a value just below the minimum line voltage expected. An oscillating power converter then supplies the voltages required by the transmitter (70 and 30 volts) and feeds back an error signal to the switching transistor for voltage regulation. The resultant regulation holds the output voltages of the converter to a ½% value over the entire range of input voltages; thus, uniform performance is assured over line voltage input extremes.

The thermal design of the transmitter presented a problem due to a requirement for operation without a coolant flow in the heat sink, and continuous operation in a vacuum for up to one hour with wall temperatures of 100°C. This situation is encountered by the vehicle during re-entry when all available cooling is required elsewhere in the spacecraft. The transmitter must absorb all the heat in a uniform manner (i.e., no hot spots) and provide a design that can perform satisfactorily with the resulting terminal temperature. Special attention to heat-sinking of the transistors plus reducing thermal interfaces with soldered heat sinks to the metal chassis solved this.

To provide a waterproof seal plus an RFI (RF interference) tight seal in a minimum of space was approached first by use of rubber *O*-rings plus silver-filled epoxy. The epoxy was later discarded for the use of a small sawtooth-like finger stock as a more effective and stable RFI seal.

TABLE I—Transmitter Performance

Frequency	225 to 260 Mc, fixed-tuned
Power output	2.0 watts
Power input	20.5 watts (18 to 30.5 volts-DC)
Frequency stability	±.01%
distortion *Modulation*, FM	25 cps to 150 kc at peak deviation of 150 kc
intermodulation distortion	3% max.
Size	38 cubic inches (2.75 x 2.25 x 6.5 inches)
Weight	41 ounces, maximum
Temperature	0°C. to +55°C. normal cooling 100°C. and no coolant flow for 60 minutes
Immersion	In salt water to a depth of 4 feet for periods up to 12 hours, not operating.

The basic problem of high-power efficiency faces any spacecraft designer, not only for power conservation but also to reduce heat dissipation. The RF circuits, particularly the high-level stages such as the power amplifier and the final multiplier, had to be operated at the maximum possible efficiency. Thus, low-loss components, such as coils and trimmer capacitors, were mandatory. Air trimmer capacitors were found necessary in all the high-level circuits, as the loss encountered with the customary ceramic and glass units caused an intolerable amount of RF power loss. This quest for the utmost in power conservation led to the use of a bandpass output filter having only 1-db insertion loss, while still suppressing two-thirds of F_o out of the multiplier by some 70 db. In this case a large filter was adapted to the allocated space by omitting the outer barrel; this packaging concept saved enough weight so that the frame and cover could be made massive enough to absorb heat and withstand vibration.

Finally, the dense packaging of the RF circuits and the push to reduce weight caused vibration problems due to resonances in the overall package design. The high-frequency and high-efficiency requirements did not permit the use of foam encapsulants which would have helped materially. A heavier cover with chassis stiffener posts plus selective potting of components solved this.

The transmitter has passed all qualification tests with some redesign found necessary, e.g., vibration problem. The first flight test of the Gemini vehicle (April, 1964) contained three transmitters for telemetering data to ground. These units were connected in an FM-FM system employing subcarrier oscillators. All three transmitters were connected for independent data transmission on each. Flight results were extremely good, with all units functioning normally. These units were not recovered.

CONCLUSION

The Gemini telemetry transmitter is a specialized design to meet the unusual Gemini spacecraft requirements. However, the transmitter embodies solutions of problems common to all space vehicles and is, therefore, suitable to other space applications.

The transmitter was designed in the DEP Communication Systems Division's UHF Communications Equipment Engineering section in Camden. A total of 69 units will be produced on this project.

BIBLIOGRAPHY

1. A. S. Katz, "High-Packing-Density Digital Recorder for the Gemini Spacecraft," RCA Engineer, 9-5, Feb.-Mar. 1964.

ELECTRON IMAGE MAGNIFICATION IN BROADCAST TV CAMERAS SIMULATES LONG-FOCAL-LENGTH LENSES

To obtain clear close-ups from a remote TV-camera position, the camera is equipped with conventional long-focal-length lens systems. But planning for the 1964 national political conventions indicated that conventional optical lenses with focal lengths of 100 inches or more would be desirable—optics that are prohibitively costly. By operating on the electron optics in the image section of the image orthicon to produce magnification of the photo-electron image, it was possible to simulate the expensive long-focal-length lenses with relatively inexpensive shorter-focal-length lenses without any apparent degradation in picture quality. This approach was developed by and exclusive with NBC at both 1964 political conventions, and provided NBC a definite advantage over other networks in obtaining excellent close-ups.

F. HIMELFARB

National Broadcasting Co., Inc., New York City, N. Y.

In the operation of the image orthicon, the photoelectrons leaving the photocathode surface are focused on the target by means of an electronic lens produced by the electric and magnetic fields in the image section. The photoelectrons emitted from the photocathode follow approximately the magnetic lines of force and are focused on the target by proper adjustment of electrode potentials.

Fig. 1 shows the electric and magnetic fields in the image section of a 3-inch image orthicon. Since the photoelectrons follow the magnetic lines of force, the electronic lens is actually a reduction lens with a magnification ratio of approximately 0.85. The magnification ratio is related to the ratio of the magnetic flux densities at the photocathode and at the target. It can be approximately given as:

Final manuscript received October 5, 1964

$$M \approx \sqrt{\frac{\textit{flux density photocathode}}{\textit{flux density target}}}$$

In a 3-inch image orthicon camera, the focusing magnetic field strength produced by the focus coil is 75 gauss; near the target, it has decreased to about 70 gauss and at the photocathode it is only about 50 gauss:

$$M \approx \sqrt{\frac{50}{70}} \approx 0.85$$

It therefore follows that to produce magnification in the image section, it is necessary to increase the magnetic flux density at the photocathode relative to the flux density at the target.

This is exactly the procedure that is followed in 4½-inch image orthicon cameras where controlled image magnification is required. The sizes of the photocathode areas used in both the 3-inch and 4½-inch image orthicons are the same, and therefore, the electron image in the 4½-inch image orthicon must be magnified in order to fill its larger target. Magnification is produced by the addition of an auxiliary focus coil in front of the photocathode connected in series aiding with the main focusing coil, to increase the magnetic field strength at the photocathode relative to the target.

Fig. 2 illustrates this technique and the principle of electronic magnification. The field strength at the target is approximately 60 gauss and in the plane of the photocathode it is approximately 120 gauss, giving the required magnification ration $M \approx 1.5$ X.

The application of these principles to the television cameras for use at the political conventions was determined by the following operational requirements and conditions:

1) To provide for controlled image magnification in 3-inch image orthicon cameras in preset steps of 1.00 X, 1.25 X, 1.50 X, 1.75 X and 2.00 X. The first step (1.00 X) was arbitrarily chosen as normal camera operation where M is actually 0.85.
2) To provide for the random selection of these preset conditions by the cameraman during operation much the same as he would select lenses normally.
3) To provide for quick installation of the necessary equipment for image magnification and for quick removal if necessary for normal operation later on, without modification of the equipment.

To satisfy these operational requirements, the following design conditions were established:

1) An auxiliary focus coil must be provided and the current to this coil must be precisely controlled in steps.
2) In order to eliminate camera modifications, an external current regulated power supply was used to supply the auxiliary focus coil current instead of tapping into the main focus coil current source. The power supply must be capable of being programmed to produce the constant regulated currents required for each magnification step.

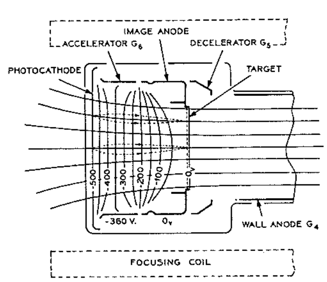


Fig. 1—Electric and magnetic fields in 3-inch image orthicon.

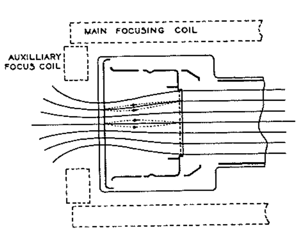


Fig. 2—Principle of electronic image magnification.

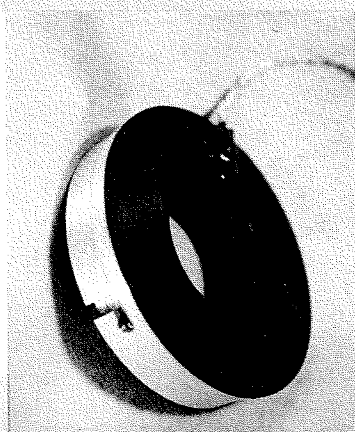


Fig. 3—Auxiliary focus coil.

Fig. 4—Auxiliary focus coil installed in the camera.

3) Electrical focus must be maintained. For each step of magnification, the photocathode voltage must be properly adjusted and because there is leakage of magnetic flux from the auxiliary focus coil into the scanning section of the image orthicon, the wall focus voltage must also be properly adjusted. A separate set of photocathode voltage and wall focus voltage controls must be provided to be switched in and preset for each magnification step. These preset controls should be at the vidoe control position where there is proper monitoring facilities for setting electrical focus.

4) In order to provide local control for the video control setup and remote control for the cameraman's selection of the desired magnification step during operation, a relay chassis must be designed to switch the current power supply programming controls, and the electrical focus controls with local pushbutton controls at the video position and remote pushbutton control at the camera position.

The auxiliary focus coil was designed to be installed in the image orthicon yoke assembly in place of the normal retaining ring. The coil form used was a bobbin made of aluminum for strength and heat conductivity fitted into an aluminum collar which is slotted to act as the retaining ring (Figs. 3 and 4). The volume of the space available for the doughnut-shaped coil is fixed by the inside diameter of the focus coil, the opening port required for the image orthicon, and the distance measured from the face of the image orthicon to the end of the yoke assembly. The efficiency of the coil is determined by the packing density of the coil. The power required for the coil is relatively independent of the wire size used over a fairly wide range. Smaller-size wire permits more turns in the given volume, requiring less current for a given flux density; but a higher voltage supply is required because of the higher coil resistance. Similarly, larger wire provides less turns, needs more current, but the supply voltage required is lower because of the lower coil resistance. The final coil design con-

FRED HIMELFARB graduated from Cornell University in 1950 with a BEE and that year joined the TV Terminal Group at RCA Camden to work on the development and field testing of color television camera equipments. In 1954 he joined NBC as an Audio Video Facilities engineer and worked on new color television studios and facilities. In 1959 he was appointed a Project Engineer in the Engineering Development Group at NBC. He is a member of Eta Kappa Nu, Phi Kappa Phi, and Tau Beta Pi.

sisted of 1,326 turns of AWG #25 heavy formex magnetic wire, form-wound. This design permitted the use of a transistorized low voltage current regulated power supply programmed to produce, in steps, constant regulated current to the coil. The coil performance results were as follows:

M	*Current*	*Approx. Power*
1.00X	0.0 amp	0.0 watts
1.25X	0.3	2.4
1.50X	0.4	4.3
1.75X	0.5	6.8
2.00X	0.7	13.0

Fig. 5 shows the remote-control box containing a set of illuminated selector pushbuttons for the cameraman. It was designed to slip over two studs mounted on the rear of the left side door of the camera for quick installation and/or removal. The auxiliary focus coil leads were also routed to a plug in the left side door and then into the control box and together with the control wires down a short cable with a standard camera cable bell connector at its end. Thus, a standard monochrome camera cable was used from the camera control position to the camera for the image magnification circuitry. This was an extra safety feature for the remote camera as it provided a possible spare main camera cable in case of trouble.

Figs. 6 and 7 show the separate electronic lens magnifier control chassis which was provided at the camera control position. This unit contains:

1) The constant current power supply
2) Switching relays
3) Local illuminated selector push keys
4) Sets of electrical focus controls
5) Current programming controls
6) Local/remote delegate switch
7) Local battery supply for the relay system

This unit requires 117 volts-AC for power input. It connects via camera cable to the coil and remote controls at the camera. It also connects via a special cable into the camera control unit which had to be modified (Fig. 8) to bring out the photocathode and wall focus voltage controls. The existing photocathode voltage control and the wall focus voltage control on the camera control unit proper are used for the 1.00 X magnifier position. A self-normalling plug is available at the control unit for use without the magnifier.

At the political conventions, an 80-inch lens and a 40-inch lens were used in conjunction with the magnifier equipped cameras. This provided the cameraman with the following combinations:

M	*80 Inch Lens*	*40 Inch Lens*
1.00X	80 inch	40 inch
1.25X	100 inch	50 inch
1.50X	120 inch	60 inch
1.75X	140 inch	70 inch
2.00X	160 inch	80 inch

Larger magnification ratios are possible but were not required for this application. The only difficulties to be encountered would be the increased power and heat dissipated in the coil and the need for increased light since the usable photocathode decreases with increases in magnification.

Fig. 5—Remote control box installed on the camera.

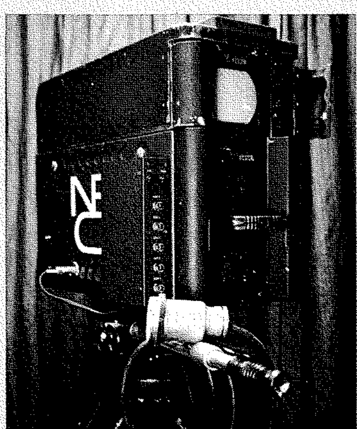


Fig. 6—Magnifier control chassis (front view).

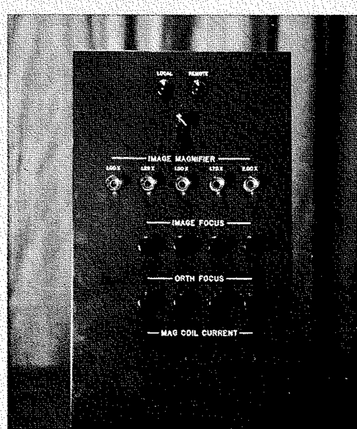
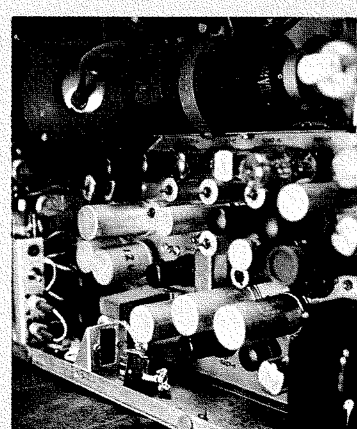


Fig. 7—Magnifier control chassis (rear view).

Fig. 8—Camera control chassis modification.



OVERLOAD CONSIDERATIONS FOR LOW-COST TRANSISTORIZED AM RECEIVERS

An important, often overlooked performance characteristic of a low-cost transistorized AM receiver is its operation without overloading in presence of a strong signal. Signal strengths exceeding 1 volt/meter can exist near a transmitting antenna. A well designed receiver must handle this strong signal and still deliver intelligible acoustic output with only a few hundred microvolts/meter present. These extremes dictate severe AGC requirements and necessitate special overload considerations. This article describes design techniques that permit improved overload performance without sacrificing receiver gain. An example of the RCA RFG20 "Marathon" portable receiver is cited wherein these techniques are successfully applied.

D. E. KOWALLEK and M. C. MEHTA

RCA Victor Home Instruments Division, Indianapolis, Ind.

OVERLOAD resulting from a strong signal will be defined as excessive distortion of the RF or IF carrier envelope. In general, for a fixed biased tuned amplifier, overload will take place in the form of distortion of the upward modulation (envelope peaks). In a tuned amplifier to which reverse AGC is applied, overload in the form of distortion of both the upward and downward modulation (envelope valleys) may occur. Either type may appear when the receiver is tuned exactly to the frequency of the transmitted signal, or when the receiver is slightly detuned. The resulting *tune-through characteristic* is a very important aspect of strong signal performance.

Fig. 1 shows the I_c vs. V_{BE} characteristic of a typical *p-n-p* germanium transistor. This transconductance characteristic may be used to predict overload, since in general, tuned amplifiers are mismatched so that the driving stage acts as a constant voltage source. The position of the operating point in the forward biased region will determine the type of overload which can occur. The position of the operating point in the reverse biased region will determine the maximum input signal that can be applied without causing overload.

Final manuscript received November 2, 1964

LARGE OUTPUT SIGNAL OVERLOAD

If a transistor is biased at Q_1 of Fig. 1 and a sufficient input signal is applied, the collector current waveform will become clipped due to current saturation. If the collector is terminated in a circuit which is tuned to the input frequency, the impedance of the tuned circuit at the harmonic frequencies will be extremely low. The voltages produced by the various current harmonics will therefore be negligible. The output voltage will then become a function of the fundamental of the current waveform. It will be a symmetrical sinusoid even though the current waveform is severely clipped. Likewise, for the case of a tuned IF amplifier biased at Q_1, a large modulated input signal will cause a symmetrically clipped voltage envelope to appear across the output tuned circuit. The result is voltage clipping as shown in Fig. 2. It is distinguished by a squared modulation envelope with a peak-to-peak voltage of approximately 2 V_{CE}.

If the tuned IF amplifier is biased at Q_2 of Fig. 1 and a large modulated input signal is applied, collector current cutoff will occur with the upward modulation. The resulting voltage envelope which appears across the output tuned circuit indicates current clipping. This is shown in Fig. 3. In this case, the envelope is distinguished by the "rounding" of the upward modulation and a peak-to-peak voltage of less than 2 V_{CE}.

SMALL OUTPUT SIGNAL OVERLOAD

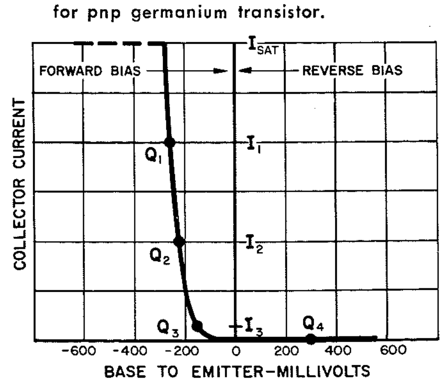
If the quiescent current of the tuned IF amplifier is reduced to a value corresponding to Q_3 of Fig. 1, the stage gain will be drastically reduced. Therefore, clipping as previously defined will not occur; however, as the input signal is increased, envelope distortion will occur as a result of the nonlinearity of the transconductance characteristic. This is shown in Fig. 4. It has been shown that envelope distortion becomes excessive if the input signal exceeds approximately 10 mv-RMS and that the distortion increases directly with the percent modulation. It is therefore desirable that the quiescent point of the transistor be moved through the knee of the transconductance characteristic toward reverse bias before the signal input exceeds approximately 10 mv-RMS.

ATTENUATION IN REVERSE BIAS

If the quiescent point of the amplifier is taken into the reverse bias region, as indicated by Q_4 of Fig. 1, attenuation of the input signal will occur. In this region, the intrinsic transconductance of the transistor is reduced to zero. However, the collector to base capacitance, C_{cb}' will cause a signal feed-through to the following tuned circuit as shown in Fig. 5. The voltage division across C_{cb}' and R_2, the effective resistance appearing at the collector of the transistor, results in signal attenuation. With a given value of C_{cb}', a lower value of R_2 will provide greater attenuation; conversely, a larger value of R_2 will provide less attenuation.

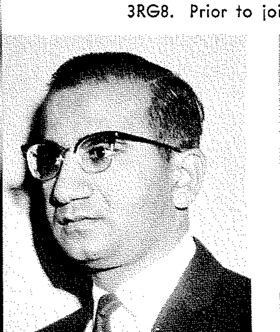
A signal input far exceeding 10 mv-RMS can be applied in the reverse bias region providing that the peaks of the upward modulation do not swing back into the forward characteristic. A sufficient reverse bias voltage is there-

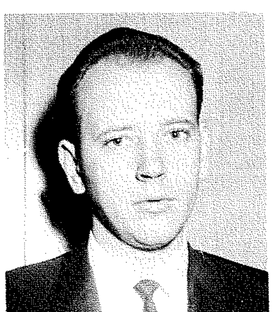
Fig. 1—Transconductance characteristic for pnp germanium transistor.



MAHENDRA C. MEHTA received his BSEE in 1960 from the University of Michigan. He also holds the Full Technological Certificate in telecommunications from City and Guilds of London. Mr. Mehta joined RCA Home Instruments Division in 1960. He has been engaged in the design of transistorized receivers. His designs include the 1RG3 and 3RG8. Prior to joining RCA, Mr. Mehta was employed by Murphy Radio, Ltd., London, for a period of one year and by Standard Telephones and Cables, Ltd., London, for a period of two years. He is a graduate member of the British IRE and a Member of the IEEE.

D. E. KOWALLEK received his BSEE from Case Institute of Technology in 1960. He is now working toward his MSEE under the sponsorship of the Home Instruments Division. Since joining Radio "Victrola" Engineering in 1960, Mr. Kowallek has been associated with the design of transistorized receiving equipment. He has designed various portable receivers including Models 3RG1, 3RG3, 4RG5, and 4RG6. He has been responsible for the development of the improved AGC systems currently used in RCA transistorized receivers. Mr. Kowallek is a Member of the IEEE.





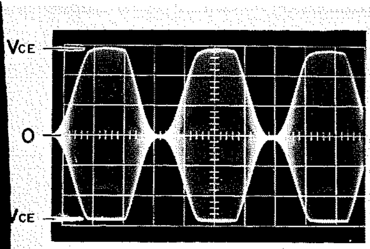


Fig. 2—Envelope distortion due to voltage clipping.

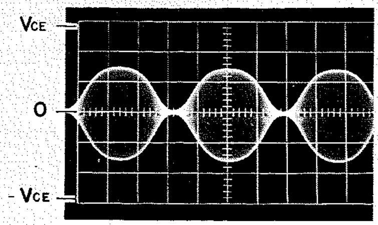


Fig. 3—Envelope distortion due to current clipping.

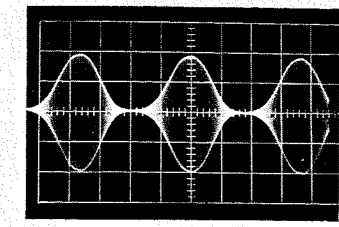


Fig. 4—Envelope distortion due to transconductance nonlinearity.

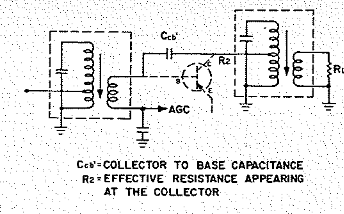


Fig. 5—Tuned amplifier in reverse bias.

fore necessary. However, this voltage should never exceed the reverse base to emitter breakdown voltage.

DESIGN CONSIDERATIONS

The amplifier immediately preceding the detector circuit will be susceptible to large output signal overload in the form of voltage or current clipping. This stage must be capable of supplying the detector with sufficient power for AGC operation before clipping takes place. Fig. 6 shows the maximum unclipped signal power output of a tuned amplifier as a function of R_2, the effective resistance appearing at the collector of the transistor. The available power reaches a maximum of $V_{CE}I_c/2$ at $R_2 = V_{CE}/I_c$ for any given set of quiescent conditions. This value of R_2 is the value at which both the full RMS current of $I_c/\sqrt{2}$ and the full RMS voltage of $V_{CE}/\sqrt{2}$ occur. Simultaneous voltage and current clipping is therefore achieved. The signal power can be increased for a given V_{CE} by an increase in I_c and a corresponding decrease in R_2. Usually, more than 1 ma of collector current is necessary to provide adequate power for AGC operation. Similarly, clipping overload in any other stage can be minimized by the choice of the proper quiescent point and a corresponding R_2.

A gain-controlled amplifier will be susceptible to small output signal overload when reverse AGC is applied. If overload is to be prevented, the AGC voltage must cause the operating point to pass through the knee of the transconductance characteristic toward reverse bias before the input signal exceeds 10 mv-RMS. In spite of the loss of gain in the controlled stage, the signal power to the detector must be sufficient to maintain reverse bias. This dictates a minimum gain requirement in the fixed gain amplifier(s) between the controlled stage and the detector. If more reverse bias attenuation is designed into the controlled stage, more gain is required in the following amplifier(s). The amount of gain required normally dictates the use of more than one stage of amplification. Therefore, in a low-cost receiver design where only one stage is used, the attempt is made to limit the signal appearing at the input of the controlled stage to 10 mv-RMS. If this is done, the stage need not be driven into reverse bias. The signal may be limited in the following three ways:

1) the transformer on the input of the controlled stage may be designed for a large voltage step down ratio;
2) the gain ahead of the controlled stage can be kept to a minimum;
3) overload protection, such as back biased diode, can be placed just ahead of the controlled stage.

The application of the various techniques for overcoming both small and large output-signal overload will result in mismatch losses which alone are not sufficient to produce stable operation. Additional mismatch losses should be distributed so that maximum stable gain per stage is achieved. In this way, overall receiver sensitivity is maintained.

The receiver should be designed to minimize overload on the selectivity skirts as well as on the center frequency. The loss of gain in the selective amplifiers as the receiver is detuned from the strong signal will allow the AGC to relax. If the AGC system is designed to reverse-bias one of the stages, the AGC may allow the operating point to return to the forward-biased region before the input signal drops to 10 mv-RMS. In this case, small output-signal overload will occur on the selectivity skirt. An undesirable tune-through characteristic will occur. To improve tune-through, the greatest portion of the receiver's selectivity should be placed ahead of the AGC-controlled stage. The gain reduction on the selectivity skirt will then reduce the input signal to the controlled stage simultaneously with the reduction of AGC voltage.

SUMMARY

A fixed-biased amplifier operating at tion. As the quiescent current is reduced, the stage gain will be reduced. Then for a given output signal, a greater input signal will be required. The inmaximum stable gain will normally require an input signal of only a few millivolts to drive the stage into clipping. The predominant envelope distortion will occur as a "flattening" or "rounding" of the peaks of the upward modulacreased signal excursion will cause envelope distortion due to the nonlinearity of the transconductance.

The envelope distortion resulting from clipping of the upward modulation may be minimized by an increase in the signal power output capability of the stage. Excessive envelope distortion which occurs at a reduced operating gain may be prevented either by 1) limiting the input signal to the controlled stage, or 2) reverse biasing the controlled stage before 10 mv-RMS appear at its input.

The RCA "Marathon" portable receiver, model RFG20, is shown in Fig. 7. This instrument utilizes two high capacity *D* cells for its power supply. Despite the limited dynamic range imposed by 3-volt operation, excellent overload performance has been achieved. At 30% modulation, this receiver can handle greater than 2 volts/meter before 10% overall harmonic distortion is produced. This excellent overload characteristic represents what can be achieved in a low-cost receiver design. Table I indicates that low-level performance has not been compromised to handle overload.

ACKNOWLEDGMENTS

The authors wish to express gratitude to W. S. Skidmore, J. B. Schultz, and E. H. Diamond for their technical assistance and contributions to this article.

TABLE I—Nominal Performance of RCA "Marathon" Portable Receiver, Model RFG20, Measured at 3.0 Volts DC.

Frequency: kc:	600	1000	1400
50-mw sensitivity, μv/meter	150	165	220
20-db S/N, μv/meter	440	340	360
Image attenuation, X	250	115	46
IF attenuation, X	50	115	121
Selectivity, A.C.A., 10-kc, X	40	17	12
AGC figure of merit, db	42	39	36
Signal strength; 30% modulation for 10% distortion	—	>2 volts/meter	—

Fig. 6—Maximum unclipped signal power vs. R_2.

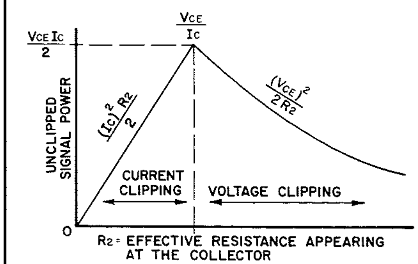
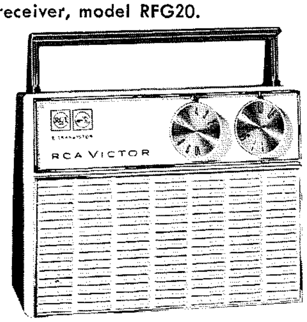


Fig. 7—RCA "Marathon" portable receiver, model RFG20.



DESIGN OF THE RC-1218 SOLID-STATE AM-FM STEREO-MULTIPLEX HI-FI RECEIVER

J. B. SCHULTZ

Radio Victrola Product Engineering
RCA Victor Home Instruments Division
Indianapolis, Ind.

Although transistors have previously enjoyed widespread use in portable receivers and military communication equipment, 1964 saw the first significant penetration of solid-state devices in line-operated home instrument equipment. Prior to 1964, relatively high cost dictated that the use of transistor circuitry had to offer significant advantages over similar vacuum-tube circuitry (e.g. low power consumption in portable entertainment receivers; in military equipment, size, weight, and reliability). Advancing device technology has made transistor-circuitry cost competitive with equivalent tube circuitry, and solid-state line-operated home entertainment equipment has become economically attractive. As a result, RCA has introduced the RC-1218 solid-state AM-FM stereo receiver into the top end of the high-fidelity product line. Its design is described herein.

THE major objective for the RC-1218 receiver program was to produce a solid-state AM-FM and stereo multiplex receiver having performance equal to or surpassing that of its vacuum tube counterpart. This objective was to be met with similar cost restrictions. Table I shows the degree to which the performance objectives were met.

The mechanical design stresses the use of automatic assembly techniques resulting in a more uniform product at lower cost. Printed boards are used for all major functions, and all components are inserted into the boards from one side. The inter-board connections are simplified by localizing the takeoff points to one area and using wire harnesses. Molded, fixed-tuned coils are used in the FM radio-frequency circuitry. Finally, the printed circuit boards are mounted to the chassis by using automatically inserted eyelets which are soldered to lugs on the chassis.

The electrical design of the RC-1218 is discussed in greater detail later in this paper; however, some of the design features may be summarized as follows:

1) an automatic AFC switch disables the AFC when the tuning knob is rotated in either direction. When a desired FM station is reached, AFC is applied by simply depressing the center of the tuning knob.
2) a stereo multiplex circuit automatically switches to monaural operation when a *mono* signal is present. This feature insures an optimum mode of operation for different signal conditions.
3) a tuning meter indicates signal strength for both AM and FM operation.
4) shock mounting of the entire receiver eliminates acoustical feedback.
5) illuminated dial and control areas.
6) a die cast escutcheon.

Final manuscript received November 2, 1964

A simplified block diagram of the RC-1218 is shown in Fig. 3. For convenience in description, the receiver can be divided into four areas: 1) the FM tuner, 2) the FM, IF, and AM receiver board, 3) the stereo multiplex board, and 4) the audio preamplifier board.

FM TUNER

The RF stage of the FM tuner employs a germanium mesa transistor operated in a common-emitter configuration. A collector current of 2 ma and a collector-to-emitter voltage of about 7.5 volts is used. The balun and input-tuned circuits losses are approximately 1.5 db. At 100 Mc, the device noise factor of the RF transistor is 3 db, and the gain of the RF stage is 14 db. With this combination, and a converter noise factor of 13 db, the receiver noise factor is about 5.5 db.

The converter circuit also uses a germanium mesa transistor operated in a common-base configuration; oscillator injection for optimum conversion gain and noise factor is about 150 mv. To avoid the loading effects of the transistor, the oscillator circuit is designed so that the circuit impedances are considerably lower than the input and output impedance of the transistor. By doing this, changes in transistor parameters will not affect oscillator frequency; the oscillator frequency change for supply voltage variations of $\pm 40\%$ is less than ± 100 kc. The choice of the 10.7-Mc load impedance in the collector circuit is a compromise between gain and overload. Overload occurs when voltage clipping of the 10.7-Mc signal in the collector circuit drastically affects the oscillator amplitude and frequency. The IF load impedance is chosen so that voltage clipping will not occur at the strongest signal anticipated. For this application, an IF load impedance of 1,500 ohms is used; with this load, the gain of the converter is 6 db.

The antenna, RF interstage, and oscillator transformers are molded coils; the need to adjust the inductance of these coils is eliminated by maintaining a 1.5% tolerance on the coils and providing an accurate and controlled assembly of the tuner board to the ganged tuning capacitor. Fig. 4 shows the assembly procedure for the FM tuner.

FM, IF, AND AM RECEIVER BOARD

This printed board includes four 10.7-Mc IF stages, a ratio detector, the AM radio frequency and converter stages, two 455-kc IF stages, and the FM tuner assembly. The second and third 10.7-Mc stages are common with the two 455-kc IF stages.

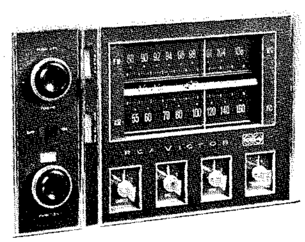


Fig. 1—RC-1218 solid-state receiver.

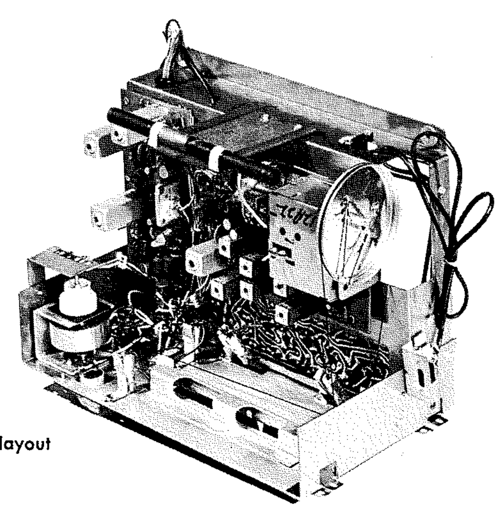


Fig. 2—RC-1218 chassis layout and mechanical assembly.

J. B. SCHULTZ joined RCA as a cooperative student in June, 1953. He received a B.S. degree in physics from St. Joseph's College, Philadelphia in 1955 and was assigned to the Home Instruments Advanced Development Section, Cherry Hill, N. J. In 1960, he became a member of the Technical Staff, Home Instruments Advanced Development Section at the David Sarnoff Research Center in Princeton. His work while with the Advanced Development groups was mainly concerned with solid state communication circuitry. In 1962, he was assigned to a position as Group Leader, AM/FM receiver design, Home Instruments Division, Indianapolis.

The 10.7-Mc IF employs the same family of transistors used in the FM tuner. Four double-tuned transformers provide a 200 kc adjacent channel attenuation of 20 db while maintaining a 3-db bandwith of 190 kc. To avoid loading effects on the tuned circuits and insure stable operation and constant bandpass characteristics, the source and load impedances of each stage are kept small compared to the input and output impedances of the transistors. The first stage operates at 30-db gain and the other three at gains of 20 db; the overall gain of the IF amplifier is approximately 90 db.

For maximum AM rejection, each IF stage is designed to limit at approximately the same signal input. The fourth IF stage limits first, and after an increase in signal level of 20 db, the third IF stage begins to limit. With an additional 20-db increase in signal level, the second IF stage begins to limit, and so on. The limiting and signal-to-noise characteristics are shown in Fig. 5.

A standard ratio detector circuit provides 25-db AM rejection at signal levels below limiting. The output of the ratio detector supplies the multiplex circuit with a wideband composite signal for stereo operation. For monaural operation, this composite signal undergoes response shaping through a 75-μsec deemphasis network.

AM RECEIVER STATION

The AM receiver section uses drift-field transistor for the RF stage and converter circuits. The two 455-kc IF stages use devices common to the second and third 10.7-Mc IF stages. The RF selectivity is provided by a ½-in-diameter, 7-inch-long ferrite antenna operating with a Q of 150, and a single-tuned RF interstage circuit operating with a Q of 100. The IF selectivity is provided by one single-tuned and two double-tuned transformers. The IF amplifier has a 3-db bandwidth of 10 kc, and a 10-kc adjacent channel attenuation of 22 db. The overall 3-db bandwidth is primarily determined by the RF selectivity, while the IF selectivity supplies most of the adjacent channel rejection.

The most difficult problem encountered in the AM receiver design involves strong-signal operation. Overload may occur when the receiver is being tuned through a strong signal, or when the receiver is tuned directly to a desired frequency of high signal strength. There are two important system considerations which must be taken into account if the transistor AM receiver is to approach the performance of its vacuum tube counterpart at strong signals.

The first consideration is placement of the greatest amount of selectivity at the lowest signal level points in the receiver. In other words, the maximum amount of selectivity should be at the front end of the receiver, while the gain should be concentrated in the final stages of the receiver. This arrangement is necessary to insure that strong signals do not cause

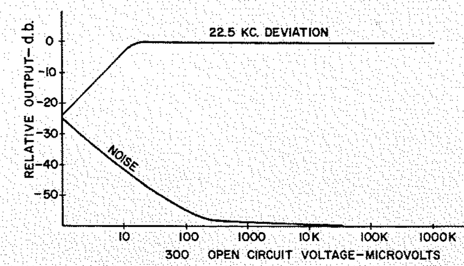


Fig. 5—Limiting and signal-to-noise characteristics.

overload when the receiver is detuned to the point where AGC is inoperative. Fig. 6 shows the gain distribution of both the AM and FM sections of the RC-1218.

The second consideration is the AGC characteristics. To operate in field strengths ranging from 50 μv/m to 2 v/m, the AGC range must be at least 80 db. To accomplish this amount of control, the RF stage must be completely cut off. However, to reduce the g_m of the transistor to zero, the forward transfer characteristic must traverse a very nonlinear region. To prevent overload in this region, the signal level at the base of the RF stage must not exceed 10 millivolts. Consequently, then, the bias of the RF stage must move through this region and into the linear reverse bias condition before a 10-mv input level is reached. The attenuation of the RF stage in a reverse bias condition is approximately 50 db. Consequently, the AGC must begin to act at the lowest signal level consistent with good noise performance. In addition, the DC gain of the AGC loop must be high so that the RF stage gain is reduced as rapidly as possible. To accomplish this, the first IF is used as a DC amplifier between the detector and the RF stage. To make optimum use of the DC output of the detector, the diode circuit is connected

Fig. 3—Functions of the RC-1218.

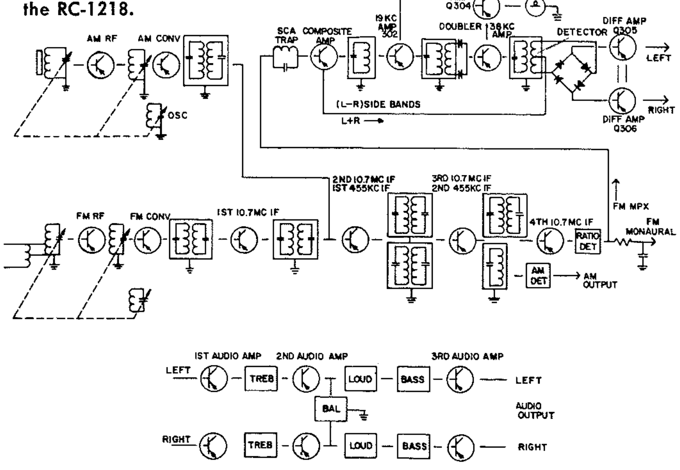
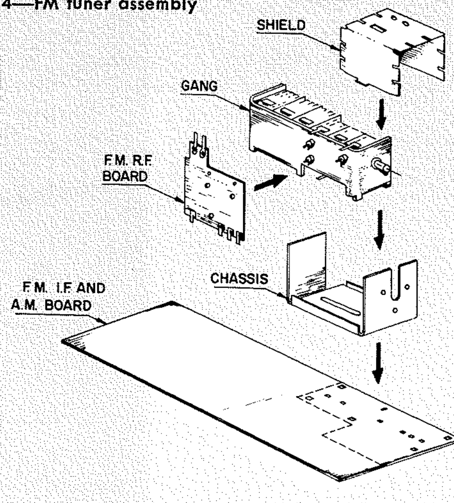


Fig. 4—FM tuner assembly



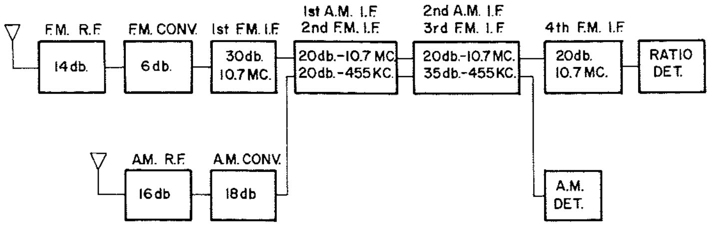


Fig. 6—Gain distribution.

directly between the base and emitter of the first IF stage. In this way, the DC degeneration of an emitter resistor is avoided. The AGC and signal-to-noise characteristics are shown in Fig. 7.

THE STEREO MULTIPLEX BOARD

The multiplex portion of the RC-1218 provides two-channel stereo service from a composite multiplex signal consisting of: a 19-kc pilot, an $(L - R)$ signal, and an $(L + R)$ signal. The $(L - R)$ information appears as amplitude modulation of a suppressed 38-kc subcarrier.

An explanation of the Fig. 3 multiplex circuit follows. The 19-kc pilot signal is amplified through a two-stage 19-kc amplifier; the signal then drives a frequency doubler, which in turn drives a 38-kc amplifier. The high-level 38-kc signal is then used to switch the diodes of a balanced wide-angle synchronous detector.

The sidebands of the suppressed 38-kc subcarrier are fed to the synchronous detector through the center tap of a bifilar secondary of the 38-kc transformer. The $(L - R)$ information contained in the AM sidebands is detected and appears out of phase at the inputs to the differential amplifier (Q305 and Q306). The $(L - R)$ information appears on one input and $-(L - R)$ on the other.

Fig. 7—AGC and signal-to-noise characteristics.

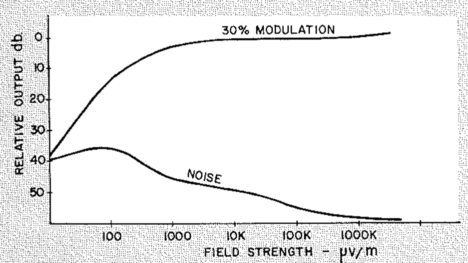
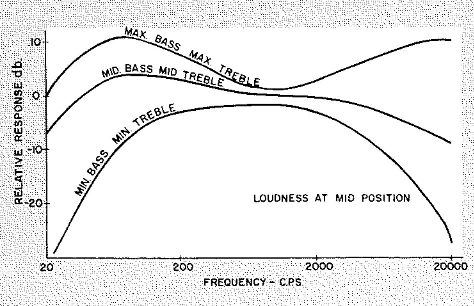


Fig. 8—Audio performance characteristics.



The $(L + R)$ signal is also coupled to the differential amplifier through the synchronous detector diodes. This $L + R$ signal appears in phase at both inputs to the differential amplifier. The combined signal at the left channel input is $[(L + R) + \eta (L - R)]$, and at the right channel input is $[(L + R) - \eta (L - R)]$, where η is the efficiency of the detector circuit and, in this case, is about 0.7.

After collecting terms, the left channel signal becomes $(1.7L + 0.3R)$, and the right channel becomes $(0.3L + 1.7R)$. Cross-coupling between the emitters of the differential amplifier is adjusted so that approximately $(0.3/1.7)$ $(0.3L + 1.7R)$ appears at the emitter of the left channel and $(0.3/1.7)$ $(1.7L + 0.3R)$ appears at the emitter of the right channel. This cancels the R signal in the left channel and the L signal in the right channel.

The separated left and right channel signals are then passed through a 15-kc low-pass filter to reduce undesirable frequency components.

In the absence of a 19-kc pilot signal, the second stage of the 19-kc amplifier (Q302) is biased to a low-gain operating point. This basis is derived from the collector circuit of the DC amplifier Q304. When a 19-kc signal appears, the rectified voltage from the doubler circuit drives the 38-kc amplifier into conduction. This in turn increases the current in Q304. The positive-going collector of Q304 reduces the negative potential at the emitter of Q302 and the loop gain rises. This regenerative process continues until Q304 is completely turned on. Conversely, if the 19-kc signal decreases, the process is reversed and a degenerative action takes place. The presence of this feedback loop results in a rapid turn on, or turn off of stereo operation as a 19-kc signal is applied or removed. In the absence of the 19-kc pilot, the multiplex circuit is inoperative and monaural operation with its superior signal-to-noise performance is automatically realized.

The DC amplifier Q304 also acts as a switch for a 40-ma incandescent lamp; this lamp is used to indicate the presence of a 19-kc pilot.

THE AUDIO PREAMPLIFIER BOARD

This board includes three audio stages for each channel, separate bass and treble tone control circuits, a compensated loudness control, and a balance control. The preamplifier is designed for use with a ceramic pickup having a capacity of 600 pf and a standard open-circuit voltage of 0.25 volts. The dynamic range referenced to standard input is 22 db. At maximum loudness and flat tone control settings, the voltage gain is approximately 20x. The response characteristic of the tone controls is shown in Fig. 6.

The first stage of the preamplifier uses a low-noise germanium alloy transistor. The second and third stages use transistors from the same family except without the low-noise specification. The preamplifier, as well as all other sections of the receiver, is designed to operate over a temperature range of 10°C to 55°C.

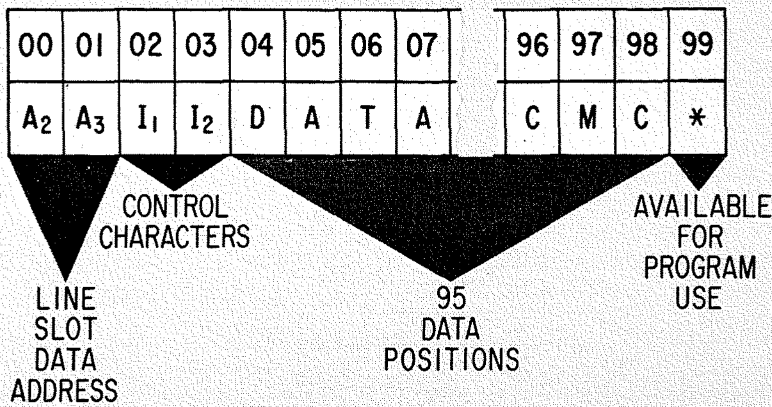
ACKNOWLEDGEMENT

The design of the RC-1218 represents a combined group effort; acknowledgement is made to the following contributions: FM tuner design, B. L. Borman; FM, IF, and AM receiver board, G. R. Solmos; stereo multiplex board, W. M. Workman; audio preamplifier board, C. W. Yong; mechanical design, D. L. Billings, C. F. Coleman; and overall receiver integration, D. J. Snyder.

TABLE I—Performance of RC-1218 Transistor Receiver vs. RC-1211 Tube Receiver

	RC 1211 1963 Deluxe Tube Receiver	RC 1218 1964 Deluxe Transistor Receiver
FM PERFORMANCE *(300 Source)*		
30-db S/N sens	7 µv	6 µv
3-db limiting knee	6 µv	10 µv
AM rejection, 10µv 30% mod.	25 db	25 db
3-db bandwidth	170 kc	190 kc
ACA 200 kc	20 db	20 db
image rej. 108 Mc	35 db	35 db
maximum input signal	0.3 volt	1 volt
stereo separation 1,000 cps	25 db	30 db
AM PERFORMANCE		
20 db S/N sens	60 µv/m	80 µv/m
Sens. rated output	30 µv/m	30 µv/m
3-db bandwidth (1,000 kc)	5 kc	6 kc
ACA 10 kc (1,000 kc)	35 db	30 db
image rej. (1,400 kc)	80 db	80 db
AGC figure of merit ref. to 0.1 v/m	55 db	55 db
maximum input 80% mod.	3 v/m	2 v/m

Fig. 1 — 100-character line slot.



COMPUTER DATA COMMUNICATION EQUIPMENT FOR ON-LINE SIMULTANEOUS PROCESSING

In modern integrated data processing systems, the main computer should be able to operate on-line with several data sources and/or other computers if the great speed and processing capacity of the modern computer is to be most efficiently used. To achieve such integrated systems, RCA Electronic Data Processing has designed a family of data communication equipment, which integrates the main computer with various data sources (e.g., teletype, EDGE) or with other computers (e.g., via telephone lines). The basic tool in the family is the Communications Mode Control, and a corresponding group of buffers that can handle various codes, speeds, and character formats.

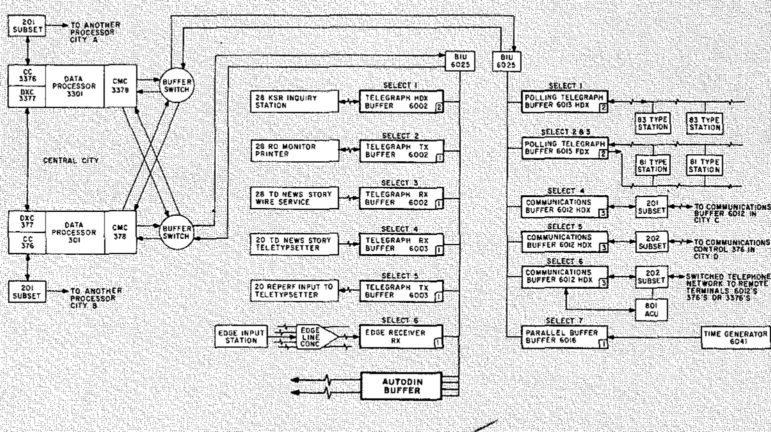


Fig. 2 — Hypothetical computer-communications system.

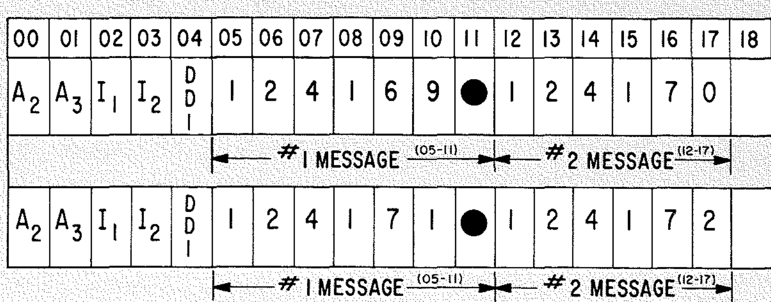


Fig. 3 — Example of format for real-time message.

B. P. SILVERMAN
Engineering Department
Electronic Data Processing,
Camden, N. J.

THE modern approach to a data processing operation is an integrated one—the system is designed and implemented such that remote data sources can communicate their data automatically over transmission facilities such as teletype or telephone lines for direct input into the computer for processing (in addition to the regular data inputs at the computer's location). Similarly, in some systems, computers at remote locations may need to communicate their data with each other. With the high processing speed and large memory capacity of modern computers, the handling of data from such various sources in "batches" becomes a deterrent to efficient use of the computer. That is, if a batch of data from one input source must be completely processed before another can be handled, obvious inefficiencies result. The solution is equipment operating on-line with the input-output section of the computer that will accept the data from multiple sources and feed it to the computer in such a manner as to achieve a simultaneous processing of the data. Thus, the computer is "integrated" with various data sources.

To meet this industry- and Government-wide need, RCA Electronic Data Processing has designed a family of data transmission equipment to integrate computers with readily available data transmission systems on-line. The basic tool in the family is the *Communications Mode Control* (CMC) and a corresponding group of buffers that can handle various codes, speeds, and character formats. Other devices classed in this family are the *Data Exchange Control,* a memory-to-memory transfer channel, and the *Communcations Control,* for computer transfer via telephone facilities.

COMMUNICATIONS MODE CONTROL

The CMC is a wired-program data processor housed within the input-output section of the main processor. The CMC shares the computer's main memory simultaneously with the data processor and with other input-output devices. It provides an additional degree of simultaniety, since it in no way affects the operation of the computer's normal and/or simultaneous modes of operation. In fact, it provides many additional degrees of simultaniety, since many data communication lines can operate independently of each other, re-

Final manuscript received November 25, 1964

quiring memory interrupts only to bring characters in and out of the main memory.

In the *transmit* mode, when a character is available for transfer out of memory and the buffer is ready to accept the character, the memory will be accessed for the appropriate transfer. In the *input* mode, when a character is available for transfer to the processor, the buffer is readied at the next scan time, and the CMC accesses the appropriate number of memory cycles to accept the character. At all other times, normal processing will proceed independent of CMC operations. When the CMC requires service, it will interrupt the memory on a preselected percentage of memory accesses.

Each CMC scan position has associated with it a 100-character portion of main memory termed a *line slot* (Fig. 1). Referring to Fig. 1, the A_2 A_3 characters are reserved for a character position indicator. The I_1 I_2 positions in memory are reserved for bit configurations used by the CMC to communicate to the program (I_1) and by the program to communicate with the CMC (I_2). The next 95 characters are data. The last character is reserved for program use.

Each half-duplex buffer will take one line slot and each full-duplex buffer will take two line slots. For full-duplex operation, one of the buffers will use four line slots. Therefore, a 20-line CMC will require 2,000 characters of main memory reserved for line-slot usage.

The maximum number of memory accesses which the Model 378 CMC uses in transferring a character between a buffer and a line slot are:

1) Read I_1 I_2 from memory.
2) Read A_2 A_3 from memory.
3) Transfer a character to or from memory in position designated by A_2 A_3 in step 2.
4) Write updated A_2 A_3 to memory.
5) Write updated I_1 I_2 to memory.

Similarly, the CMC for the RCA 3301 System may use a maximum of four memory accesses per character transfer.

In the RCA 3301, one of the accesses is associated with signaling a program interrupt and inserting the line slot address in a service table whenever a condition calling for an interrupt occurs. When the program interrupt is detected, the program need only examine the service table within main memory to determine the address of the line slot demanding attention. The maximum possible data rate from the RCA 301 CMC to the computer is 7.1 kc, which is distributed among the line slots. The maximum data rate distributed over the number of active line slots is 18.5 kc for the RCA 3301.

BUFFERS AND RELATED EQUIPMENT

A broad range of buffers have been designed to interface with the various CMC's. Fig. 2 depicts a hypothetical system which shows the versatility of the buffer system. The organization of the system allows communication lines to share a Buffer Interface Unit through one set of cables to 10 line slots of the CMC. A second set of cables permits buffer-to-buffer interconnection.

CMC-Buffer Interface Unit (CMC-BIU), Model 6025

The CMC-BIU has the necessary line drivers and receivers so that it can be positioned 100 cable feet away from the CMC. Thus, the buffer system can be housed in separate racks with separate power supplies, which enhances system reliability. This also allows for the use of switches which are required in some redundant CMC computer systems. Since the operating speed of various communication buffers is dependent upon the communications system in which the buffer is to operate (and it is possible to have a mixture of these speeds in a system) the basic CMC-BIU can incorporate one or more crystal-controlled oscillators, which provide the primary data clocking for individual buffers. The clock signals are transmitted to each buffer; each buffer, in turn, selects the required clock.

Five-Level Telegraph Buffer, Model 6002

The Model 6002 is designed for half-duplex remote inquiry applications whereby for each inquiry there is a reply. The same buffer may also be used for simplex operation by locking the unit in either the receive or transmit mode. In the half-duplex remote inquiry application, the buffer is quiescently in the receive mode.

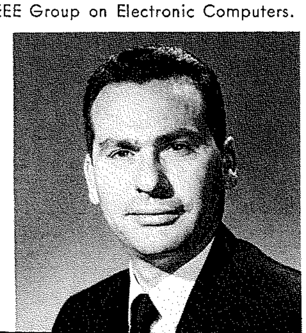
The message is transmitted a character at a time at the operator's own speed. Since memory is interrupted only when a character is present in the buffer, the operator's speed does not affect the system. When the complete message has been transmitted and visually verified, the operator releases the message by transmitting a special control character called *DD2*. Receipt of the *DD2* by the CMC causes the line slot to prohibit further input, causes an I_1 bit to be set in the line slot, and causes a *DD2 recognized signal (DD2R)* to be transmitted to the buffer. Receipt of *DD2R* at the buffer causes the buffer to change states from receive to transmit. The data processor's program will now process the inquiry message and respond with a reply message. The processor's program must format the message such that *DD1* is the last character transmitted. When the CMC transmits the last character of the message *(DD1)*, it will send the *DD1R* signal to the buffer which will cause it to return to the quiescent receive mode ready for another inquiry. The program will then re-establish the I_1 I_2 input conditions.

The Model 6002 includes a two-register buffer and uses common hardware for the receive and transmit modes of operation. The two registers allow for one complete character time between the time the last bit is received and the time in which the character must be transferred to the processor.

Six-Level Telegraph Buffer, Model 6003

The Model 6003 specifically operates in conjunction with the RCA 301 Data Processing System associated with newspaper typesetting. It handles the 6-level teletypesetter code and operates with Model 20 teletype equipment commonly used in the newspaper industry and press wire services. The operation and design of this buffer is identical with the Model 6002 with the exception of the addition of the sixth bit in the storage register and shift register and, of course, a change in the clock to extend the character time by one bit. In the hyopthetical system shown in Fig. 2, the buffers are being used to bring in a news story on a six-level or a five-level transmitter distributor, which allows the computer to convert from 5-level code to RCA 301 code. The computer then processes the coded text against its stored rules for the newspaper column width desired and the "breaking" (hyphenating) words, so that when the typesetting is done the column will be "justified" (i.e., have even right-hand margins). This processed text is then converted to 6-level teletypesetter code, and transmitted to a Model 20 reperforator. This output is fed to a teletypesetter which then

BERNARD P. SILVERMAN received his BSEE from the University of California in 1949. He spent a year with the U.S. Naval Radiological Defense Laboratory in San Francisco, and then was with Friden, Inc., San Leandro, California, for 10 years where he was Manager of the Integrated Data Processing Division. He joined RCA Electronic Data Processing in 1961, and has worked on data communications systems and optical character recognition equipment. He is a member of the IEEE and past chairman of the San Francisco section of the IEEE Group on Electronic Computers.



automatically sets the type in the form of the usual linotype lead slugs, ready for makeup into newspaper pages.

Half-Duplex Polling Telegraph Buffer, Model 6013

The Model 6013 is used in conjunction with Bell System Type-83 selective-calling, sequential-polling half-duplex teletype systems. The combination of the computer's program and the Model 6013 buffer takes the place of the master control unit of the original Bell 83 system. The Bell 83 peripheral station itself remains unchanged. Since the system operates in a nonsimultaneous two-way transmission mode, the buffer requirements are such that either the peripheral Bell 83 station or the computer may originate transmission. This necessitates a neutral mode concept, which indicates that the buffer can lock on either the input or output operating mode. The particular mode which it locks onto depends on the first service request.

Full Duplex Polling Buffer, Model 6015

The Model 6015 is similar in application to the Model 6013 with the exception that simultaneous two-way traffic can be handled. The receive section of the buffer is identical to the Model 6013 and indeed contains the same logic. The transmit section, however, is a transmit only buffer with provision for a timer for generation of a pause required in the full-duplex polling operation.

This buffer requires two line slots for operation, one termed Receive and the other Transmit. The program treats the two line slots as one full-duplex line.

Communications Buffer, Model 6012

The Model 6012 is basically designed for memory-to-memory transfer via the telephone network. The speed at which transfer is accomplished is dependent upon the speed of the telephone network. The channel coordination and error protection procedures are compatible with communication control modules for the RCA 301 and RCA 3301 Computers.

This buffer is used where high speed and the utmost in data integrity is required. It uses, in addition to character parity, a block parity checking system. Each message or line block must be verified prior to initiating transmission of the next. The buffer is used in half-duplex operation and occupies one line slot in the high-speed memory. The transmission line code contains 8 bits per character consisting of 6 information bits, 1 parity bit, and 1 control bit. The control bit is added by the buffer prior to transmission and is removed prior to the transfer of data to the memory.

The Model 6012 buffer is used with Bell System Digital Data Subsets (Models 201 and 202) and is also compatible with their Automatic Calling Units. The interface is consistent with EIA interface specification RS232 and as such may be used with any subset which conforms.

When using the Automatic Calling Unit, the computer's program can automatically load the telephone number of a compatible station into the line slot and automatically set up a connection to that station. When transmission is complete, the program may turn the line slots around, and the receiving computer becomes the originating station, and vice versa. Upon completion of all data transfers, a terminate sequence may be transmitted which terminates the call and allows for a new station to be set up.

Time Generator, Model 6041, and Parallel Buffer, Model 6016

The Model 6041 and Model 6016 are required to read time into a line slot as Fig. 2 shows. The arrangement is such that program need never service the line slot.

The line slot will always contain the latest time. The data format is such that once the line slot is conditioned by program for the first time, a message will be transmitted to the line slot each 360 msec. The first message to be transmitted will contain an item separator symbol and then the time message, while the next will contain a *DD1* and time.

Fig. 3 shows the line slot for four successive readouts of time. Program need only analyze $A_2\ A_3$ to determine which time should be read out. If $A_2\ A_3 \geqslant 10$, correct time should be read from $04 \rightarrow 09$; if $A_2\ A_3 < 10$, correct time should be from $11 \rightarrow 16$.

SYSTEM OPERATION WITH EDGE OR AUTODIN

RCA's Electronic Data Gathering Equipment[1] (EDGE), may be operated on-line to RCA Computers through the CMC. An EDGE receiver has been developed to operate with the normal EDGE system codes and messages as input using the high-speed memory as output. A system employing this equipment was installed at a Lockheed plant in California in September 1962, and has been in successful operation ever since.

The AUTODIN Buffer, Model 6009 operates with the data processor on one end, via the CMC, and one of the message switching centers of the AUTODIN network (formerly COMLOGNET[2]) on the other. The buffer operates in the continuous mode with all of the sophisticated channel coordination procedures associated with the AUTODIN Network. The continuous mode implies that data is transferred in continuous, 80-character line blocks in the full-duplex mode and that each line block is acknowledged automatically with the acknowledgement signal being interspersed with the data being received on the other half of the line. If the line block is not acknowledged before the end of transmission of the second line block, transmission is interrupted until it is received or an error condition is received. If an error is received, the first and second block must be retransmitted. In order to accomplish this feat, the buffer uses four line slots in memory, two for the receive mode and two for the transmit mode. The line slots are alternated by the buffer, and are programmed in such a way that the last line block transmitted is held in memory until the previous block is acknowledged.

CONCLUSION

A data communications system has been developed which is modular in its make-up and versatile in its implementation. The system is capable of handling data rates up to 4,800 bits per second and may accept up to 160 half-duplex lines. The system handles non-parity, unformated teletype traffic on the one hand and the very sophisticated computer information messages on the other. As new communications requirements are established, other new buffers, similar in concept, may be designed to handle them. The buffer concept allows for continued compatibility as a users requirement changes from the RCA 301 to the RCA 3301.

ACKNOWLEDGEMENTS

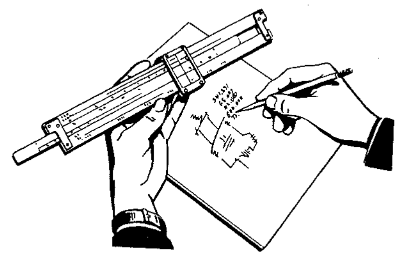
The author wishes to acknowledge the many contributions of members of the EDP activity of RCA. In particular, design effort contributions were made by F. E. Brooks, J. B. Cottroll, N. Evins, R. A. Hammel, R. E. Hurd, M. F. Kaminsky, Y. Rachovitsky, and W. C. Ross. The laboratory work of E. Hoffman and R. J. Palmer was also noteworthy.

BIBLIOGRAPHY

1. R. E. Montijo, "Electronic Data Gathering Equipment," RCA ENGINEER, 9-2, Aug.-Sept. 1963.
2. R. J. Segal and H. P. Guerber, "Four Advanced Computers—Key to Air Force Digital Data Communications System," *Proceedings 1961 Eastern Joint Computer Conference. Also see* R. J. Segal and H. P. Guerber, "COMLOGNET Automatic Store-and Forward Message-Switching Centers, RCA ENGINEER, 7-5, Feb.-Mar. 1962.

Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST



Filter Design by Digital Computer

T. G. MARSHALL, JR.,
Broadcast and Communications Products Division, Camden, N. J.

Final manuscript received October 5, 1964

This *Note* describes the design of filters by a set of recently prepared digital computer programs. Many of the filters designed using these programs have been built, and the measured responses agree accurately with the calculated responses. The filters meet stringent cost, reproducibility, and temperature requirements.

Although prepared specifically for the design of filters for the CV-600 microwave multiplex equipment, the programs are sufficiently general to solve a wide variety of design problems for filters composed of discrete elements. The programs are so organized that no change or additional programming is required for designing filters of different structures. The programs are based upon modern network theoretic approaches to filter design,[1] and they give greatly improved results as compared to the classical image-parameter filter theory.

Program Use: Some experience in designing a particular single-sideband filter will be described to illustrate how the computer programs can be used. The structure of the filter is shown in Fig. 1, and its response is shown in Fig. 2. (Although the structure indicates that there should be three peaks of attenuation in the lower stopband, the peak closest to the stopband was not measurable, due to presence of losses, and is not shown in Fig. 2.) For economy, the number of coils has been minimized so the ratio of coils to capacitors is quite low. In addition, the coils have the same design value, a novel feature incorporated to reduce manufacturing costs. Predistortion techniques[1] were used to minimize the effects of coil losses.

The coils are adjusted in an alignment procedure, suggested by a sensitivity analysis,[2] whereby each coil is tuned to resonate with adjacent capacitors in the completed filter after shorting appropriate nodes to ground.

The use of a digital computer permitted some 35 distinct filter designs to be made and evaluated in the course of arriving at the design shown in Fig. 1. Because good correlation was obtained between computer calculated responses and measured responses, only four of the designs were actually constructed, each introducing a major design change: The first was a minimum inductor design employing predistortion to cancel loss effects; the second had, in addition, the equal coil feature; the third had, in addition, much improved response; and the fourth was, in addition, less sensitive to element variations. The other designs were evaluated on the basis of computer output data alone.

The total computation time required for a filter increases rapidly with the order of the filter. The design of the twelfth-order filter of Fig. 1 took about 1½ hours of computer time on a relatively slow computer. The time was about equally divided between *synthesis* (obtaining element values) and *analysis* (checking frequency response and element sensitivity). Sixteen digits are used for all calculations in synthesis and eight are used in analysis.

The use of faster computers such a the RCA 301 or RCA 601 would reduce the computation time. For example, the RCA 601 could reduce the time by a factor of 1,000 and the RCA 301 could reduce it by a factor of 5 to 10. The analyis program is now usually run on an RCA 301 which reduces the computation time indicated above by a factor of 5 or more. This analysis program has been used by several RCA divisions which have RCA 301's.

Program Description: A bare minimum of data has to be coded for input. The initial input data for the synthesis programs consists of the pole and zero locations of either the desired response function or its related characteristic function.[1] The determination of these locations, the approximation problem, is done prior to the time the programs described herein are employed. This problem is to determine pole and zero locations such that the corresponding response meets or exceeds whatever attenuation and/or return loss specifications are given at various frequencies. A new design of potential analog plane[3] has most often and most conveniently been used to solve this problem, although a digital computer has sometimes been employed.

The synthesis programs require this pole and zero data plus data specifying the filter structure desired, which must be consistent with the former data. (The possible branch configurations are given in Fig. 3 of Ref. 1.) The output is a printed sheet giving element values of a ladder structure filter having the specified response. It is well known that the synthesis problem is, in many cases, not unique; i.e. many designs (sets of element values) can be obtained for a given structure for which the responses will be the same as the specified response.[1,4] These programs are such that any of these possible designs can be obtained. This flexibility was exploited in making all the coils equal in the filter of Fig. 1.

To simplify the use of these programs an option is provided which will cause the computer to automatically decide on one of the many possible designs. The criterion for this choice is that the synthesis be most likely to succeed, an eventuality which is not always assured.[5]

In addition to the print-out of element values, the synthesis programs provide punched cards which serve as input to the analysis program. This latter program calculates for each specified frequency, the attenuation and phase, impedances looking away from source and load, and the deviations in attenuation and phase that occur if each branch is varied in turn from its nominal value. Parasitics such as coil losses and distributed capacity may be included. These deviations are calculated by methods much more efficient than the often used method of giving each branch a specified deviation and recalculating the gain and phase.[2] On the basis of this data obtained from the analysis program, a decision can be made as to whether a new design is to be made or whether the present one should be constructed and tested further.

Acknowledgment: The author wishes to extend his thanks for the assistance he has received in preparing and running these programs. S. W. Kahng (Burroughs Corporations, Detroit, Michigan. Formerly with the Applied Mathematics Group, RCA Laboratories, Princeton, N. J.) aided in the programming and did the coding of the synthesis programs. F. M. Brock and R. Binks provided many varied sets of poles and zeros for input and experimentally confirmed the designs. J. F. Parker prepared the RCA 301 Bell Interpretive System and advised on its use. H. F. L. Cameron authorized and encouraged the preparation of flexible, nonrestrictive programs.

Fig. 1—Single-sideband filter.

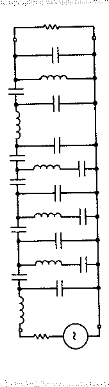
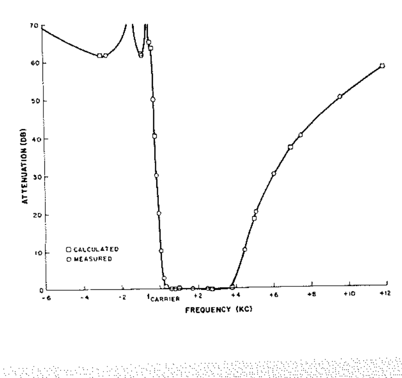


Fig. 2—Single-sideband filter response.



1. R. Saal and E. Ulbrich, "On the Design of Filters by Synthesis," *IRE Transactions on Circuit Theory,* Vol. CT-5, Fig. 3, p. 288, Dec. 1958.
2. T. G. Marshall, Jr., *Private Communication,* January 3, 1964. (Describes network theorems for ladder networks which permit the rapid determination of branch sensitivity.)
3. F. M. Brock and R. Binks, "Generating Network Functions with an Infinite Potential Analog Plane," *RCA Review,* 1964.
4. L. Weinberg, "Explicit Formulas for Tschebyscheff and Butterworth Ladder Networks," *IRE National Convention Record,* part 2, p. 202; 1957.
5. Hitoshi Watanabe, "Synthesis of Band-pass Ladder Network," *IRE Transaction on Circuit Theory,* Vol. CT-5, pp. 256-264; Dec. 1958.

Regulation of Sensor Operating Parameters for Unattended Camera Systems

H. Wittlinger

E. Vaerewych and H. Wittlinger,
Astro-Electronics Division,
DEP, Princeton, N.J.

Final manuscript received May 5, 1964

To ensure satisfactory operation of unattended television camera systems, particularly in satellite applications, it is necessary to maintain stable operating parameters for the vidicon sensors between environmental extremes for the predicted life of the system. In addition to providing compensation for the effects of sensor aging, extremely close regulation of the sensor parameters must be maintained to meet the stringent requirements for resolution, gray scale, and linearity called for in specific satellite systems.

Maintaining the high level of performance for satellite television camera systems such as those aboard the Nimbus Meteorological Satellite requires considerable care in the design of the regulating circuitry. It is necessary to maintain stable performance in a relatively hostile environment, where thermal conduction is the major means of dissipating heat generated within the camera system. Not only is there a wide temperature excursion to contend with, but there is also aging of the components. Aging of the vidicon presents the most challenging problem, since these cameras must function for a period of 6 months with no adjustments to compensate for changing vidicon characteristics.

To maintain uniform performance through the environment under the conditions described above, one should first consider the parameters that must remain constant to insure the required performance. (Practically, this environment was considered to be the extremes of the thermal-vacuum tests specified, with a temperature range from —5°C to 55°C, at a vacuum of approximately 10^{-5} torr.) Starting with the vidicon filament, a constant filament supply voltage must be maintained; so that the filament does not become stressed by over-voltage. This is accomplished by operating the vidicon filament from a regulated voltage supply. Even with the vidicon filament voltage constant, the vidicon cathode emission diminishes with time, so some type of device is required to ensure constant cathode current throughout the useful life of the camera. Effects of cathode aging are minimized by a circuit called a vidicon beam current regulator. Once the vidicon beam current is established, the electron accelerating field must be kept uniform. This is accomplished by regulating the vidicon mesh and target supply voltages. Now that a uniform beam current and accelerating field are established, means must be provided to maintain electrical focus. A focus current regulator keeps the current to the focus coil constant regardless of supply voltages or temperature.

Fig. 1—Regulator, 6.3-volt.

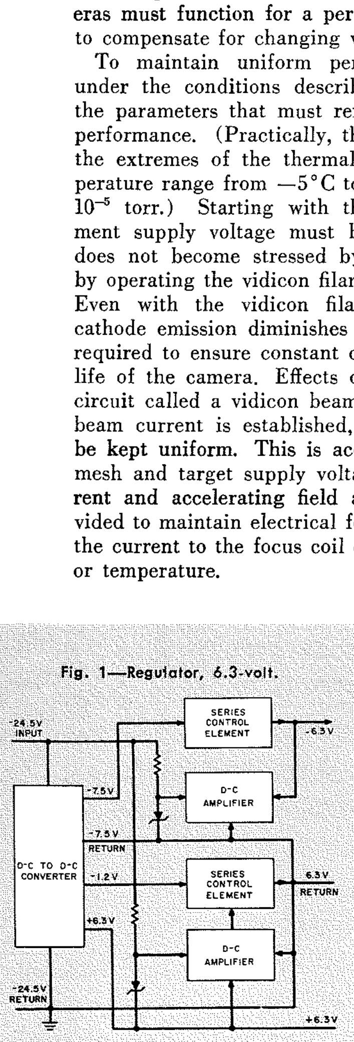
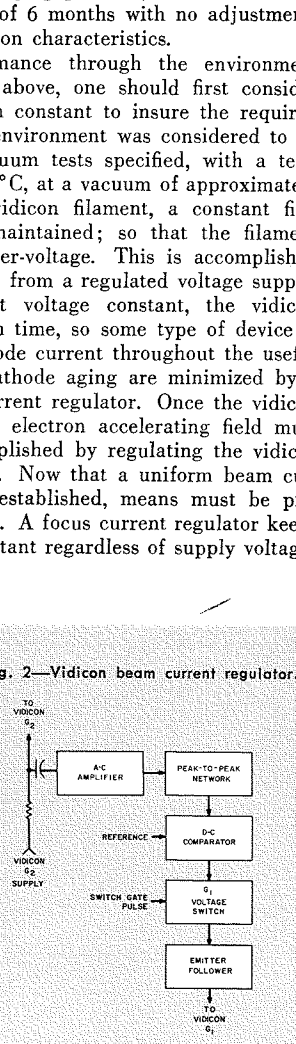


Fig. 2—Vidicon beam current regulator.



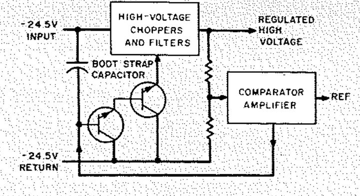


Fig. 3—High-voltage regulator.

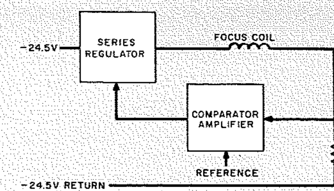


Fig. 4—Focus current regulator.

Control of these four vidicon operating parameters has been attained by a group of circuits.

Least complex of the circuits is the filament-supply voltage regulator (Fig. 1). This consists of a low-voltage input from a transistorized DC-to-DC converter, a series-control element, a two-stage amplifier, and a temperature-compensated zener reference diode. Three silicon transistors maintain the vidicon filament voltage within 1%. The only voltage to the camera from the Nimbus power supply is —24.5 volts, which is supplied to two DC-to-DC converters which develop the secondary voltages used by the filament voltage regulator as well as other circuits in the camera. Besides supply vidicon filament voltage, this same regulator supplies other voltages to the camera. To make the voltage more useful, both +6.3- and —6.3-volt regulators are used. The —6.3-volt regulator is used to supply vidicon filament and preamplifier filament voltages. The 6.3-volt supply furnishes power to lamps used to illuminate the vidicon target during a portion of the operating cycle. Both power supplies derive reference voltage from the —24.5 volts supplied to the camera. This permits a higher reference supply voltage and hence a more nearly constant current operation for the zener diode reference elements. By using a DC-to-DC converter to supply lower voltages to the series regulating element, a compromise must be reached between: 1) *how much voltage drop in the —24.5-volt bus can be tolerated* and 2) *the voltage drop, and hence dissipation, in the series-control element.* In this case, the —24.5-volt bus may drop 3 volts before the supply ceases regulation and the series element saturates.

The effects of aging of the vidicon cathode is minimized by the vidicon beam-current regulator (Fig. 2). Beam current is the final current after the electron beam passes through the vidicon mesh. This current is less than 10^{-8} amperes, so low that it is difficult to use direct control to maintain this current constant—so one simplifying assumption is made (one which is reasonably accurate over a limited current range and throughout vidicon life). It is assumed that the ratio of G_2 current to beam current will be constant. Therefore, currents in the order of only 10^{-6} amperes must be regulated—a much easier job. Regulating this current is further simplified since the electron beam is turned *on* and *off* during each scanning line. Thus, there are two distinct signal levels to work with: essentially a zero-current level and a maximum-signal beam-current level. This then gives a chopped signal that can be amplified by a stable AC amplifier and converted to a high DC voltage level by a peak-to-peak detector which can then be compared with a reference voltage to control the beam current by varying the vidicon G_1 voltage. Fig. 2 shows the regulation scheme used. The temperature coefficient of the reference voltage is such that it compensates for the temperature coefficients of the detector diodes and comparator transitor. During the vidicon picture-taking operation, it is desirable to gate the vidicon beam *off.* This function is performed in the circuits following the comparator by means of a transistor switch and a diode gate.

The problem of supplying a regulated mesh and target voltage to the vidicon is complicated by the fact that there were no high-voltage series regulators available. Control of the high voltage therefore is performed indirectly by controlling the input voltage to the high-voltage DC-to-DC converters on the return side, as shown in Fig. 3. Regulating the voltage on this side helps simplify the control amplifier circuitry. Filtered high voltage is divided down by a stable voltage divider to 9.2 volts and compared with a 9.2-volt reference diode in a double-differential amplifier to hold the high voltage within 0.5%. Because of the inherit lag of the regulation system, due to the filtering network, considerable dampening is required to prevent the regulator from oscillating. Because the load changes are negligible with respect to input-voltage variations, capacitance is placed between the series-regulator control-element input and the —24.5-volt supply. This capacitor supplies the necessary dampening and also "boot straps" the input voltage to the transformer, so that output voltage is insensitive to input voltage transients. Because the G_1 and G_2 supplies come from the same transformer as the regulated mesh and target supplies, indirect regulation of these two supplies is also gained.

The last remaining vidicon operating parameter that must be controlled to insure stable unattended vidicon camera performance is the focus current. The current is regulated by sensing the focus current with a stable resistor in series with the focus coil, then comparing this voltage with a reference, and varying the resistance of a series regulator (Fig. 4).

For simple amplifier design, it is desirable to make the voltage drop across the current sampling resistor as large as possible. Conversely, for good operating range with respect to supply variations, it is desirable to make the voltage drop across the series control element as high as possible. One limitation, however, is the power dissipation in the series regulator. A compromise was reached in this system with a voltage drop across the sample resistor of —1.3 volts. A double-differential amplifier compares the —1.3-volt signal with a —1.3-volt reference derived from a —9.2-volt zener reference diode to give a focus current variation of less than .05%.

Using the circuits described, the vidicon operating parameters have been successfully maintained at sufficiently stable values that no adjustments were required through the specified space-environment-simulating thermal-vacuum tests.

Multiple Diode Theorems

R. L. Ernst,
Systems Laboratory,
Communications Systems Division, DEP,
New York, N. Y.

Final manuscript received December 2, 1964

In any mixer network, the dynamic range may be increased and the relative intermodulation distortion decreased by increasing the local oscillator or pump power. For single-diode networks, the maximum permissible pump power is limited by mixer noise figure and diode burnout. This limit may be increased by incorporating more diodes in the mixer network and distributing the pump power among the individual diodes. In order to minimize intermodulation distortion in such networks, two design problems must be solved: 1) *how should the signal power be distributed among the individual diodes,* and 2) *what is the best way to arrange the diodes in the circuit (push-pull, parallel, etc.).*

These problems are solved by the following two theorems. These theorems are applicable to mixer networks within all frequency ranges. It is assumed that intermodulation products caused by signals outside the desired band are eliminated by

THEOREM I: Given a multiple diode mixer network in which 1) the diodes are identical, 2) all ports are matched, and 3) each diode is fully pumped, then the optimum configuration (in terms of intermodulation distortion) is one in which the signal power applied to the circuit is equally distributed to each diode.

PROOF: By reason of the three stated conditions, the IF output of the complete circuit is independent of the circuit configuration. It is therefore sufficient to determine what configuration will minimize the total intermodulation power, because this will minimize the intermodulation to IF power ratio.

Call the total signal power applied to the circuit P. Each of the diodes receives a fraction of this power, i.e., $P_n = M_nP$, where P_n is the signal power applied to the nth diode and M_n is the fraction of the total power applied. Summing over N, the total number of diodes in the circuit, gives:

$$\sum_{n=1}^{N} M_n = 1 \qquad (1)$$

The intermodulation power produced in each diode is of some functional relationship of the type:

$$(IM)^2_n = \sum_{k=1}^{\infty} A_k P_n^{\,k} \qquad (2)$$

where $(IM)_n^2$ is the intermodulation power output of one diode, k is the index of summation, and A_k is the series coefficient. The total intermodulation power is, therefore, of the form:

$$\sum_{n=1}^{N}\sum_{k=1}^{\infty} A_k P_n^{\,k} = \sum_{n=1}^{N}\sum_{k=1}^{\infty} A_k (M_nP)^k = \sum_{k=1}^{\infty} A_k P^k \sum_{n=1}^{N} M_n^{\,k} \qquad (3)$$

Calling:

$$f = \sum_{n=1}^{N} M_n^{\,k} \qquad (4)$$

Then, the problem becomes one of determining what values of M_n will minimize f. By setting the partial derivatives of f equal to zero and realizing that $M_n = 1 - M_1 - M_2 - \ldots - M_{n-1}$, the following equations result:

$$\frac{\partial f}{\partial M_1} = kM_1^{\,k-1} - k(1 - M_1 - M_2 - \ldots - M_{n-1})^{k-1} = 0$$

$$\frac{\partial f}{\partial M_2} = kM_2^{\,k-1} - k(1 - M_1 - M_2 - \ldots - M_{n-1})^{k-1} = 0$$

$$\vdots \qquad\qquad \vdots$$

$$\frac{\partial f}{\partial M_{n-1}} = kM_{n-1}^{\,k-1} - k(1 - M_1 - M_2 - \ldots - M_{n-1})^{k-1} = 0$$

From these equations the following relations are found:

$$M_1 = M_2 = \ldots = M_{n-1}$$

$$M_1 = 1 - M_1 - M_2 - \ldots - M_{n-1} = M_n.$$

Therefore, all M_n are equal.

Comparing the steps giving Eqs. 1 and 4, it is seen that $M_n = 1/N$. Therefore, the optimum circuit configuration is one in which the signal power is equally distributed to each diode.

THEOREM II: In a multiple diode mixer network, the intermodulation distortion is independent of circuit configuration for any network which satisfies the conditions that: 1) the diodes are identical; 2) all ports are matched; and 3) the total power applied to the circuit is equally distributed to each diode.

PROOF: Contributions *(2)* and *(3)* require that each diode convert the same power regardless of circuit configuration. This fact, considered with condition *(1)*, reveals that the total voltage across each diode is the same. The intermodulation distortion produced by each diode is a function of the voltages across that diode.

At any one diode the phase of the fourth-order intermodulation output is given by $(2\,\theta_{s1} - \theta_{s2} - \theta_{sp})$ and the phase of the desired intermediate frequency output is given by $(\theta_{s1} - \theta_{sp})$, where: θ_{s1} is the relative phase of the desired signal input; θ_{s2} is the relative phase of the unwanted signal; and θ_{sp} is the relative phase of the pump; and one particular diode in the circuit is chosen as a reference, i.e., $\theta_{s1} = 0$, and $\theta_{s2} = 0$, and $\theta_{sp} = 0$ at this particular diode.

Because the frequencies of the desired signal and the unwanted signal are practically identical, and because both signals must pass through the same network, their relative phases at any diode are essentially equal, i.e., $\theta_{s1} = \theta_{s2}$. Therefore, the phases of the intermodulation and intermediate frequency output are given by: $(2\,\theta_{s1} - \theta_{s2} - \theta_{sp}) = (2\,\theta_{s1} - \theta_{s1} - \theta_{sp}) = (\theta_{s1} - \theta_{sp})$ for the intermodulation term and by: $(\theta_{s1} - \theta_{sp})$ for the intermediate frequency terms. Since the relative phases of these two terms are equal, any phase cancellation scheme that eliminates the intermodulation term will also eliminate the intermediate frequency term.

Repeating the steps in the above two paragraphs for higher-order intermodulation terms, such as the sixth and the eighth, will produce the identical result. Therefore, the intermodulation distortion output is independent of circuit configuration.

When saturation effects are not present, and the conditions stated in the theorems are satisfied, the change in relative fourth-order intermodulation distortion for a given total signal power is given by:

$$(\Delta D)_{db} = -20 \log_{10} N$$

This result is a consequence of the fact that a 1-db increase in total signal power causes a 2-db increase in fourth-order intermodulation distortion.[2]

1. This Note is the result of work done on USAEL Contract DA 36-039-AMC-02345 (E), *Interference Reduction Techniques for Receivers,* July, 1963—June, 1965.
2. *First Quarterly Progress Report, Interference Reduction Techniques for Receivers,* July-September 1963, USAEL Contract DA-36-039-AMC-02345 (E).

Patents Granted
TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

RCA LABORATORIES

3,157,847—Multilayered Waveguide Circuitry Formed by Stacking Plates Having Surface Grooves, November 17, 1964; R. M. Williams (patent assigned to U.S. Government).

3,158,512—Semiconductor Devices and Methods of Making Them, November 24, 1964; H. Nelson and C. W. Benyon

3,158,841—Data Script Conversion System, November 24, 1964; K. Li

3,159,486—Method of Making Electrical Conductors, December 1, 1964; C. W. Henderson

3,160,762—Hall Effect Device Employing Mechancial Stress Applied Across Crystal to Effect Change in Hall Voltage, December 8, 1964; M. C. Steele and R. Braunstein

3,160,873—Negative Resistance Analog to Digital Converter, December 8, 1964; J. J. Amodei and W. F. Kosonocky

3,162,589—Methods of Making Semiconductor Devices, December 22, 1964; L. Pensak

3,162,729—Modulation System for Multiplex Frequency-Modulation Signal Transmitter, December 22, 1964; F. R. Holt

3,162,774—Network for Obtaining a Threshold Function Utilizing Majority Gates in an Array, December 22, 1964; R. O. Winder

3,162,792 — Apparatus for Manufacturing Magnetic Recording Tape, December 22, 1964; R. A. Hackley and D. F. Martin

3,162,824 — Resonator with Intermediate Diode Oscillator or Amplifier, December 22, 1964; G. B. Herzog

3,162,842—Memory Circuits Employing Negative Resistance Elements, December 22, 1964; J. C. Miller and L. S. Onyshkevych

3,163,608—Luminescent Materials, December 29, 1964; P. N. Yocom

3,163,610—Bare Earth Activated Alkaline Earth Halofluoride Luminescent Materials, December 29, 1964; P. N. Yocom

3,164,737—Cathode Ray Tube, January 5, 1965; P. J. Messineo and J. Gross

3,164,744—Color Tube Beam Indexing with Ultra-Violet Rays, January 5, 1965; J. D. Bowker

3,164,813 — Magnetic Device, January 5, 1965; J. A. Rajchman

3,165,581—Keyed AGC Circuit with Means for Controlling Horizontal Sync Pulse Level of Signals Below the AGC Threshold, January 12, 1965; J. Avins

ELECTRONIC DATA PROCESSING

3,158,368—Card Feed Mechanism, November 24, 1964; S. M. Shelley

3,160,766—Switching Circuit with a Capacitor Directly Connected Between the Lower of Opposite Conductivity Transistors, December 8, 1964; W. K. Reymond

BROADCAST AND COMMUNICATIONS PRODUCTS DIV.

3,160,829 — Starting Circuit For Transistor Converter, December 8, 1964; E. W. Mahland

3,162,816—Generator of Different Patterns of Time-Sequential Pulses, December 22, 1964; L. L. Rakoczi and L. M. Paoletti

3,164,834—Waveguide Tower with Stacked Slot Radiators, January 5, 1965; N. Nikolayuk

ELECTRONIC COMPONENTS AND DEVICES

3,161,859—Modular Memory Structures, December 15, 1964; A. H. Medwin and E. Luedicke

3,162,933 — Method of Processing Cathode Ray Tubes, December 29, 1964; A. M. Trax and J. J. Monagle

3,163,862—Radar System and Component Apparatus, December 29, 1964; H. K. Jenny

3,164,115—Electron Tube Mounting Apparatus, January 5, 1965; W. T. Ackermann

3,164,175—Method of Making Wire-Wound Grids for Electron Tubes, January 5, 1965; O. H. Schade, Sr.

3,164,426—Electron Gun, January 5, 1965; R. E. Benway

3,164,740—Electron Tube Grids and Method of Making the Same, January 5, 1965; J. J. Moscony and R. W. Etter

DEFENSE ELECTRONIC PRODUCTS

Reissue 25,699 — Simplified Two-Channel Multiplex System, December 15, 1964; M. C. Kidd

3,164,826—Analog to Digital Converter Including Comparator Comprising Tunnel Diode Balanced Pair, January 5, 1965; E. P. McGrogan, Jr.

RCA SERVICE COMPANY

3,162,815—Sequential Pulse Generator Employing First and Second Delay Means Controlling Pulse Duration and Spacing, Respectively, December 22, 1964; H. Mogensen

HOME INSTRUMENTS DIVISION

3,163,797—Electron Beam Convergence Apparatus, December 29, 1964; G. W. Singleback

3,163,822—Automatic Frequency Control System Utilizing a Reference Oscillator, December 29, 1964; D. J. Carlson and G. B. Waters

3,165,090 — High-Frequency Sonic Signal Transmitter Mechanism, January 12, 1965; T. D. Smith

3,165,579 — Color Television Receiver Video Amplifier, January 12, 1965; J. Stark, Jr. and G. E. Kelly

3,165,666—Vertical Deflection Circuit with Height Control Feedback, January 12, 1965; A. H. Rickling

DATES and DEADLINES

Professional Meetings and Calls for Papers

Meetings

March 10-12, 1965: Particle Accelerator Conf., IEEE, G-NS et al.; Shoreham Hotel, Wash., D.C. *Prog. Info.:* R. S. Livingston, Oak Ridge Natl. Lab., P.O. Box X, Oak Ridge, Tenn.

March 22-25, 1965: IEEE International Convention, IEEE, All Groups TOC Committees; Coliseum & N.Y.-Hilton, N.Y., N.Y. *Prog. Info.:* Dr. E. L. Harder, IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

March 28-Apr. 2, 1965: 97th Semiannual Conf. and Exhibit, SMPTE; Ambassador Hotel, Los Angeles, Calif. *Prog. Info.:* Dr. R. J. Goldberg, Technicolor Corp., Res. and Dev. Div., 2800 W. Olive Ave., Burbank, Calif.

April 5-7, 1965: Second Space Congress, Canaveral Council of Tech. Societies; Cocoa Beach, Fla. *Prog. Info.:* Dr. L. E. Mertens, Tech. Prog. Chairman, RCA-Missile Test Project, MU 741, Bldg. 423, Patrick AFB, Fla.

April 6-8, 1965: Batch Fabrication Proc. & Their Impact on Computer Tech., IEEE-GC; Los Angeles, Calif. *Prog. Info.:* Sam Nissim, Bunker Ramo Corp., 8433 Fallbrook Ave., Canoga Park, Calif.

April 13-15, 1965: Natl. Telemetering Conf., IEEE, AIAA-ISA; Shamrock Hilton, Houston, Texas. *Prog. Info.:* R. W. Towle, Philco Corp., Western Dev. Labs., 3825 Fabian Way, Palo Alto, Calif.

April 14-15, 1965: 1965 Electronics & Instrumentation Conf. & Exhibit, IEEE & ISA, Cinc. Sect.; Cincinnati Gardens, Cincinnati, Ohio. *Prog. Info.:* J. R. Ebbeler, Avco Corp., 2630 Glendale-Milford Rd., Cincinnati, Ohio.

April 15-16, 1965: First Intl. Conf. on Programming and Control, U.S. Air Force Academy, Univ. of Calif., Berkeley; *Prog. Info.:* Major Orlando J. Manci, Jr., USAF, FJSRL, OAR, Air Force Academy, Colorado.

April 20-23, 1965: URSI-IEEE Spring Mtg., U.S. Natl. Committee of the Intl. Scientific Radio Union, American Geophysical Union, IEEE; Wash., D.C. *Prog. Info.:* Prof. A. T. Waterman, Jr., Stanford Electronics Labs., Stanford Univ., Stanford, Calif.

April 21-23, 1965: Southwestern IEEE Conf. & Elec. Show (Swieeeco), IEEE, Region 5; Dallas Memorial Auditorium, Dallas, Texas. *Prog. Info.:* E. F. Sutherland, Genl. Radio Co., 2501-A Mockingbird Lane, Dallas, Texas.

April 21-23, 1965: 1965 Intl. Nonlinear Magnetics Conf. (Intermag), IEEE; Sheraton Park Hotel, Wash., D.C. *Prog. Info.:* E. W. Pugh, IBM Components Div., Poughkeepsie, N.Y.

April 21-23, 1965: 6th Symp. on Eng. Aspects of Magnetohydrodynamics, ASME, Univ. of Pittsburgh, Carnegie Inst. of Tech. *Prog. Info.:* Dr. Eli Reshotko, Prog. Chairman, Div. of Eng., Case Inst. of Tech., Univ. Circle, Cleveland, Ohio.

April 27-29, 1965: American Power Conf., IEEE, et al.; Sherman Hotel, Chicago, Ill. *Prog. Info.:* W. A. Lewis, Ill. Inst. of Tech., Chicago, Ill.

May 5-7, 1965: 1965 Microwave Theory & Techniques Symposium, IEEE, G-MTT; Jack Tar Harrison Hotel, Clearwater, Fla. *Prog. Info.:* J. E. Pippin, Sperry Microwave Elec. Co., Box 1828, Clearwater, Fla.

May 5-7, 1965: Electronic Components Conf. (ECC), IEEE-EIA; Marriott Motor Hotel, Wash., D.C. *Prog. Info.:* Bernard Schwartz, IBM Components Div., Poughkeepsie, N.Y.

May 6-8, 1965: 6th Natl. Symp. on Human Factors in Electronics, IEEE-HFE; Sheraton Hotel, Boston, Mass. *Prog. Info.:* Dr. James Degan, MITRE Corp., P.O. Box 208, Bedford, Mass.

May 10-12, 1965: Naecon (Natl. Aerospace Electronics Conf.), IEEE-G-ANE, AIAA, Dayton Section; Dayton, Ohio; *Prog. Info.:* IEEE Dayton Office, 1414 E. 3rd St., Dayton 2, Ohio.

May 13-14, 1965: Symp. on Signal Transmission and Processing, IEEE, G-CT; Columbia Univ., N.Y., N.Y. *Prog. Info.:* Dr. L. E. Franks, Bell Tel. Labs., North Andover, Mass.

May 19-21, 1965: Power Industry Computer App. Conf. (PICA), IEEE, G-P & Florida Westcoast Section; Jack Tar Hotel, Clearwater, Fla. *Prog. Info.:* G. W. Stagg, American Elec. Power Ser. Corp., 2 Broadway, N.Y.

May 24-29, 1965: IFIP Congress '65, IEEE, IFIP; N.Y. Hilton, NYC. *Prog. Info.:* Dr. A. Householder, Oak Ridge Natl. Lab., Oak Ridge, Tenn.

June 7-9, 1965: 1st Ann. IEEE Communication Convention (*includes* Globecom VII), IEEE G-Comm. Tech.; Univ. of Colo. & NBS Labs., Boulder, Colo. *Prog. Info.:* W. F. Ulaut, National Bureau of Standards, Boulder, Colorado.

June 20-24, 1965: Aerospace Tech. Conf., IEEE, G-AS, Houston Sect.; Shamrock-Hilton Hotel, Houston, Texas. *Prog. Info.:* Thos. P. Owen, 635-20 St., Santa Monica, Calif.

June 21-25, 1965: San Diego Symp. for Biomedical Engineering, IEEE, U.S. Naval Hosp.; San Diego, Calif. *Prog. Info.:* Dean L. Franklin, Scripps Clinic & Res. Foundation, La Jolla, Calif.

June 22-25, 1965: Joint Automatic Control Conf., IEEE-ASME, AIChE, ISA; Rensselaer Polytech. Inst., Troy, N.Y. *Prog. Info.:* Prof. James W. Moore, Univ. of Va., Charlottesville, Va.

June 28-30, 1965: 7th Natl. Symp. on Electromagnetic Compatibility, IEEE, G-EMC; Waldorf-Astoria, N.Y., N.Y. *Prog. Info.:* D. Fidelman, Electromag. Meas. Co., Farmingdale, N.Y.

Calls for Papers

Aug. 23-27, 1965: 6th Intl. Conf. on Medical Elec. & Biological Eng., IFMEBE; Tokyo, Japan. **Deadline:** Abstracts, approx. **4/30/65.** *TO:* Dr. L. E. Flory, RCA Labs., Princeton, N.J.

Aug. 24-27, 1965: Wescon; IEEE, WEMA; Cow Palace, San Francisco, Calif. **Deadline:** Abstracts, approx. **4/15/65.** *FOR INFO.:* IEEE L.A. Office, 3600 Wilshire Blvd., Los Angeles, Calif.

Aug. 30-Sept. 1, 1965: Antennas & Propagation Intl. Symp., IEEE, G-AP; Sheraton Park Hotel, Wash., D.C. **Deadline:** Abstracts, approx. **3/2/65.** *FOR INFO.:* Dr. R. J. Adams, Search Radar Branch, Naval Res. Lab., Wash., D. C.

Sept. 8-10, 1965: 13th Ann. Indus. Elec. & Control Inst. Conf., IEEE, G-IECI, Phila. Section; Sheraton Hotel, Phila., Pa. **Deadline:** Abstracts, approx. **5/1/65.** *FOR INFO.:* Lewis Winner, 152 W. 42 St., New York 25, N.Y.

Sept. 12-17, 1965: 6th Natl. Electrical Insulation Conf., IEEE-NEMA; N.Y. Hilton at Rockefeller Ctr., N.Y., N.Y. *FOR DEADLINE INFO.:* H. W. Marquardt, NEMA-155 E. 44th St., N.Y., N.Y.

Sept. 16-17, 1965: 13th Ann. Joint Eng. Management Conf., IEEE, ASME, et al.; Roosevelt Hotel, N.Y., N.Y. *FOR DEADLINE INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Sept. 22-24, 1965: Intl. Convention on Military Electronics (MIL-E-CON 9), IEEE, G-MIL; Wash. Hilton Hotel, Wash., D.C. *FOR DEADLINE INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Oct. 4-6, 1965: 1965 Canadian Electronics Conf., IEEE, Region 7; Toronto, Ont., Canada. *FOR DEADLINE INFO.:* Canadian Elec. Conf., 1819 Yonge St., Toronto 7, Canada.

Oct. 21-23, 1965: Electron Devices Mtg., IEEE, G-ED; Sheraton Park Hotel, Wash., D.C. **Deadline:** Abstracts, approx. **8/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Oct. 25-27, 1965: Natl. Electronics Conf., IEEE, et al.; McCormick Place, Chicago, Ill. **Deadline:** Abstracts, approx. **5/1/65.** *FOR INFO.:* NEC Office, 228 La Salle St., N., Chicago, Ill.

Oct. 27-29, 1965: East Coast Conf. on Aerospace & Navig. Electronics (ECCANE), IEEE, G-ANE, Baltimore Section. **Deadline:** Abstracts, approx. **6/4/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Nov. 1-3, 1965: Industrial Static Power Conversion Conf., IEEE; Benj. Franklin Hotel, Phila., Pa. *FOR DEADLINE INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Nov. 2-5, 1965: IEEE Ann. Symp. on Space Electronics, IEEE-G-SET; Fontainebleu Hotel, Miami Beach, Fla. *FOR DEADLINE INFO.:* Thos. Broskie, NASA, Cape Kennedy Complex, Cocoa Beach, Fla.

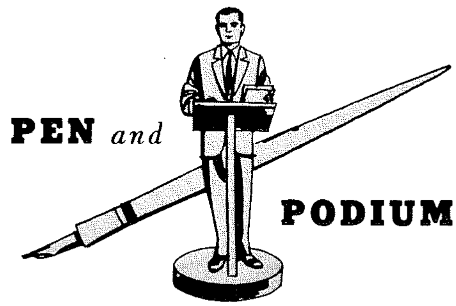
Nov. 3-5, 1965: Nerem (Northeast Elec. Res. and Eng. Mtg.), IEEE, Region 1; Boston, Mass. **Deadline:** Abstracts, approx. **6/7/65.** *FOR INFO.:* NEREM, IEEE Boston Office, 313 Wash. St., Newton 58, Mass.

Nov. 10-12, 1965: 18th Ann. Conf. on Eng. in Medicine & Biology, IEEE-ISA; Univ. of Pa. & Sheraton Hotel, Phila., Pa. **Deadline:** Abstracts, approx. **8/1/65.** *FOR INFO.:* Dr. H. Schwan, Moore School of EE, Univ. of Pa., Phila., Pa.

Nov. 15-18, 1965: 11th Ann. Conf. on Magnetism & Mag. Matls., IEEE-AIP; Hilton Hotel, San Francisco, Calif. **Deadline:** Abstracts, approx. **8/19/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

Nov. 30-Dec. 1-2, 1965: Fall Joint Computer Conf., IEEE, AFIPS, ACM; Convention Center, Las Vegas, Nevada. **Deadline:** Abstracts, approx. **5/1/65.** *FOR INFO.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

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.



A SUBJECT-AUTHOR INDEX TO RECENT RCA PAPERS

Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal from your library—or write or call the author for a reprint. For information on verbal presentations, write or call the author. This index is prepared from listings provided bimonthly by divisional Technical Publications Administrators and Editorial Representatives—who should be contacted concerning errors or omissions (see inside back cover).

SUBJECT INDEX

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

AMPLIFICATION

Preamplifier, A 144-MC Antenna-Matching—L. W. Aurick (ECD, Lanc.) *RCA Ham Tips*, Fall 1964

VHF/UHF Tuned Amplifiers, Achieving High Performance in—T. J. Robe (ECD, Som.) *Electronic Design*, Dec. 21, 1964

ACOUSTIC THEORY: PHENOMENA

Cinerama Theatre Acoustics—M. Rettinger (BCD, Camden) *Jour. SMPTE*, July 1964

Sound Velocity Measurements in $CaWO_4$ Single Crystal—D. Gerlich (Labs, Pr.) *Physics Letters*, Vol. 12, No. 4, Oct. 15, 1964

ANTENNAS

Butler Matrix, The Systematic Design of the—H. J. Moody (RCA Ltd., Montreal) *Trans. IEEE on Antennas and Propagation*, Nov., 1964, AP-12, No. 6

Spherical Reflector, Optics of the Focal Region of a—R. C. Spencer, G. Hyde (DEP-MSR, Moores.) Annual Mtg. of the Optical Soc. of America, N.Y., Oct., 1964; *Journal of American Optical Soc.*, Vol. 54, Nov. 1964

Spherical Reflector, Transverse Focal Region Properties of a—G. Hyde (DEP-MSR, Moores.) 14th Annual Symp. on USAF Antenna R&D, Univ. of Ill., Oct. 6-7-8, 1964; *Proceedings*

ATOMIC ENERGY: PHENOMENA

Comparative Anatomy of Models for Double Injection of Electrons and Holes in Solids—A. Rose (Labs, Pr.) *Applied Physics*, Vol. 35, No. 9, Sept. 1964

Dielectric Behavior of Nonrigid Molecules. II. Intramolecular Interactions and Dielectric Relaxation—F. K. Fong (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Quantum-Mechanical Effects in Simulated Optical Emission. II—R. C. Williams (Labs, Pr.) *The Physical Review*, Vol. 136, No. 3a, Nov. 2, 1964

CHECKOUT; MAINTENANCE

Advanced Servicing Techniques, Vol. II, Part III — Tape Recorders—M. P. Rosenthal (DEP-CSD, N.Y.) Manual published by J. F. Rider, Inc., N. Y., October 1964

Designing Dynamic Test Sets for Use Optimization—F. W. Stirner (DEP-CSD, Camden) *IEEE Transactions of PTGPEP*, Apr. 1964

Measurement Accuracies—W. D. Moon (DEP-ASD, Burl.) *IEEE Transactions on Aerospace*, Aug. 21, 1964

Multisystem Automatic Test Equipment, Applications of—P. M. Toscano (DEP-ASD, Burl.) Northeastern States U.S. Navy Research & Development Clinic, Phila., Pa., Nov. 20, 1964

System Test Evaluation and Control—W. J. O'Leary (DEP-MSR, Mrstn.) Princeton Conf., Princeton University, Princeton, N.J., Dec. 5, 1964

CIRCUIT THEORY; ANALYSIS

Network Functions with an Infinite Potential Analog Plane, Generating—F. M. Brock, R. Binks (BCD, Camden) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Non-Linear RC Circuits, Step Response of—G. E. Roberts, H. Kaufman (RCA Ltd., Montreal) *Journal of Electronics and Control*, Vol. 17, No. 4, Oct. 1964

Silicon Rectifiers Used in Capacitive-Load Circuits, Simplified Rating System for—J. M. S. Neilson, B. J. Roman (ECD, Mttop.) *Semiconductor Products*, Sept. 1964

CIRCUIT INTERCONNECTIONS; PACKAGING

Circuit Interconnections; Packaging Microelectronics; A Typical Packaging Concept—R. C. Leunis (DEP-CSD, Camden) IEEE Mtg. of Professional Groups on Engineering and Production, and Component Parts, Phila., Pa., Dec. 3, 1964

Conductive Paths—J. H. Wolff (DEP-CSD, Camden) Overall Comm. Systems Planning, IEEE Educational Committee, Newark, N.J., Nov. 3, 1964

Temperature Elevation in an Electric Module—G. Rezek (DEP-CSD, Camden) *Electromechanical Design*, Oct. 1964

COMMUNICATIONS, DIGITAL

Interference Control Techniques, Digital—Communication—J. R. Neubauer (DEP-CSD, Camden) Nat'l. Electronics Conf., Chicago, Ill., Oct. 19, 1964

COMMUNICATIONS SYSTEMS; THEORY

Fundamentals of Radio—M. P. Rosenthal (DEP-CSD, N.Y.) textbook published by J. F. Rider, Inc., N. Y., Dec. 1964

Microwave Communication, System Concepts—B. Bossard, K. Chang, W. Y. Pan, L. Burns (DEP-CSD, N.Y.) NEREM, Baston, Mass., Nov. 4, 1964

Narrow Beam Communication System Acquisition Problem—J. S. Greenberg (DEP-Pr.) *IEEE Trans. on Military Electronics*, Vol. MIL-8-No. 1, Jan. 1964

RADA Communications, On the Optimization of—R. Sommer (DEP-CSD, Camden) *Proc. of IEEE Corres.*, Aug. 1964

RADA Systems and Techniques—W. J. Bieganski (DEP-CSD, Camden) Northeastern States Navy R&D Clinic, Phila., Pa., Nov. 20, 1964

Satellite Design, Economics of—An American Assessment—S. Gubin, J. S. Greenberg (DEP-Pr.) Published by Iliffe Books, Ltd., London, England, Apr. 1964 as Chapter 13 in book entitled *Telecommunication Satellites;* also published by Prentice-Hall, Inc., Englewood, N.J., July 1964

Satellite Telecommunications, Future of—Dr. N. I. Korman, Dr. M. Handelsman (DEP-Pr.) Published by Iliffe Books, Ltd., London, England, Apr. 1964 as Chapter 14 in book *Telecommunication Satellites;* also published by Prentice-Hall, Inc., Englewood, N.J., July 1964

Seismic Communication—K. H. Powers (Labs, Pr.) Northeast Electronics Research and Engineering Mtg., NEREM-64, Nov. 4, 5, 6, 1964

Simulation Techniques for Simulation of a Communication System—E. W. Veitch (DEP-CSD, Camden) Univ. of Michigan, Ann Arbor, Mich., June 18, 1964

Tactical Radio Relay—AN/TRC-97—N. E. Edwards (DEP-CSD, Camden) Northeastern States Navy R&D Clinic, Phila., Pa., Nov. 20, 1964

COMMUNICATIONS, VOICE SYSTEMS

Singapore Police Force Mobile Network—G. Sartore (ECD, Camden) IEEE Group on Vehicular Communications, Cleveland, Ohio, Dec. 3, 1964

Transmitter, Efficient High-Power Mobile—F. A. Barton (BCD, Camden) Nat'l. Convention of PTGVC (IEEE), Cleveland, Ohio, Dec. 4, 1964

VHF Pipeline System for the Richmond Petroleum Co.—J. C. Kaltenbach, Jr. (BCD, Camden) IEEE Petroleum Industry Conf., San Francisco, Aug. 26, 1964

COMMUNICATIONS, EQUIPMENT COMPONENTS

Dielectric Resonators for Microwave Applications—R. V. D'Aiello, H. J. Prager (Labs, Pr.) *IEEE Transactions G-MTT*, Vol. 12, No. 5, September 1964

Mixers, Intermodulation Distortion in—B. Bossard, P. Torrione, S. Yuan (DEP-CSD, N.Y.) 10th Tri Service Conf. on Electromagnetic Compatibility, Chicago, Ill., Nov. 17, 1964

Mixers, Nonlinear-Admittance—L. Becker, R. L. Ernst (RCA Comm., N.Y.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Preamplifier, A 144-Mc Antenna-Matching—L. W. Aurick (ECD, Lanc.) *RCA Ham Tips*, Fall 1964

VHF/UHF Tuned Amplifiers, Achieving High Performance in—T. J. Robe (ECD, Som.) *Electronic Design*, Dec. 21, 1964

COMPUTER APPLICATIONS

Computer Solutions Aid Rectifier Filter Design—W. M. Austin, K. W. Angel (ECD, Hr.) *Electronic Industries*, Dec. 1964

Conditional Least Squares Polynomial Approximation—R. W. Klopfenstein (Labs, Pr.) *Mathematics of Computation*, Vol. 18, No. 88, October, 1964

OGO Satellites, Real-Time Quick-Look Analysis for the—F. H. Fowler, Jr. (DEP-CSD, Camden) *Computering Reviews*, Nov.-Dec. 1964

Ordinal Transformations, Inverse Table Look-up for—F. H. Fowler, Jr. (DEP-CSD, Camden) *Control Engineering*, Nov. 1964

COMPUTER CIRCUITRY; DEVICES

Flexode, The Point-Contact—B. E. Tompkins (Labs, Pr.) *Proceedings of the IEEE*, Sept. 1964, Vol. 52, No. 9

Laser Digital Devices—W. F. Kosonocky, O. A. Reimann (Labs, Pr.) RADC Symp. on Optical and Electro-Optical Info. Processing Technology, Boston, Mass., Nov. 9-10, 1964

Ryotron—A New Cryogenic Device—R. A. Gange (Labs, Pr.) *Proc. of the IEEE*, Oct. 1964

Ryotron—A Variable Inductance Cryogenic Device—J. C. Miller, C. M. Wine, L. S. Cosentino (Labs, Pr.) *Proc. of the IEEE.*

Transistor Logic Circuits, Switching Response of Complementary-Symmetry MOS—J. R. Burns (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

COMPUTER STORAGE

Analysis of the "Shmoo" Plot for Coincident Current Core Memory Operation—Y. L. Yao (DEP-CSD, Camden) *Electronic Design*, Dec. 31, 1964

Cryoelectric Memory Planes, Cavity Sensing of—L. L. Burns (Labs, Pr.) Decennial Conf. Magnetism and Magnetic Materials, Minneapolis, Minn., Nov. 16-19, 1964

Integrated Magnetic and Superconductive Computer Memories—J. A. Rajchman (Labs, Pr.) Boston Chapter of the IEEE, Dec. 16, 1964

COMPUTER SYSTEMS

Inside Digital Computers—Dr. L. R. Lavine (DEP-Pr.) Univ. of Penna., Oct. 24, 1964

Real-Time Computer Systems, Design of—W. A. Levy (DEP-CSD, Camden) Univ. of Michigan, Ann Arbor, Mich., June 17, 1964

DISPLAYS

Displays, Papers, and Lighting—The Visual System in Command Centers—A. C. Stocker (DEP-MSR, Moores.) *Information Display*, Oct. 1964, Vol. I, No. 1

Electron Microscopy Using Image Intensification and Television Display—J. H. Reisner, Dr. (BCD, Camden) *Scientific Instruments News*, Oct. 1964

DOCUMENTATION; WRITING

A Billion-and-a-Half a Year; A Ton-and-a-Half a Day: Reducing the Cost and Bulk of Defense Documentation—C. W. Fields, J. J. Gillespie, R. E. Patterson, W. W. Thomas (DEP-CSD, Camden) *WFLN* Radio, Phila., Pa., Dec. 5 & 19, 1964

Communication—The Engineer's Job?—M. Hertzberg (DEP-CSD, Camden) *IEEE Transactions on EWS*, EWS 7-2, Sept. 1964

How to Write a Technical Book and Get It Published—M. P. Rosenthal (DEP-CSD, N.Y.) *IEEE Transaction on EWS*, EWS 7-2, Sept. 1964

Proposal Activity, Organization and Management of a—J. A. Doughty (DEP-CSD, Camden) Proposal Management, American Management Assoc., N.Y., Nov. 18, 1964

Proposal Preparation, Cost Engineering Approach to Government—R. W. Greenwood (DEP-CSD, Camden) Amer. Inst. of Ind. Engrs., Region II Conf., Baltimore, Md., Oct. 8, 1964

EDUCATION

Address to Awards Day Ceremony—Engineering Department—Dr. J. R. Whitehead (RCA Ltd., Montreal) Univ. of Saskatchewan, Nov. 25, 1964

ELECTROMAGNETIC THEORY; PHENOMENA

Butler Matrix, The Systematic Design of the—H. J. Moody (RCA Ltd., Montreal) *Trans. IEEE on Antennas and Propagation,* Nov. 1964, AP-12, No. 6

Cyclotron Harmonics in Warm Plasmas, Excitation of—T. W. Johnston (RCA Ltd., Montreal) Amer. Physical Soc. Plasma Physics Mtg., N.Y., Nov. 1964

Collisional Effects on E-M Wave Propagation Near the Electron Cyclotron Frequency—M. P. Bachynski, B. W. Gibbs (RCA Ltd., Montreal) Amer. Physical Soc. Plasma Physics Mtg., N.Y., Nov. 1964

Electron-Beam Noise, Effect of High Magnetic Field on—J. M. Hammer, C. P. Wen (Labs, Pr.) *RCA Review,* Vol. XXV, No. 4, Dec. 1964

Fundamentals of Radio—M. P. Rosenthal (DEP-CSD, N.Y.) Textbook published by J. F. River, Inc., N.Y., Dec. 1964

Laser Transmission Measurements at the David Taylor Model Basin—H. Okoomian (DEP-ASD, Burl.) 2nd Mine Advisory Committee of the Nat'l. Academy of Sciences, Nat'l. Research Council 60th Annual Mtg., Univ. of Calif., Berkeley, Calif.

Microwave Properties of Superconductors—J. I. Gittleman, B. Rosenblum (Labs, Pr.) *Proceedings of the IEEE,* Oct. 1964

Microwave Surface Impedance of Superconductors of Periodic-Medium—G. Fischer (Labs, Pr.) *Journal of Mathematics Physics,* Vol. 5, No. 8, Aug. 1964

Microwave Surface Impedance of Superconductors of the Second Kind—G. Fischer (Labs, Pr.) *Physical Review,* Vol. 135, No. 5a, Aug. 31, 1964

Narrow Beam Communication System Acquisition Problem—J. S. Greenberg (DEP-Pr.) *IEEE Trans. on Military Electronics,* Vol. MIL-8-No. 1, Jan. 1964

Photoconductivity in Dispersed Organic Systems—W. Mehl, N. E. Wolff (Labs, Pr.) *Journal of Physics and Chemistry of Solids,* Vol. 25, June 4, 1964

Space-Charge-Limited Currents Injected From a Point Contact—M. A. Lampert, A. Many, P. Mark (Labs, Pr.) *Physical Review,* Vol. 135, No. 5a, Aug. 31, 1964

Theory of One-Carrier, Space-Charge-Limited Currents Including Diffusion and Trapping—M. A. Lampert, F. Edelman (Labs, Pr.) *Journal of Applied Physics,* Vol. 35, No. 10, Oct. 1964

ELECTROMAGNETISM

Anomalous Resistivity Nb_3Sn—D. W. Woodward, G. D. Cody (Labs, Pr.) *Physical Review,* Vol. 135, No. 1A, Oct. 5, 1964

Differential and Thermogravimetric Analysis of Mn-Zn Ferrite—R. E. Hurley, R. Degenkolb (H.I., Indpls.) Indiana Branch of the Amer. Ceramic Soc., Oct. 26, 1964

High-Temperature Susceptibility of Heisenberg Ferromagnets Having First- and Second-Neighbor Interactions—P. J. Wojtowicz, R. I. Joseph (Labs, Pr.) *Physical Review,* Vol. 135, No. 5a, Aug. 31, 1964

Selected Topics in Magnetism—I. Gordon (Labs, Pr.) Graduate Seminar, School of Ceramics College of Engineering, Rutgers Univ., New Brunswick, N.J., Nov. 7, 1964

Sign of the Trigonal Field Splitting of B-Site Ions in Spinel—S. B. Berger (Labs, Pr.) Conf. on Magnetism and Magnetic Mat'ls., Minneapolis, Minn., Nov. 17, 1964

Site Preference of Ge^{4+} in Magnetic Spinels—M. Robbins (Labs, Pr.) Magnetic Conf., Minneapolis, Minn., Nov. 17, 1964

ELECTRO-OPTIC SYSTEMS; TECHNIQUES

Abberations in Electron Optics—E. G. Ramberg (Labs, Pr.) Lecture for Colloquium at Electron Physics Laboratory, Penna. State Univ., Oct. 23, 1964

Broad-Band Optical Detectors: Comparison of Photodiode Varactor Photodiode and Photoconductor in a Cavity—H. S. Sommer, Jr., (Labs, Pr.) Stanford Univ., Calif., Nov. 17, 1964

Electron Microdiffraction from Circular Areas of Less Than 100 Angstrom Diameter—Dr. J. W. Coleman (BCD, Camden) Electron Microscope Soc. of America, Detroit, Mich., Oct. 1964

Electron Microscopy Using Image Intensification and Television Display—J. H. Reisner, Dr. (BCD, Camden) *Scientific Instruments News,* Oct. 1964

Imaging Systems, Resolution Analysis of—I. M. Krittman (DEP-AED, Pr.) City College of N.Y. Chapter of the IEEE, Nov. 12, 1964

Integrated Thin-Film Image Scanner—P. K. Weimer, H. Borkan, L. Meray-Horvath, F. V. Shallcross (Labs, Pr.) 1964 Internat'l. Solid-State Circuits Conf. Session 8, Feb. 8, 1964

Laser Digital Devices—W. F. Kosonocky, O. A. Reimann (Labs, Pr.) RADC Symp. on Optical and Electro-Optical Info. Processing Technology, Boston, Mass., Nov. 9-10, 1964

Light Modulators—F. Sterzer (ECD, Pr.) Johnson Foundation, Univ. of Penna., Nov. 20, 1964

Quantum-Mechanical Effects in Stimulated Optical Emission. II—R. C. Williams (Labs, Pr.) *The Physical Review,* Vol. 136, No. 3a, Nov. 2, 1964

ENERGY CONVERSION; SOURCES

Cesium Reference Anodes—J. R. Fondley, Jr. (Labs, Pr.) 1964 Thermionic Conversion Specialist Conference NASA Lewis Research Center, Cleveland, Ohio, Oct. 26, 1964

Transistorized Microwave Power Source—M. Caulton, R. Ernst, H. Sobol (DEP-CSD, Camden) Electron Devices Conf., Wash., D.C., Oct. 31, 1964

ENVIRONMENTAL FACTORS

Designing Electronic Equipment for the Combined Random and Sinusoidal Vibration Environment—A. W. Sinkinson (DEP-ASD, Burl.) 34th Symp. on Shock, Vibration and Associated Environments, Monterey, Calif., Oct. 14, 1964

Temperature Elevation in an Electric Module—G. Rezek (DEP-CSD, Camden) *Electromechanical Design,* Oct. 1964

FILTERS

Computer Solutions Aid Rectifier Filter Design—W. M. Austin, K. W. Angel (ECD, Hr.) *Electronic Industries,* Dec. 1964

GEOPHYSICS

Noble Equation for the Diffusion of a Circular Dye Patch, A Simple Derivation of the—F. C. W. Olson (DEP-Pr.) *The Journal of Geophysical Research,* Vol. 69, No. 2, Jan. 15, 1964

Simulation of Geophysical Phenomena in the Laboratory—M. P. Bachynski (RCA Ltd., Montreal) *A.I.A.A. Journal,* Vol. 2, No. 11, Nov. 1964

Variation of the Magnetosphere with Solar Wind Properties, Laboratory Studies of the—F. J. F. Osborne, M. P. Bachynski, J. V. Gore (RCA Ltd., Montreal) *Journal Geophysical Research,* Vol. 69, No. 21, Nov. 1, 1964

INFORMATION PROCESSING; RETRIEVAL

ASW Vehicles, A Semi-Automatic Tactical Real-Time-Information Data-Exchange Concept for—D. Greenberg (DEP-CSD, Camden) Northeastern States Navy R&D Clinic, Phila., Pa., Nov. 20, 1964 (*classified* paper; *unclassified* title)

INSTRUMENTATION; LAB EQUIPMENT

Electron Microdiffraction from Circular Areas of Less Than 100 Angstrom Diameter—Dr. J. W. Coleman (BCD, Camden) Electron Microscope Soc. of America, Detroit, Mich., Oct. 1964

Electron Microscopy Using Image Intensification and Television Display—J. H. Reisner, Dr. (BCD, Camden) *Scientific Instruments News,* Oct. 1964

Focussed Microwave Systems for Plasma Diagnostics—A. I. Carswell, C. Richard (RCA Ltd., Montreal) Amer. Physical Soc. Plasma Physics Mtg., N.Y., Nov. 1964

Simulation of Geophysical Phenomena in the Laboratory—M. P. Bachynski (RCA Ltd., Montreal) *A.I.A.A. Journal,* Vol. 2, No. 11, Nov. 1964

Two-Phase Mercury Plasma Tunnel—A. I. Carswell (RCA Ltd., Montreal) *Review of Scientific Instruments,* Vol. 35, No. 11, Nov. 1964

X Lasers (Properties of) and Their Applications to Spectroscopical Problems—H. J. Gerritsen (Labs, Pr.) Brookhaven Nat'l. Lab., Upton, L.I., N.Y., Nov. 4, 1964

X-Ray Spectrometric Analysis, Solution Techniques in—E. P. Bertin (ECD, Hr.) Soc. for Applied Spectroscopy, N.Y. Chapter, Dec. 8, 1964

LASERS

Blue Gas Laser Using Hg^{2+}—H. J. Gerritsen, P. V. Goedertier (Labs, Pr.) *Journal of Applied Physics,* Vol. 35, No. 10, Oct. 1964

CW Operation of Ga As Injection Lasers—M. F. Lamorte, R. B. Liebert, T. Gonda (ECD, Som.) *Proceedings of the IEEE* (Corres.) Oct. 1964

Divalent Rare Earths in Optical Maser Oscillator—G. J. Goldsmith (Labs, Pr.) Department of Physics, Purdue Univ., Oct. 16, 1964

Laser Digital Devices—W. F. Kosonocky, O. A. Reimann (Labs, Pr.) RADC Symp. on Optical and Electro-Optical Info. Processing Technology, Boston, Mass., Nov. 9-10, 1964

Laser Transmission Measurement at the David Taylor Model Basin—H. Okoomian (DEP-ASD, Burl.) 2nd Mine Advisory Committee of the Nat'l. Acadamy of Sciences, Nat'l. Research Council 60th Annual Mtg., Univ. of Calif., Berkeley, Calif.

Quantum-Mechanical Effects in Stimulated Optical Emission. II—R. C. Williams (Labs, Pr.) *The Physical Review,* Vol. 136, No. 3a, Nov. 2, 1964

Threshold Current in GaAs Lasers, Temperature Dependence of—G. C. Dousmanis, H. Nelson, D. L. Staebler (Labs, Pr.) *Applied Physics Letters,* Vol. 5, No. 9, Nov. 1, 1964

X Lasers (Properties of) and Their Applications to Spectroscopical Problems—H. J. Gerritsen (Labs, Pr.) Brookhaven Nat'l. Lab., Upton, L.I., N.Y., Nov. 4, 1964

MANAGEMENT; BUSINESS

A Billion-and-a-Half a Year; A Ton-and-a Half a Day: Reducing the Cost and Bulk of Defense Documentation—C. W. Fields, J. J. Gillespie, R. E. Patterson, W. W. Thomas (DEP-CSD, Cam.) *WFLN* Radio, Phila., Pa., Dec. 5, 19, 1964

Communications Part in Corporate Systems—E. J. Tomko (DEP-CSD, Camden) AMA Orientation Seminar, N.Y., Nov. 18, 1964

Income Control Through Marketing Standards—H. N. Garber (Labs, Pr.) Budget Executive Institute, Boston, Mass., Oct. 23, 1964

New Perspectives for Consumer Electronics—J. Hillier (Labs, Pr.) IEEE Consumer Electronics Award Dinner-part of 1964 National Electronics Conf., Chicago, Ill.

Patents in the United States—M. S. Winters (Labs, Pr.) Jewish Center of Princeton Men's Club, Nov. 16, 1964

Program Management—C. K. Law (DEP-CSD, Camden) Air Force Institute, Dayton, Ohio, Apr. 1964

Program Management, Guidance and Control of—C. K. Law (DEP-CSD, Camden) IEEE PTGEM Mtg., Point Mugu, Calif., Oct. 19, 1964

Proposal Activity, Organization and Management of a—J. A. Doughty (DEP-CSD, Camden) Proposal Management, Amer. Management Assoc., N.Y., Nov. 18, 1964

Proposal Preparation, Cost Engineering Approach to Government—R. W. Greenwood (DEP-CSD, Camden) Amer. Inst. of Ind. Engrs., Region II Conf., Baltimore, Md., Oct. 8, 1964

MATHEMATICS

Conditional Least Squares Polynomial Approximation—R. W. Klopfenstein (Labs, Pr.) *Mathematics of Computation,* Vol. 18, No. 88, Oct. 1964

Noble Equation for the Diffusion of a Circular Dye Patch, A Simple Derivation of the—F. C. W. Olson (DEP-Pr.) *The Journal of Geophysical Research,* Vol. 69 No. 2, Jan. 15, 1964

Ordinal Transformations, Inverse Table Lookup for—F. H. Fowler, Jr. (DEP-CSD, Camden) *Control Engineering,* Nov. 1964

MECHANICAL COMPONENTS

Versatile Fiberglass in an Electronics Model Shop—I. M. Frank (DEP-MSR, Moores.) IEEE-GPEP, Phila. Chapter, Oct. 27, 1964

MILITARY SYSTEMS

ASW Vehicles, A Semi-Automatic Tactical Real-Time-Information Data-Exchange Concept for—D. Greenberg (DEP-CSD, Camden) Northeastern States Navy R&D Clinic, Phila., Pa., Nov. 20, 1964 (*classified* paper; *unclassified* title)

MOTION-PICTURE EQUIPMENT

Cinerama Theatre Acoustics—M. Rettinger (BCD, Camden) *Jour. SMPTE,* July 1964

OPTICS

Space Optics—R. Jorden (DEP-AED, Pr.) Optical Soc. of America, Delaware Valley Sect., Temple Univ., Dec. 3, 1964

Spherical Reflector, Optics of the Focal Region of a—R. C. Spencer, G. Hyde (DEP-MSR, Moores.) Annual Mtg. of the Optical Soc. of America, N.Y., Oct. 7, 1964; *Journal of American Optical Soc.,* Vol. 54, Nov. 1964

PLASMA

Cyclotron Harmonics in Warm Plasmas, Excitation of—T. W. Johnston (RCA Ltd., Montreal) Amer. Physical Soc. Plasma Physics Mtg., N.Y., Nov. 1964

Focussed Microwave Systems for Plasma Diagnostics—A. I. Carswell, C. Richard (RCA Ltd., Montreal) Amer. Physical Soc. Plasma Physics Mtg., N.Y., Nov. 1964

Sustained Plasma Oscillations Near the Crest of an Ion Acoustic Wave—G. W. Swartz, L. S. Napoli (Labs, Pr.) Mtg. of the Plasma Physics Div. of the American Physical Soc., N.Y., Nov. 4-7, 1964

Two-Phase Mercury Plasma Tunnel—A. I. Carswell (RCA Ltd., Montreal) *Review of Scientific Instruments*, Vol. 35, No. 11, Nov. 1964

Variation of the Magnetosphere with Solar Wind Properties, Laboratory Studies of the—F. J. F. Osborne, M. P. Bachynski, J. V. Gore (RCA Ltd., Montreal) *Journal Geophysical Research*, Vol. 69, No. 21, Nov. 1, 1964

Wake Diagnosis Using Cross Polarized Backscatter—R. S. Ruffine (DEP-MSR, Moores.) AMRAC Mtg., Nov. 16-18, 1964 (*Secret* paper; *unclassified* title).

RADAR

Search with Concealment—N. S. Potter (DEP-MSR, Moores.) *Proceedings of Nat'l. Electronics Conf.*, Chicago, Ill., Oct. 19-21, 1964, pp. 1877-1887

Wake Diagnosis Using Polarized Backscatter—R. S. Ruffine (DEP-MSR, Moores.) AMRAC Mtg., Nov. 16-18, 1964 (*Secret* paper; *unclassified* title)

RADIO RECEIVERS, ENTERTAINMENT

Demodulator, Transistorized FM Stereo—J. W. Englund, L. Plus, H. A. Hansen (ECD, Som.) *Electronics World*, Dec. 1964

Dynamic Range Problems in Transistorized FM Receivers—J. B. Schultz (H.I., Indpls.) Mtg. Audio Eng. Soc., N.Y.C., Oct 16, 1964

Self-Oscillating Vertical Circuit Using a Dual-Control Pentode Tube—W. M. Austin, J. A. Dean (ECD, Hr.) *IEEE Transactions on Broadcast and Television Receivers*, Nov. 1964

Transistors (Output) in Class B Audio Output Stages, Protection of—M. S. Fisher (ECD, Som.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

RECORDING COMPONENTS; MATERIALS

Thermoplastic Organic Photoconductive Recording Media—Electrophotographic Characteristics and Processing Techniques—E. C. Giaimo (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

RECORDING AUDIO

Advanced Servicing Techniques, Vol. II, Part III—Tape Recorders—M. P. Rosenthal (DEP-CSD, N.Y.) Manual published by J. F. Rider, Inc., N.Y., Oct. 1964

Stereo Disc Recording, The Measurement of Vertical Recorded Angle in—D. H. T. Ong, H. D. Ward (Record, Indpls.) Audio Eng. Soc. Convention, N.Y., Oct. 1964

RELIABILITY; QUALITY CONTROL

Risk-Oriented Reliability Program—G. Beckhart (DEP-MSR, Moores.) 1964 Quality Fair, Marriott Hotel, Dallas, Dec. 15-16-17, 1964

Understanding MIL-Q-9858A—H. D. Greiner (DEP-MSR, Moores.) *Quality Assurance*, Nov. 1964

SIMULATION

Cryogenics, Vacuum, and Space Simulators—J. T. Mark (ECD, Lanc.) Amer. Society of Heating, Refrigeration, and Air-Conditioning Engineers, Dec. 9, 1964

Simulation of Geophysical Phenomena in the Laboratory—M. P. Bachynski (RCA Ltd., Montreal) *A.I.A.A. Journal*, Vol. 2, No. 11, Nov. 1964

Simulation Techniques for Simulation of a Communication System—E. W. Veitch (DEP-CSD, Camden) Univ. of Michigan, Ann Arbor, Mich., June 18, 1964

SOLID-STATE DEVICES; CIRCUITRY

Flexode, The Point-Contact—B. E. Tompkins (Labs, Pr.) *Proceedings of the IEEE*, Sept. 1964, Vol. 52, No. 9

Microwave Solid-State Devices—The Present State of the Art—K. K. N. Chang (Labs, Pr.) Seminar Talk—New Horizons in Solid State Electronics, Rochester Inst. of Technology, N.Y., Nov. 30, 1964

Ryotron—A New Cryogenic Device—R. A. Gange (Labs, Pr.) *Proc. of the IEEE*, Oct. 1964

Ryotron—A variable Inductance Cryogenic Device—J. C. Miller, C. M. Wine, L. S. Cosentino (Labs, Pr.) *Proc. of the IEEE.*

Silicon Rectifiers Used in Capacitive-Load Circuits, Simplified Rating System for—J. M. S. Neilson, B. J. Roman (ECD, Mttop.) *Semiconductor Products*, Sept. 1964

Transistor for the Consumer Market, A New UHF/VHF Silicon—L. Plus, R. A. Santilli, H. Thanos (ECD, Som.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Transistorized Microwave Power Source—M. Caulton, R. Ernst, H. Sobol (DEP-CSD, Camden) Electron Devices Conf., Wash., D.C., Oct. 31, 1964

Transistorized Television Deflection Circuits, Design Considerations for—C. F. Wheatley (ECD, Som.) *Solid State Design*, Oct. & Nov. 1964

Transistor Logic Circuits, Switching Response of Complementary-Symmetry MOS—J. R. Burns (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Transistor, The MOS—D. M. Griswold (ECD, Som.) IEEE Student Chapter, N.Y. Univ., Nov. 17, 1964

Transistors (Silicon), Boosting DC Voltage with—H. T. Breece (ECD, Som.) *Electronics*, Nov. 16, 1964

(Transistors): Understanding and Using the MOS-FET—D. M. Griswold (ECD, Som.) *Electronics*, Dec. 14, 1964

Transistors (Field Effect), Brochure on—S. R. Hofstein, F. P. Heiman (Labs, Pr.) *Electronics*, Nov. 30, 1964, Vol. 37, No. 30

Transistors (Output) in Class B Audio Output Stages, Protection of—M. S. Fisher (ECD, Som.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Tunnel Diodes, Permanent Degradation of GaAs—R. D. Gold, L. R. Weisberg (Labs, Pr.) *Solid State Electronics*, Vol. 7, pp. 811-821

SOLID-STATE MATERIALS

Anomalous Hall Effect in n-Type InsB in Pulsed High Electric Fields—F. Okamoto, K. Ando (Labs, Pr.) *Japanese Journal of Applied Physics*, Vol. 3, No. 10, Oct. 1964

Anomalous Resistivity Nb_3Sn—D. W. Woodward, G. D. Cody (Labs, Pr.) *Physical Review*, Vol. 136, No. 1A, Oct. 5, 1964

Bromine Oxidation in a Highly Selective ECTA Titration of Thallium—K. L. Cheng (Labs, pr.) *Microchemical Journal*, Vol. 8, No. 3, Sept. 1964

Comparative Anatomy of Models for Double Injection of Electrons and Holes into Solids—A. Rose (Labs, Pr.) *Applied Physics*, Vol. 35, No. 9, Sept. 1964

Crystal Growth and Color Centers of Alkaline Earth Halides—P. N. Yocom, F. K. Fong (Labs, Pr.) *Journal of Chemical Physics*, Vol. 41, No. 5, Sept. 1964

The Dielectric and Electro-optical Properties of A Molecular Crystal—Hexamine—G. H. Heilmeier (Labs, Pr.) *Applied Optics*, Vol. 3, No. 11, Nov. 1964

Dielectric Behavior of Nonrigid Molecules. II. Intramolecular Interactions and Dielectric Relaxation—F. K. Fong (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Differential and Thermogravimetric Analysis of Mn-Zn Ferrite—R. E. Hurley, R. Degenkolb (H.I., Indpls.) Indiana Branch of the Amer. Ceramic Soc., Oct. 26, 1964

Divalent Rare Earths in Optical Maser Oscillator—G. J. Goldsmith (Labs, Pr.) Department of Physics, Purdue Univ., Oct. 16, 1964

Elastic Constants of Barium Fluroide Between 4.2 and 300°K—D. Gerlich (Labs, Pr.) *Physical Review*, Vol. 135, No. 5a, Aug. 31, 1964

Electrolytic Reduction of Trivalent Rare-Earth Ions in Alkaline-Earth Halides—F. K. Fong (Labs, Pr.) *Journal of Chemical Physics*, Vol. 41, No. 8, Oct. 15, 1964

Electronic Transport in Heavily Doped GeSi Alloys—A. Amith (Labs, Pr.) *DUNOD*, International Conf. on Physics of Semiconductors, July 1964

Exchange Interactions in Yttrium Iron Garnet—P. J. Wojtowicz (Labs, Pr.) *Physics Letters*, Vol. 1, No. 1, July 1964

Injection Electroluminescence in ZnSe Metal-Semiconductor Diodes—A. G. Fischer (Labs, Pr.) *Physics Letters*, Vol. 12, No. 4, Oct. 15, 1964

Lattice Parameter and Density in Germanium Silicon Alloys—J. P. Dismukes, L. Ekstrom, R. J. Paff (Labs, Pr.) *Journal of Physical Chemistry*, Vol. 68, No. 10, Oct. 1964

Low-Temperature Elastic Constants of Indium Arsenide—D. Gerlich (Labs, Pr.) *Journal of Applied Physics*, Vol. 35, No. 10, Oct. 1964

Observation of Divalent Dysprosium in CaF_2 By Paramagnetic Resonance—E. S. Sabisky (Labs, Pr.) *Journal of Chemical Physics*, Vol. 41, No. 3, Aug. 1964

Optical and Electrical Properties of Single-Crystal GaP Vapor-Grown on GaAs Substrate—H. Flicker, B. Goldstein, P. A. Hoss (Labs, Pr.) *Journal of Applied Physics*, Vol. 35, No. 10, Oct. 1964

Photoconductivity in Dispersed Organic Systems—W. Mehl, N. E. Wolff (Labs, Pr.) *Journal of Physics and Chemistry of Solids*, Vol. 25, June 4, 1964

Photo-Induced Adsorption on Insulator Surfaces—P. Mark (Labs, Pr.) Physical Chemistry Coll. at Polytechnical Inst. of Brooklyn, Nov. 20, 1964

Sound Velocity Measurements in $CaWO_4$ Single Crystal—D. Gerlich (Labs, Pr.) *Physics Letters*, Vol. 12, No. 4, Oct. 15, 1964

Stable Divalent Rare-Earth Alkaline Earth Halide Systems—Z. J. Kiss, P. N. Yocom, (Labs, Pr.) *Journal of Chemical Physics*, Vol. 41, No. 5, Sept. 1964

Thermal and Electrical Properties of Heavily Doped Ge-Si Alloys up to 1300°K—J. P. Dismukes, L. Ekstrom, E. F. Steigmeier, I. Kudman, D. S. Beers (Labs, Pr.) *Journal of Applied Physics*, Vol. 35, No. 10, Oct. 1964

Trace Inorganic Analysis Utilizing Semi-micro and Micro Samples—K. L. Cheng, B. L. Goydish (Labs, Pr.) Eastern Analytical Symp., N.Y., Nov. 13, 1964

Trimethylphenylammonium Ioside, Quantitative Precipitant for Gold—W. W. White, J. R. Zuber (ECD, Hr.) *Analytical Chemistry*, Nov. 1964

X-Ray Spectrometric Analysis, Solution Techniques in—E. P. Bertin (ECD, Hr.) Soc. for Applied Spectroscopy, N.Y. Chapter, Dec. 8, 1964

Zeeman Effect of the $2F_{5/2}E_{5/2} \rightarrow F_{7/2}$, E5/2 Transition in $CaF_2:Tm^{2+}$—H. A. Weakliem, Z. J. Kiss (Labs, Pr.) *Journal of Chemical Physics*, Vol. 41, No. 5, Sept. 1964

SOLID-STATE MICROELECTRONICS

Integrated Switching Circuits, Using MOS Transistors in—A. H. Medwin, B. Zuk (ECD, Som.) *Electronic Design*, Nov. 23, Dec. 7, 1964

SOLID-STATE, THIN FILMS

Integrated Thin-Film Image Scanner—P. K. Weimer, H. Borkan, L. Meray-Horvath, F. V. Shallcross (Labs, Pr.) 1964 Internat'l. Solid-State Circuits Conf. Session 8, Feb 8, 1964

SPACE COMPONENTS

Space Optics—R. Jorden (DEP-AED, Pr.) Optical Soc. of America, Delaware Valley Sect., Temple Univ., Dec. 3, 1964

SPACE NAVIGATION; TRACKING

B-Chart, Theory and Application of the—J. Breckman (DEP, Camden) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

SPACE VEHICLES; SATELLITES

Economics of Satellite Design—An American Assessment—S. Gubin, J. S. Greenberg (DEP, Pr.) Published by Iliffe Books, Ltd., London, England, Apr. 1964 as Chapter 13 in book entitled *Telecommunication Satellites;* also published by Prentice-Hall, Inc., Englewood, N.J., July 1964

OGO Satellites, Real-Time Quick-Look Analysis for the—F. H. Fowler, Jr. (DEP-CSD, Camden) *Computering Reviews*, Nov-Dec 1964

TIROS—G. Corrington (DEP-AED, Pr.) Advance Base Command, Acorn Div. 4-2, NAS, Willow Grove, Pa., Dec. 15, 1964

SPACE SYSTEMS

Cryogenics, Vacuum, and Space Simulators—J. T. Mark (ECD, Lanc.) Amer. Society of Heating, Refrigeration, and Air-Conditioning Engineers, Dec. 9, 1964

RANGER Program, RCA Accomplishments on the—J. J. Gillespie (DEP-CSD, Camden) Stratford High School, Stratford, N.J., Nov. 18, 1964

Satellite Telecommunications, Future of—Dr. N. I. Korman, Dr. M. Handelsman (DEP, Pr.) Published by Iliffe Books, Ltd., London, England, Apr. 1964 as Chapter 14 in book *Telecommunication Satellites;* also published by Prentice-Hall, Inc., Englewood, N.J., July 1964

SUPERCONDUCTIVITY

Anomalous Resistivity Nb_3Sn—D. W. Woodward, G. D. Cody (Labs, Pr.) *Physical Review*, Vol. 136, No. 1A, Oct. 5, 1964

Cryoelectric Memory Planes, Cavity Sensing of—L. L. Burns (Labs, Pr.) Decennial Conf. Magnetism and Magnetic Materials, Minneapolis, Minn., Nov. 16-19, 1964

Microwave-Phonon Assisted Superconducting Tunneling—Y. Goldstein, B. Abeles (Labs, Pr.) APS Mtg., Berkeley, Calif., Dec. 21-23, 1964

Microwave Properties of Superconductors—J. I. Gittleman, B. Rosenblum (Labs, Pr.) *Proceedings of the IEEE*, Oct. 1964

Microwave Surface Impedance of Superconductors of Periodic-Medium—G. Fischer (Labs, Pr.) *Journal of Mathematics Physics*, Vol. 5, No. 8, Aug. 1964

Microwave Surface Impedance of Superconductors of the Second Kind—G. Fischer (Labs, Pr.) *Physical Review*, Vol. 135, No. 5a, Aug. 31, 1964

Ryotron—A New Cryogenic Device—R. A. Gange (Labs, Pr.) *Proc. of the IEEE*, Oct. 1964

Ryotron—A Variable Inductance Cryogenic Device—J. C. Miller, C. M. Wine, L. S. Cosentino (Labs, Pr.) *Proc. of the IEEE*

Superconducting Tunnelling from Pure Lead Above the Thermodynamic Critical Field—Y. Goldstein (Labs, Pr.) *Physics Letters*, Vol. 12, No. 3, Oct. 1964

Type II Superconductivity, Recent Developments in—G. D. Cody (Labs, Pr.) Proc. of Annual Mtg., German Physical Society, Dusseldorf, Germany, Oct. 5, 1964

SWITCHING

Transistor Logic Circuits, Switching Response of Complementary-Symmetry MOS—J. R. Burns (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

TELEVISION COMPONENTS

Color Picture Tube, Development of the RCA 25-Inch 90-Degree Rectangular—A. M. Morrell, A. E. Hardy (ECD, Lanc.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Self-Oscillating Vertical Circuit Using a Dual-Control Pentode Tube—W. M. Austin, J. A. Dean (ECD, Hr.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Television, Fundamentals of—W. H. Buchsbaum (DEP-CSD, Camden) Published by J. F. Rider, Inc., N.Y., Oct. 1964

Transistorized Television Deflection Circuits, Design Considerations for—C. F. Wheatley (ECD, Som.) *Solid State Design*, Oct. & Nov. 1964

TESTING

Designing Dynamic Test Sets for Use Optimization—F. W. Stirner (DEP-CSD, Camden) *IEEE Trans. of PTGPEP*, Apr. 1964

TUBE DESIGN; APPLICATION

Color Picture Tube, Development of the RCA 25-Inch 90-Degree Rectangular—A. M. Morrell, A. E. Hardy (ECD, Lanc.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Nuvistors, UHF Applications of—R. M. Mendelson (ECD, Som.) Tricounty Amateur Radio Assoc., N.J., Nov. 16, 1964

Photomultiplier Tubes and Applications, Recent Developments in—A. G. Nekut (ECD, Lanc.) Accelerator Engineering Group, Princeton Univ., N.J., Dec. 17, 1964

Self-Oscillating Vertical Circuit Using a Dual-Control Pentode Tube—W. M. Austin, J. A. Dean (ECD, Hr.) *IEEE Trans. on Broadcast and Television Receivers*, Nov. 1964

Traveling-Wave Tubes, VSWR Measurement of Attenuators for Helix-Type—E. Belohoubek (ECD, Pr.) *IEEE Trans. on Electron Devices* (Corres.), Sept. 1964

TUBE MATERIALS; THEORY

Electron-Beam Noise, Effect of High Magnetic Field on—J. M. Hammer, C. P. Wen (Labs, Pr.) *RCA Review*, Vol. XXV, No. 4, Dec. 1964

Firing Techniques for Precision-Tolerance Electronic Ceramics—T. F. Berry (ECD, Hr.) Metropolitan, N.Y. Sect. of Amer. Ceramic Soc., Nov. 6-13, 1964

AUTHOR INDEX

Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. Where an author has more than one paper, his name is repeated for each.

Engineering NEWS *and* HIGHLIGHTS

RCA CITED FOR FOUR OF THE "MOST SIGNIFICANT NEW PRODUCTS" OF 1964

RCA produced four of the 100 most significant new products of 1964, according to *Industrial Research* magazine. Only two companies, General Electric with 6, and Honeywell, Inc., with 5, had more products on the list than RCA. Three companies had three products, and nine had two. The remaining 58 came from individual organizations.

The RCA products cited were: 1) Parametric amplifier providing the first demonstration of parametric amplification in superconductors developed by the Microwave Research Laboratory, RCA Laboratories, Princeton, N.J., 2) Laminated ferrite memories for digital computers developed by the Computer Research Laboratory, RCA Laboratories, 3) Vidicon camera tube for RANGER 7 developed by ECD Industrial Tube and Semiconductor Division, Lancaster, Pa., 4) Superconductive magnet—the world's most powerful (107,000 gauss) with practical bore size (1 inch)—developed by the Superconductor Materials and Devices Laboratory, ECD Special Electronic Components Division, Princeton.

All these developments have been described in recent issues of RCA ENGINEER and *RCA Review.*

RCA AND PRENTICE-HALL NEGOTIATING MERGER

Preliminary negotiations for a merger of RCA and Prentice-Hall, Inc., were announced in December 1964. The negotiations are subject to the approval of the directors of both firms. The final agreements will be submitted to the stockholders of the two companies. If successfully concluded, the transaction will provide that each share of Prentice-Hall common stock presently outstanding would be exchanged for ½ share of RCA common stock and 3/10 share of a new $1.75 cumulative convertible RCA preferred stock to be issued.

RCA Chairman **David Sarnoff,** in commenting on the proposed merger, explained: "Prentice-Hall has long played an influential role in communicating and teaching through the printed page. At the opposite end of the communications spectrum, RCA has profoundly influenced the development and growth of electronic means for conveying information in sight and sound to people everywhere.

"If our preliminary plans for merger are ultimately approved, I believe that this will work to the benefit of both organizations, and will also advance the art of communications as a whole.

"Richard P. Ettinger, co-founder and Chairman of the Board of Prentice-Hall, has agreed to become a member of the RCA Board of Directors if present negotiations are successfully concluded. We look forward to having the benefit of his long experience and advice.

"RCA has always had a deep interest in education. We are conscious of the demands that are being made upon our education system, and of the responsibility which all of us bear in this age of mounting educational complexity.

"Against this background, I believe the merger which we now propose is indeed promising and stimulating. I also believe that it can open to us major opportunities in all fields of educational endeavor."

RCA SIGNS COMPUTER PACT WITH SIEMENS-HALSKE

RCA and Siemens & Halske A.G. of Germany have signed patent, license, and technical information and sales agreements to strengthen the position of both companies in the expanding world-wide computer market. The new arrangement, expected to develop a multi-million dollar business between the two firms, was announced by **Dr. Elmer W. Engstrom,** RCA President, and Dr. Hans Kerschbaum, Board Chairman of Siemens & Halske.

Siemens & Halske and RCA will each make available to the other technical information relating to the engineering and manufacture of data processing equipment. Also included will be information on programming, testing, installation, training, and service and maintenance.

The sales agreement is expected to result in substantial purchases by Siemens & Halske of the new RCA Spectra 70 series of computers. Siemens & Halske will market and service the electronic data processing systems it purchases from RCA, as well as those it manufactures itself, through its worldwide sales and maintenance organization. It also is anticipated that RCA will have available from Siemens devices and systems which can be included in RCA electronic data processing product lines.

Dr. Engstrom said the agreements will assure RCA of expanded use of its electronic data processing equipment and techniques in the overseas market.

Siemens ranks among the top ten industrial firms in Western Europe with more than $1.5 billion in annual sales revenue. It employs more than 240,000 people and enjoys a wide manufacturing and sales representation in about 100 countries—it owns distributing companies in 36 countries and has representatives and agencies in more than 60 countries.

RCA FIRST U.S. COMPANY TO SELL MILITARY ELECTRONICS PRODUCTS DIRECTLY TO INDIA

RCA has become the first U.S. company to negotiate a military electronics product order directly with the government of India. The equipment includes 2,400 manpack tactical FM receiver-transmitter sets and kits of parts and subassemblies. The AN/PRC-25 sets, originally developed by RCA for the U.S. Army, are lightweight 920-channel two-way instruments. They will be built for India by the Communications Systems Division.

RCA also negotiated a license and technical aid agreement under which the Indian government may eventually build the radio sets. Assembly lines for the kits will be set up by Bharat Electronics Ltd., a company wholly owned by the Indian government.

EIA TO HONOR E. C. ANDERSON

E. C. Anderson, recently retired RCA Executive Vice President, Staff, has been named to receive the *1965 Medal of Honor*, the highest award of the Electronic Industries Association. Mr. Anderson will be cited for his "distinguished contribution to the electronics industries," particularly for his efforts on behalf of the consumer products industry.

Mr. Anderson retired late in 1964 after 42 years with RCA. Also, last year he retired as a representative of the Consumer Products Division on the EIA Board of Directors, a post he had held since 1955.

DR. CHANG GETS ACHIEVEMENT AWARD

Dr. Kern K. N. Chang, head of the solid state devices group of the Microwave Research Laboratory of RCA Laboratories, Princeton, N.J., has been honored by the Chinese Institute of Engineers, New York, Inc. (CIE). Dr. Chang was given a CIE Achievement Award for his outstanding contributions in the field of electronic devices.

Dr. Chang is a graduate of the National Central University of Nanking, China. In 1948 he received an MSEE from the University of Michigan, and in 1954 a PhD at the Polytechnic Institute of Brooklyn. Since 1948, Dr. Chang has been a member of the technical staff of RCA Laboratories, where he has engaged in research of magnetrons, traveling wave tubes, beam focusing devices, parametric amplifiers and tunnel diode devices. In 1956 and 1960 he received RCA Laboratories Achievement Awards for outstanding theoretical and experimental research on electron beam focusing and on parametric and tunnel diode devices.

J. ST. THOMAS HONORED FOR WORK IN PHOTO-OPTICAL INSTRUMENTATION

The Society of Photo-Optical Instrumentation Engineers (SPIE) has selected **Jean St. Thomas,** Test Operations Analyst for the RCA Service Company's Missile Test Project on the Air Force Eastern Test Range, as the recipient of one of its *1964 Karl Fairbanks Memorial Awards.*

Only two of the awards are granted annually. One is presented to an individual in private industry and the second goes to a person employed by the government. Each is awarded to recognize "outstanding achievements in the field of photo-optical instrumentation engineering."

St. Thomas was selected for the award as a result of his many contributions to photo-optical instrumentation. Of particular note have been his efforts in the area of codification for photo-optical instrumentation and the leading role he played in promoting publication of the Shaftan papers, which document the early portion of the development of photographic instrumentation engineering.—*T. Elliott*

W. M. SHEAHAN NAMED FELLOW OF SMPTE

William M. Sheahan, Manager of Range Photography for the RCA Service Company's Missile Test Project, has been named *Fellow* of the Society of Motion Picture and Television Engineers (SMPTE). The designation, made in recognition of contributions in the photographic field, is the highest honor that SMPTE bestows upon its members.

Sheahan has headed the Missile Test Project's Range Photography unit since 1960. He joined the Company following a distinguished career in the U.S. Army, where he served in several high level photographic capacities, including Chief of the Pictorial Engineering and Instrumentation Office of the Army Pictorial Service.

Active in several professional organizations, Sheahan is one of the founders of the Cape Kennedy SMPTE Chapter. He is also the current chairman of the Canaveral Council of Technical Societies.—*T. Elliott*

RCA RECORDS WIN PRIZES

The Academie du Disque Francais has awarded three Grand Prix awards to RCA Victor recordings and artists. Pianist Artur Rubinstein won the *Grand Prix du President de la Republique* for his newest recording, "A French Program." Miriam Makeba's recordings were grouped together to win her the *Grand Prix* in the category of folk singing excellence. The RCA Victor recording of Verdi's "Falstaff" won the *Grand Prix Charles Cros* as the finest operatic recording of the year.

RCA COMMUNICATIONS EXPANDS PACIFIC CABLE NETWORK

RCA Communications, Inc., completed a major expansion of its communications facilities in the Pacific with the inauguration of services on the new Guam-Philippine segment of the Transpacific Cable System in December.

Thompson H. Mitchell, RCA Communications President, said the company has acquired 27 wideband circuits in the Philippines segment, bringing to 59 the number of circuits RCA operates in the Transpacific Cable System. The 59 circuits were acquired at a cost of approximately $15 million and more than double RCA's capacity to provide overseas communications services for both government and commercial customers in the Pacific.

GIBBSBORO ANTENNA FACILITY EXPANDS

The Antenna Engineering Facility at Gibbsboro is now undergoing major expansions. These include new roadways, a new VHF building and trestle, new instrumentation house and instruments and major capital equipment, a travel lift and a turntable. New facilities now in planning include a new model range and a three-axis turntable.

At a Broadcast Division consulting engineering seminar at Meadowlands, Pa., on November 18, 1964, the Antenna Engineering Staff made a presentation of the new facilities at Gibbsboro and on new antenna developments. Speakers included **R. L. Rocamora,** Manager, Gibbsboro Antenna Facility, **H. E. Gihring, M. S. Siukola** and **H. H. Westcott. Edmund A. Laport,** Director of Communications Engineering on **Dr. G. H. Brown's** R&E staff, is conducting a seminar at Gibbsboro covering the design of antennas for the International market and special problems associated with such a market.—*H. E. Gihring*

CAMDEN HOLDS TRAINING PROGRAM IN INTEGRATED CIRCUITS

The RCA Camden plant held an Integrated Circuits Orientation Program, one of a series of programs which will be offered to assist technical employees in becoming knowledgeable in new technological areas.

The integrated circuit program consisted of four two-hour sessions on Tuesday evenings in the Little Theatre, Building 2, Floor 1. The first session was held on Tuesday, January 19, 1965. *Information on the program series may be obtained from Harry A. Moos, Training, Building 5-2, Camden, N.J.*

LICENSED ENGINEERS

M. F. Bondy, DEP-CSD, Camden, PE-13735, N.J.
A. R. Campbell, DEP-AED, Pr., PE-13135, N.J.
D. Mackey, RCA Staff, Camden, PE-13627, N.J.
N. Seidman, ECD, Lanc., PE-10014E, Pa.
P. V. Smith, RCA Ser. Co., Cherry Hill, PE-10161E, Pa.
S. M. Zollers, ECD, Lanc., PE-13685, N.J.

TEN-SECOND, DRY, HIGH-SPEED FILM PROCESSORS DESIGNED BY M&SR TO USE NEW BIMAT

High speed processors for 10-second, dry, continuous developing of photographic film have been designed by the Special Application Engineering activity of the DEP Missile and Surface Radar Division, Moorestown, N.J. The first in the industry to use the recently announced Eastman Kodak 10-second *Bimat* technique, these processors are an outgrowth of M&SR work on optical data processing and display equipment for military applications.

Bimat permits the use of silver halide films for the first time in systems requiring fast, dry image formation with a high packing density. Silver halide films have sensitivities at least 100 times greater than other dry recording processes and resolutions greater than 100 line pairs per millimeter compared with resolutions of 3 to 5 line pairs for other dry processes.

Two 35-mm Bimat processors have been developed during the past year. Fabrication is under way on a 16-mm quick-access processor for optical data correlation and on a 5-inch continuous tone, high resolution display in which the data is projected onto a screen promptly after being recorded.

High speed Bimat processing potentially can be used in many areas for the recording, storage, and readout of optical information. M&SR engineers state that the simplicity, cleanliness, and reduced handling of the Bimat film processors establishes them as logical replacements for existing wet systems.

DR. PETERSON, COMMUNICATIONS PIONEER, RETIRES

A most-distinguished RCA engineering career reached its climax recently with the retirement of **Dr. Harold O. Peterson,** after an association with RCA that has spanned almost 43 years and virtually every development in modern communications and electronics. A 1921 graduate of the University of Nebraska, Dr. Peterson joined RCA in 1922.

Most of Dr. Peterson's career with RCA was spent at the Communications Laboratory at Riverhead, Long Island, where he was associate director of the laboratory before transferring to the Missile Test Project of the RCA Service Co. in 1961. His efforts there resulted in a vast number of innovations and wave propagation data, as evidenced by his 130 patents.

For his contributions to the science of communications, Dr. Peterson was recognized with an honorary Doctor of Engineering by his alma mater in 1951. Dr. Peterson was also the recipient of the National Association of Manufacturers *Modern Pioneer Award* in 1941, and a Fellowship in the IRE. —*T. L. Elliott*

RCA AWARD-WINNING COLOR FILM AVAILABLE

"The Challenge of Tomorrow," a 28-minute color motion picture portraying RCA's varied activities in electronics is available for intra-company and public showings. The film won the Best Photography Award of the Fourth International Film and TV Festival in New York. In addition to being loaned for showings within RCA, the film is available for presentations before educational institutions, social and civic groups, and industry and fraternal organizations. *To borrow a copy of the film, write to Mr. Coffin at 30 Rockefeller Center, New York.*

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parentheses.

Electronic Components & Devices

B. J. Walmsley: from Eng. Ldr., Product Development to *Eng. Ldr., Manufacturing* (G. Stolpman, Product Assurance Testing, Somerville)

DEP Astro-Electronics Division

D. Silverman: from Engr. to *Ldr. Engrs.* S. Gubin, Mgr., Electronic Systems Eng., Princeton)

DEP Aerospace Systems Division

R. Benedict: from Sr. Member D&D Eng. Staff to *Ldr., D&D Eng. Staff* (F. Worth, Van Nuys)
R. E. Richards: from Ldr., Dev. and Des. Eng. Staff to *Mgr., Electronics Eng.* (R. Landee, Van Nuys)

RCA Service Company

A. P. Frankowski: from Engr., BMEWS to *Ldr., Engrs., BMEWS* (P. C. Groot, Site II Eng.)
Z. S. Hauser: from Engr., BMEWS to *Ldr., Engrs., BMEWS* (H. H. Lugg, Site I Eng.)
R. L. Johnson: from Engr., BMEWS to *Ldr., Engrs., BMEWS* (R. E. Shannon, Eng.)
A. L. Lea: from Engr. to *Ldr., Engrs., BMEWS* (H. M. Hochreiter, Nuclear & Scientific Svcs.)
D. E. Price: from Field Engr. to *Ldr., Engrs.* (J. W. Martin, Signature Support Eng.)
P. C. Groot: from Ldr., Engrs., BMEWS to *Mgr., Site Eng.* (E. E. Terrien, Site Eng., Clear, Alaska)
W. J. Ewing: from Engr. to *Ldr., Eng.* (G. B. Cope, Data Translation Eng., Missile Test Project)

DEP Communications Systems Division

J. S. Griffin: from Engr. to *Eng. Ldr.* (J. D. Rittenhouse, Magnetic Recording Eng., Camden)
A. S. Katz: from Project Engr. to *Eng. Ldr.* (F. D. Kell, Magnetic Recording Eng., Camden)

C. A. RACKEY, PIONEER BROADCAST STUDIO DESIGNER, RETIRES

Chester A. Rackey recently retired from NBC after 41 years of service. At the time of his retirement, he was Manager, Facilities Design and Construction in NBC Engineering. Mr. Rackey joined AT&T in 1923 in the Radio Division, Station WEAF, which was sold to RCA and became the nucleus of NBC along with Station WJZ in New York. He joined NBC at the time the Company was formed in 1926 and became a charter member of the NBC Engineering staff in which he served the rest of his career.

At that time, Mr. Rackey had charge of design and construction of NBC's first radio studio plant at 711 5th Avenue, New York. Later he was in charge of the design and installation of the original radio studios at the Merchandise Mart in Chicago 1930-31, Radio City New York 1932-33, Sunset & Vine Studios Hollywood, as well as other NBC locations in San Francisco, Cleveland and Washington.

DEGREES GRANTED

M. Fomin, ECD . . . . BS in EE, Fairleigh Dickinson University
J. Wilder, RCA Labs . . . . PhD in EE, Univ. of Penna.

C. M. Sinnett

G. A. Kiessling

C. M. SINNETT RETIRES

Chester M. ("Mack") Sinnett has retired from full-time RCA activity after a distinguished 40-year engineering and management career highlighted by important contributions to modern professional improvement programs for engineers, and to the stimulation and understanding of engineering creativity. (See RCA ENGINEER Vol. 1, No. 6, "(Ideas)ⁿ—Is There a Limit?".) His technical career was intimately involved with the growth of home radio receivers, and the birth and growing pains of hi-fi and both monochrome and color TV home receivers.

Mr. Sinnett received his BSEE from the University of Maine, and joined Westinghouse Electric and Manufacturing Company in Pittsburgh in 1924. When the RCA Victor Company was established in 1929, he transferred to Camden as Manager of Phonograph Design and Development. Later, he was named Manager of the Loudspeaker and Phonograph section.

In 1945 he was appointed Manager of Home Instruments Advanced Development. In 1959 he was appointed Director of Product Engineering Professional Development, a position he held until his retirement.

Mr. Sinnett has been issued 30 U.S. patents, and is a *Fellow* of the IEEE. He is a Registered Professional Engineer in New Jersey, and a member of the NSPE and Tau Beta Pi.

C. M. Sinnett helped pioneer the introduction of the RCA ENGINEER, served as an Engineering Editor for several years and then until his retirement as an Advisory Board member.

He pioneered *Trend*, the RCA engineering news digest, on which he served as Editor. As a Contributing Editor of *Research/Development* magazine, Mr. Sinnett is currently writing a series of monthly articles on "The Challenge of Personal Professional Development."

CERAMIC SOCIETY INDIANA SECTION

Recently, a new Indiana Section of the American Ceramic Society was organized in a meeting held at the RCA Indianapolis plant at which 60 attended. Active at the meeting and in the organizing effort were: **W. H. Liederbach, H. M. Dess, T. M. Gainer, R. A. Gaiser, A. M. Hossenlopp, J. D. McKeown, R. S. Degenkolb,** and **R. E. Hurley.** A slate of officers and a program for 1965 is being set up.

KIESSLING NAMED MANAGER, PRODUCT ENGINEERING PROFESSIONAL DEVELOPMENT

Appointment of **George A. Kiessling** as Manager, Product Engineering, Professional Development, was recently announced by **D. F. Schmit,** Staff Vice President, Product Engineering. He replaces **C. M. Sinnett,** who has recently retired. Mr. Kiessling has been active in RCA Professional Development Programs involving engineering and engineering management communications, recognition, rewards, and, in collaboration with Personnel and Staff, training, performance evaluation and measurement, and employee relations. Mr. Kiessling received the BEE degree from Manhattan College, New York, in 1951 and the MSIE degree in Engineering Management from the Stevens Institute of Technology, Hoboken, N.J. in 1953. He was a member of the technical staff of the Physics Laboratories, Sylvania Electric Products, Inc. before joining RCA's Engineering Products Division as Administrator, Engineering Financial Planning in 1954. Upon formation of Commercial Electronics Prdoucts in 1956, Mr. Kiessling was made Manager, Engineering Standards and Services continuing this assignment with the successor, Industrial Electronic Products, organization. In 1961, he joined Electronic Data Processing as Staff Engineer, and in 1962 was named Manager, Product Administration, Custom Projects Marketing. Mr. Kiessling is a member of the IEEE and the IEEE Group on Engineering Management.

PINSKY NAMED EDITOR OF "TREND"

A. N. Pinsky, Administrator, Professional Development Communications, has been named Editor of *Trend*—the RCA research and engineering news digest. Mr. Pinsky had been Assistant Editor of Trend. He reports to G. A. Kiessling, Manager Product Engineering Professional Development.

RADIO LECTURE ON DOCUMENTATION

R. E. Patterson, C. W. Fields, and **J. J. Gillespie** of CSD, and **W. W. Thomas** of Central Engineering participated in a panel discussion over radio station *WFLN*, Philadelphia on December 5 and 19, 1964, titled, "A Billion-and-a-Half a Year; A Ton-And-A-Half A Day." The two-part talk outlined the problems of bulk and expense accruing to Defense documentation in industry, and the steps which industry and the Department of Defense are taking to solve these problems.—*C. W. Fields*

At a recent meeting of the DEP Editorial Board, at which technical papers activities of the DEP Divisions were discussed and the CSD microfilm activity toured, this group was snapped during a coffee break: l. to r.: W. O. Hadlock, Editor, RCA ENGINEER; C. W. Fields, CSD; M. Pietz, Applied Research; J. Phillips, AED M. Rosenthal, CSD; E. R. Jennings, Assistant Editor, RCA ENGINEER, G. Lieberman, CSD; D. B. Dobson, ASD; F. D. Whitmore, Chairman, DEP Editorial Board; J. J. Lamb, Central Eng. This DEP group regularly meets every other month. Should you have matters concerning technical papers or the RCA ENGINEER that you wish discussed at one of these meetings, contact your DEP Editorial Representative (see inside back cover).

J. WALTER RETIRES

John C. Walter retired from RCA recently after 28 years service. Mr. Walter made many important contributions to the high power transmitter design functions in Camden. He was responsible for the design and installation of the famous Jim Creek 1000 kw VLF transmitter and headed design teams which developed such products as the 50-D, 50-E and 150-A broadcast transmitters, TTU-12 and TTU-25 TV transmitters and the Cambridge Electron Accelerator.

A strong advocate of registration for professional engineers, Mr. Walter encouraged many of his associates to sit for State Board Professional Engineer examinations and initiated the RCA ENGINEER policy of publishing a continuing roster of RCA employees holding active licenses as Professional Engineers.

DR. C. B. JOLLIFFE RETIRES

Dr. Charles B. Jolliffe, Vice President and Technical Consultant of RCA, retired on December 1st, after nearly 30 years' association with RCA. Dr. Jolliffe received his BS in 1915 and his MS in 1920 from West Virginia University, and his PhD from Cornell University in 1922. He was awarded an honorary LLD degree from West Virginia University in 1942. Dr. Jolliffe joined RCA in 1935 after five years' association with the FCC. In 1941, he was named Chief Engineer for RCA Laboratories, and in 1945 upon the retirement of Dr. Otto S. Schairer, he became Executive Vice President in charge of the RCA Laboratories Division. From 1951 to 1961 he served as Vice President and Technical Director of RCA. In 1957 he was also named Technical Director of Defense Electronic Products.

D. PARKER HEADS PHILA. IEEE "BASIC SCIENCE" LECTURE SERIES

The purpose of the IEEE's Basic Science Technical Group is to present lectures on new or fast-moving advanced technologies of interest to today's scientist. The lectures are tutorial, designed for an audience of varied background. Speakers prominent in the field give lectures which include a review of the pertinent physical principles, a discussion of the significant problem areas and predictions of future applications.

D. J. Parker, Manager of RCA's Applied Research, is Chairman of the Basic Science Technical Group of the IEEE, Philadelphia Section, and **G. K. Zin,** Physicist in Applied Research, is heading its Publicity Committee.

Reservations and information on future meetings can be gotten from Miss Helen Yonan, University of Pennsylvania, Philadelphia, Pa.; (215) 594-8106.

PLANNING FOR APRIL 1965 "SPACE CONGRESS" HEADED BY MERTENS AND TABELING

The Second Space Congress will meet during the first week of April 1965 in Cocoa Beach, Florida. The theme for this Congress is "New Dimensions in Space Technology" and will include all aspects of space science on systems, equipment, techniques, and associated fields.

Dr. L. E. Mertens, Staff Scientist for the RCA Missile Test Project, Patrick AFB, Florida, is Program Chairman for this Congress. Speaker Chairman is **R. H. Tabeling,** System Project Manager, RCA Missile Test Project, Patrick AFB, Florida. Many other RCA personnel are active in running this year's Congress, which is expected to surpass the tremendously successful first meeting of the Congress in 1964.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

DEFENSE ELECTRONIC PRODUCTS

F. D. Whitmore* *Chairman, Editorial Board, Camden, N. J.*

Editorial Representatives

Aerospace Systems Division

D. B. Dobson *Engineering, Burlington, Mass.*

S. Hersh *Engineering, Van Nuys, Calif.*

Astro-Electronics Division

J. Phillips *Equipment Engineering, Princeton, N. J.*

I. Seideman *Advanced Development and Research, Princeton, N. J.*

Missile & Surface Radar Division

I. N. Brown *Systems Engineering, Moorestown, N. J.*

T. G. Greene *Engineering Dept., Moorestown, N. J.*

Communications Systems Division

C. W. Fields *Engineering, Camden, N. J.*

G. Lieberman *Systems Engineering, Camden, N. J.*

W. C. Praeger *Engineering, Cambridge, Ohio*

M. P. Rosenthal *Systems Labs., New York, N. Y.*

Defense Engineering

I. N. Brown *System Engineering, Evaluation and Research Moorestown, N. J.*

J. J. Lamb *Central Engineering, Camden, N. J.*

M. G. Pietz *Applied Research, Camden, N. J.*

BROADCAST AND COMMUNICATIONS PRODUCTS DIVISION

D. R. Pratt* *Chairman, Editorial Board, Camden, N. J.*

Editorial Representatives

H. E. Gihring *Brdcst. Transmitter & Antenna Eng., Gibbsboro, N. J.*

C. E. Hittle *Closed Circuit TV & Film Recording Dept., Burbank, Calif.*

R. N. Hurst *Studio, Recording, & Scientific Equip. Engineering, Camden, N. J.*

D. G. Hymas *Microwave Engineering, Camden, N. J.*

W. J. Sweger *Mobile Communications Engineering, Meadow Lands, Pa.*

NEW BUSINESS PROGRAMS

N. Amberg *Industrial & Automation Products Engineering, Plymouth, Mich.*

ELECTRONIC DATA PROCESSING

H. H. Spencer* *EDP Engineering, Camden, N. J.*

R. R. Hemp *Palm Beach Engineering, West Palm Beach, Fla.*

B. Singer *Data Communications Engineering, Camden, N. J.*

RCA LABORATORIES

C. W. Sall* *Research, Princeton, N. J.*

ELECTRONIC COMPONENTS AND DEVICES

C. A. Meyer* *Chairman, Editorial Board, Harrison, N. J.*

Editorial Representatives

Commercial Receiving Tube & Semiconductor Division

P. L. Farina *Commercial Receiving Tube and Semiconductor Engineering, Somerville, N. J.*

J. Koff *Receiving Tube Operations, Woodbridge, N. J.*

G. R. Kornfeld *Memory Products Dept., Needham and Natick, Mass.*

R. J. Mason *Receiving Tube Operations, Cincinnati, Ohio*

J. D. Young *Semiconductor Operations, Findlay, Ohio*

Television Picture Tube Division

J. H. Lipscombe *Television Picture Tube Operations, Marion, Ind.*

E. K. Madenford, *Television Picture Tube Operations, Lancaster, Pa.*

Industrial Tube & Semiconductor Division

E. F. Breniak *Industrial Semiconductor Engineering, Somerville, N. J.*

R. L. Kauffman *Conversion Tube Operations, Lancaster, Pa.*

K. Loofburrow *Semiconductor and Conversion Tube Operations, Mountaintop, Pa.*

G. G. Thomas *Power Tube Operations and Operations Svcs., Lancaster, Pa.*

H. J. Wolkstein *Microwave Tube Operations, Harrison, N. J. and Los Angeles, Calif.*

Special Electronic Components Division

P. L. Farina *Direct Energy Conversion Dept., Harrison, N. J.*

I. H. Kalish *Integrated Circuit Dept., Somerville, N. J.*

RCA VICTOR HOME INSTRUMENTS

K. A. Chittick* *Chairman, Editorial Board, Indianapolis*

Editorial Representatives

J. J. Armstrong *Resident Eng., Bloomington, Ind.*

D. J. Carlson *Advanced Devel., Indianapolis, Ind.*

R. C. Graham *Radio "Victrola" Product Eng., Indianapolis, Ind.*

P. G. McCabe *TV Product Eng., Indianapolis, Ind.*

J. Osman *Electromech. Product Eng., Indianapolis, Ind.*

L. R. Wolter *TV Product Eng., Indianapolis, Ind.*

RCA SERVICE COMPANY

M. G. Gander* *Cherry Hill, N. J.*

B. Aaront *EDP Svc. Dept., Cherry Hill, N. J.*

W. W. Cook *Consumer Products Svc. Dept., Cherry Hill, N. J.*

E. Stanko *Tech. Products Svc. Dept., Cherry Hill, N. J.*

T. L. Elliott, Jr. *Missile Test Project, Cape Kennedy, Fla.*

L. H. Fetter *Govt. Svc. Dept., Cherry Hill, N. J.*

RCA COMMUNICATIONS, INC.

C. F. Frost* *RCA Communications, Inc. New York, N. Y.*

RCA VICTOR RECORD DIVISION

M. L. Whitehurst *Record Eng., Indianapolis, Ind.*

NATIONAL BROADCASTING COMPANY, INC.

W. A. Howard* *Staff Eng., New York, N. Y.*

RCA INTERNATIONAL DIVISION

L. A. Shotliff* *New York City, N. Y.*

RCA VICTOR COMPANY, LTD.

H. J. Russell* *Research & Eng., Montreal, Canada*

*** Technical Publication Administrators for their major operating unit.**