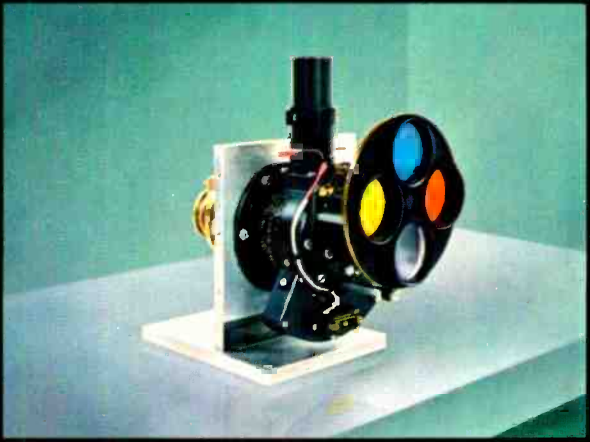
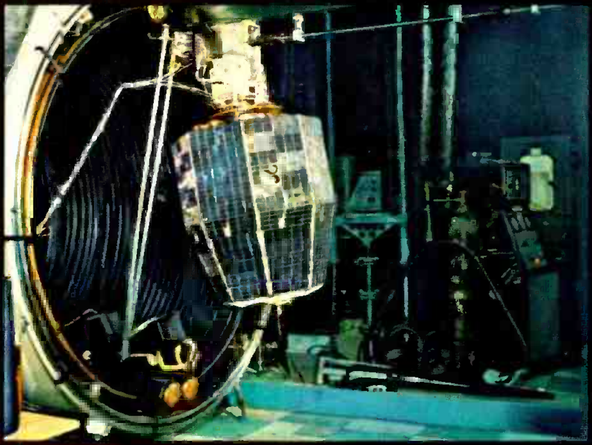
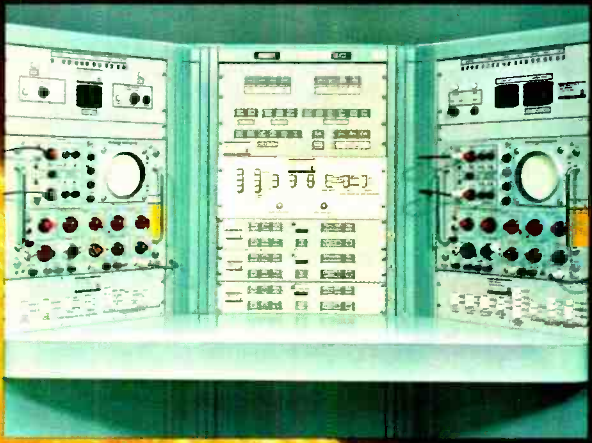
J.D. Callaghan, 215-800

RCA ENGINEER







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RCA ENGINEER *Staff*

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OUR COVER

Against an artist's conception of cislunar space, the inset photos depict the varied scope of engineering for space systems at the Astro-Electronics Division, Princeton N.J. Top, an experimental model of a color TV camera for spacecraft application; middle, a RELAY satellite entering a thermal vacuum chamber for environmental testing; bottom, control console of the ground-based data acquisition station for the NIMBUS satellite system. (Cover executed by Charles Rogers and Ronald Schreiner, Astro-Electronics Division.)

Space . . . and Systems Engineering

In the past two years, progress on space projects has been rapid, distinguished by the successful performance in orbit of RCA-built NASA spacecraft such as the seven TIROS satellites and Project RELAY, by the JPL MARINER probe of the Planet Venus, as well as by Bell's TELSTARS, the Hughes SYNCOM, and Ball Brothers' ORBITING ASTRONOMICAL SATELLITE, together with the Lockheed-built Air Force DISCOVERERS, SAMOS, and MIDAS satellites. Technical achievement has in many ways been revolutionary.

The United States Government, recognizing the usefulness of space systems and techniques, has funded the national effort at a consistently increasing level until at $5.6 billion for FY '64 for the NASA effort and approximately $1.0 billion attributable to the DOD effort (chiefly in the Air Force), the U.S. space program represents one of the largest discrete segments of our economy. For example, the Space Agency, created in 1958, has grown to a population of 30,000 people located in nine centers spread across the country, and no less than 50 industrial companies have completed or are installing space environmental test facilities.

But other, more subtle changes have transpired. In 1957, The U.S. EXPLORER, following the larger Soviet SPUTNIK, attracted world-wide acclaim, as did the "Talking ATLAS" satellite of Project SCORE in 1958. In 1961, TIROS I created banner newspaper headlines, and, in 1962, TELSTAR I captivated an international television audience. But, by 1963, with a string of TIROS "hurricane watches" accomplished and a multi-country operational TIROS meteorological system in daily use, a TIROS life in orbit of more than one year (TIROS VI) caused hardly a ripple in the press. International television was so well accepted that the funeral of Pope John and President Kennedy's European trip, transmitted by RELAY and TELSTAR, were considered almost routine news broadcasts. Identification of RELAY or TELSTAR as the transmission medium was completely obscured.

A far greater interest has centered about the creation of the Government-sponsored *Communications Satellite Corporation* to develop communication by satellite as a private business.

In less than six years, technical pioneering and glamour are beginning to give way to operational services and commercial enterprise.

Of course, almost endless scientific and experimental payloads will yet be flown, biophysical research will be intensified, new systems evaluated in orbit, and the new worlds of lunar and planetary bodies probed and visited by man. Even the search for extraterrestrial life may start on the Planet Mars.

But, these missions and the operational orbital systems pose different problems currently and in the years ahead for engineers involved in space systems. Now this spiraling onset of an early maturity is forcing concentration on the engineering considerations of reliability, performance, cost, and delivery. "Mean-time-to-failure" of 3 to 5 years must be achieved, trade-off analyses between redundancy and complexity require consideration, "secure" systems are needed, multiple-access communications satellites are a prime requisite, and the economic considerations attending each launch force realistic planning for multiple-payload launch from one booster. Incentive contracting has been employed based upon delivery and cost performance by the contractor, but fixed price hardware, incentives based upon performance in orbit, and even payment on a toll basis are under consideration.

Evolution from glamour projects to an emerging field of operational space systems poses not only difficult engineering problems in a radically new field, but presents them accompanied by the need for those sound engineering decisions concerning reliability, logistics, and economics that mark the truly professional engineer.

Barton Kreuzer
Division Vice President and General Manager
Astro-Electronics Division
Defense Electronic Products
Radio Corporation of America

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● *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.

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What is systems engineering? This familiar but not always well understood term is explored from three viewpoints in the first three papers in this issue. First, Dr. Nathaniel Korman discusses the basic meaning of the term in modern engineering. Then, Dr. Richard Guenther discusses in depth how the concepts of systems engineering are implemented in the origination and realization of complex communications systems and equipment. In the third paper, Ralph Montijo explores the systems engineering approach as applied to the development and design of modern electronic data processing systems and hardware. Many of the other technical papers in this issue describe work in which systems engineering played a major role. Thus, these "three viewpoints" provide a meaningful background of philosophical and practical understanding.

The Engineer and the Corporation

SYSTEMS ENGINEERING—THREE VIEWPOINTS

I—THE ROLE OF SYSTEMS ENGINEERING AT RCA

Dr. N. I. KORMAN, Director
Advanced Military Systems
Technical Programs
Princeton, N.J.

Webster's New International Dictionary of the English Language defines the word *system* in a number of different ways. The two definitions most pertinent to our discussion are the following:

> "An aggregation or assemblage of objects united by some form of regular interaction or interdependence; a group of diverse units so combined by nature or art as to form an integral whole, and to function, operate, or move in unison and, often, in obedience to some form of control; an organic or organized whole, as, to view the universe as a *system*; the solar *system*; a new telegraph *system*.
>
> "An organized or methodically arranged set of ideas; a complete exhibition of essential principles or facts, arranged in a rational dependence or connection; as, to reduce the dogmas to a *system*; also, a complex of ideas, principles, doctrines, laws, etc., forming a coherent whole and recognized as the intellectual content of a particular philosophy, religion, form of government, or the like; as, the theological *system* of Augustine; the American *system* of government; hence a particular philosophy, religion, etc."

For our purposes, we can now add to Webster's two definitions of a system a third that includes:

> ". . . assemblages of a diversity of objects and ideas functioning together to accomplish some useful purpose."

We must understand that the ideas referred to are not those which result in novel and improved objects. They are the concepts which cooperate with and sometimes organize and control the objects. The objects of this definition are sometimes refered to as *hardware*, the ideas as *software*.

WHAT IS A SYSTEM?

Obviously now, a system can be anything from a transistor to a complex radar equipment. It can be an assemblage of objects and ideas such as comprise the hardware and software of a data-processing system or the program material plus the electronic equipment which together perform a television broadcasting service. Systems may be simple, small, and inexpensive—or they may be complex, costly, and difficult to understand. They may be based upon a single technology such as that of the solid state of matter—or they may be based upon many and diverse fields of technology and understanding; ranging from electronics and information theory, to rocket propelled vehicles and orbital mechanics.

The system requirements may be as simply expressed as the characteristics of a transistor for some specific service, or they may be almost impossible to define closely because they must satisfy the needs arising from poorly understood and rapidly changing disciplines—such as the sociology and psychology of mass communications or the tactics and strategies of world politics and nuclear warfare.

WHAT REQUIRES SYSTEM ENGINEERING?

In the light of these definitions, almost anything that RCA is likely to engineer is a system. However, we do not customarily consider many of RCA's products to require systems "engineering." In common usage, we do not consider the engineering of a transistor or even of a television receiver to require systems engineering. Whether this is merely a quirk of language or whether it denotes a lack in the engineering outlook is an introspective question which might well be pondered by all engineers. But first, it would be well to discuss what is meant by the term *systems engineering*.

We can define systems engineering as the sequence of:

1) the inquiry into what the system is expected to do (i.e., establish requirements),

2) the determination as to what are the possible systems which might satisfy the needs,

3) the selection of the most promising of these not only in their potential for economically satisfying the customers' needs but also in the potential ease with which they might be engineered, produced and merchandised at a profit,

4) the optimization of the parameters of the system chosen, and

5) the translation of the system concepts into such terms that a system can be designed to fulfill in some optimum fashion the requirements established.

The mark of good systems engineering is the creation of a system which satisfies some need so well and so economically that it will be placed into use for the purpose intended. Often, this is in the face of stiff competition from similar devices as well as from dissimilar devices which are competing for the consumers' dollars.

REQUIRED: CREATIVITY AND UNDERSTANDING

Competent systems engineering, like any other brand of competent engineering, must be highly creative and in addition must be based upon a thorough understanding of the elements with which it deals. These elements comprise not only various branches of technology and thought but also customer needs, distribution and merchandising methods, the economic constraints on both the customer and the producer, and the skills in engineering, programming, production, distribution, maintenance which can be applied to the product. It is hardly surprising, therefore, to find systems-engineering responsibility vested in the most creative, mature, and widely experienced individuals to be found in the engineering organization. These systems engineers often work in small groups which collectively can possess the breadth of knowledge which is both necessary and difficult to find in a single individual. They find it essential to keep in close communication with marketing, planning and many other functions of the total organization of which they are a part.

OF GREAT IMPORTANCE TO RCA

The importance of systems engineering to RCA is far greater than in most industrial organizations. The nature of the electronics industry in general and RCA's position in this industry in particular is such that a continuous flow of new products in an absolute necessity. Older products become either obsolete or relatively unprofitable when their market evolves from a large-scale new equipment market into a relatively smaller-scale replacement market. The introduction of new products is costly not only in dollars but also in the allocation of technical skills which may be in scarce supply. The introduction of new products is also risky; with many products falling by the wayside for every one which is successful. Systems engineering—by carefully determining requirements, selecting the best possible system, optimizing the system, and taking courses which minimize technical and commercial hazards—can greatly reduce the risk of failure. It can increase the possibility of finding new products which should have a good market and it can optimize the product characteristics to give the greatest likelihood of satisfying the market demand.

DR. NATHANIEL I. KORMAN received his BSEE in 1937 from Worcester Polytechnic Institute, where he was graduated with "Highest Distinction." As an undergraduate at Worcester Polytechnic Institute, he was elected first, as an associate member of Sigma Xi and later, as a full member. He received his MSEE from the Massachusetts Institute of Technology in 1938, where he studied as a Charles A. Coffin Fellow. He received his Ph.D. from the University of Pennsylvania in 1958. He joined RCA in 1938 as a student engineer and has held positions of increasing responsibility after being promoted to supervision in 1945. In recognition of his work, Dr. Korman was awarded the 1951 "RCA Victor Award of Merit." In 1956, he was appointed Chief Systems Engineer of Missile and Surface Radar Engineering, responsible for the systems engineering of such major projects as TALOS and BMEWS. In 1958, Dr. Korman was appointed Director of DEP Advanced Military Systems, Princeton, N. J. In this capacity, he is responsible for the creation and development of new and advanced system concepts and for the initiation of RCA corporate action to exploit these ideas and concepts. Dr. Korman has served the Department of Defense for a number of years in various advisory roles. He is a member of the American Ordnance Association, the American Society of Naval Engineers, an Associate Fellow of the Institute of Aerospace Sciences, a Senior Member of the American Astronautical Society, and a member of Sigma Xi. He has made numerous contributions to technical journals and has been granted 33 patents. Dr. Korman is listed in "The American Men of Science" and "Who's Who in Engineering." In 1956, he was elected a Fellow of The Institute of Radio Engineers.

The engineering of an entire communications system, with all of its many integrated functions and equipments (often spread over a large geographical area) has historically required a strong "systems" approach. Thus, in many ways, the communications industry has laid the groundwork for systems engineering concepts in other fields of electronic applications. This paper analyzes the basic tools and methodology of systems engineering as it is practiced in the conception, design, and implementation of an optimal communications system—one that will most efficiently relate the performance sought, the operational characteristics, and the cost. Important byproducts of such communications systems engineering are the technical knowledge that can guide marketing activities toward promising areas of new business, and a constructive influence on the company-sponsored research that will lead to the most rewarding areas of future technical competence.

The Engineer and the Corporation

SYSTEMS ENGINEERING—THREE VIEWPOINTS

II—COMMUNICATIONS SYSTEMS ENGINEERING

Dr. R. GUENTHER, Chief Scientist
Communications Systems Division
DEP, Camden, N. J.

What is systems engineering? According to the most generally accepted definition, *a system is a complex arrangement of a relatively large number of interacting units or pieces of equipment.* A typical example is the telephone system, where large numbers of cables and other transmission and switching equipment are connected to a still larger number of user sets to provide intercommunication for any user with every other user in the system.

The extreme opposite to a system would be any large number of units operated in complete isolation from one another. A good example of this is the operation of the many broadcast or television receivers without interaction among the sets.

In a well designed system, it is obvious that the interaction of the different parts of a system has to take place in an orderly and systematic fashion according to the operational service the system is supposed to provide to its users.

The development of a master plan for the implementation of such a system to a given set of operational requirements with the best scientific and engineering tools available is called *systems engineering.*

The operational requirements are not always fully developed or rigid. In such cases an operational analysis has to precede the actual engineering phase. This is particularly important when new systems or new requirements are introduced. A full systems design process has to include also the evaluation of several approaches to the implementation in order to arrive at an optimal or near optimal system plan before the usually quite costly hardware development is started.

Thus, it is clear that systems engineering should not be identified only with systems projects. The management of the latter, of course, includes systems engineering as a necessary ingredient for the successful completion of a specific project. However, *a systems engineering activity as part of a continuous business operation*, such as a communications equipment manufacturer, *has to perform these functions continuously* to uncover new requirements, new concepts, and better techniques of implementation. The systems activity then has to evaluate the possible solutions and trade-offs *to assure the most competitive design of its products.* "Competitive" in this sense means not only in price but also in performance as a most efficient link in a system. To succeed in this process it is mandatory to have the most up-to-date know-how and experience in the development and manufacture of all the major equipment areas which constitute a typical communications system combined with the best understanding of the ultimate operational use of the equipment within the system.

In summary, the major steps in systems engineering can be listed as follows:

1) Definition of the operational requirement (operations analysis).
2) Development and evaluation of new concepts and techniques (systems analysis).
3) Study of trade-offs (cost evaluation).
4) Definition of performance goals and interfaces (systems integration).

These steps, if successfully completed, will result in a system design plan with realistic functional equipment specifications.

COMMUNICATIONS—THE CRADLE OF SYSTEMS ENGINEERING

The previous reference to the telephone operation was quite significant since communication systems are the most typical examples of a system. For this reason the engineering of an entire communication system with all its integrated functions such as signaling, supervision, dialing, switching, transmission, traffic handling, network connectivity, message accounting, and equipment spread over a large geographical area has dictated from the beginning a strong systems approach. Thus, the communications industry laid the ground work for systems engineering in other fields of applications such as weapon systems, data processing systems, warning systems, etc.

Let us have a quick look at the block diagram of a typical general purpose communication system and its ingredients such as a commercial telephone system, or the Defense Communication System (DCS), or the Field Army Communication System (FACS).

To the left in Fig. 1 is the interface between the users, in our example the human users, called subscribers, and the communication system. The subscriber may have different kinds of subscriber sets depending on the mode of service he wants, such as telephone, teletypewriter, facsimile sets, etc. The subscriber set has to act as a translator of the user's language such as speech, print, pictures, or digital data into the acceptable language of the communication system. In addition, it also has to transmit a service request to the system (*supervision*), receive a service call (*signaling*), transmit the address of the called party (*dialing*), permit a record of the performed service (*message accounting*), and, in many cases, request special

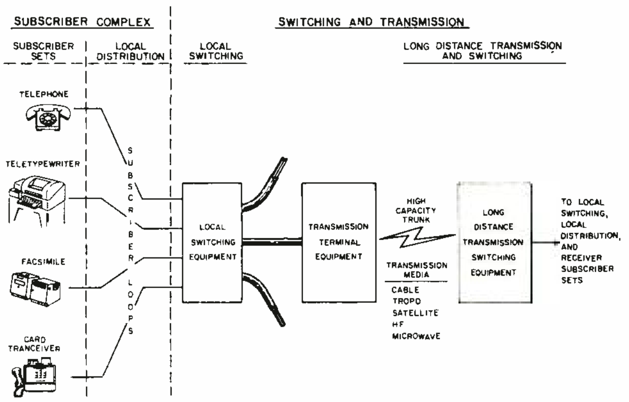


Fig. 1—Typical communication system.

services such as person-to-person calls in a telephone system. or preemption for higher priority in military systems, etc. A large number of the overall system parameters. therefore. have to be fixed with the design of the subscriber set. To the systems design engineer the subscriber complex is particularly important for two reasons: 1) it represents the only way the user can inject information into the system at the originating site and receive it at the designated point of destination (man-machine interface) and, 2) it is the most numerous equipment in the whole system. which makes it usually the major cost factor.

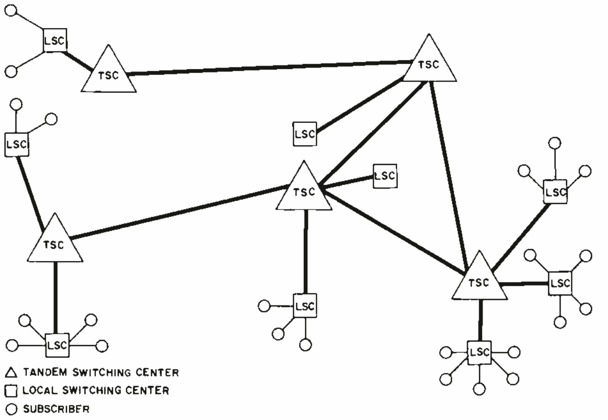
Subscribers are usually spread over a relatively large geographical area and interconnected by a rather complex communication network as illustrated in Fig. 2.

The information injected into the system by the user is transmitted over the local distribution system and collected in a local switching center, through which it has access to the rest of the entire network. The local switching center will recognize the service request and, according to the instructions given in the form of the address or dialing code, execute this service call. From the user to this point of the system—that is. subscriber set and local distribution—is on a per-subscriber basis.

The local switching center is shared by an appropriate number of users which is determined by the frequency of service demands; i.e., traffic considerations. From the local switching center the information is transmitted to higher echelon switching centers (long distance or tandem offices) if the service call cannot be completed within the local area. Transmission highways between long distance switching centers, the so-called trunks, are not assigned to individual users, as are the local subscriber lines. but are shared by every one who needs service over this particular route. As these bundles of trunk circuits increase in cross section, that is the number of lines along one trunk route goes up, the cost per circuit mile is decreased due to more efficient transmission methods (primarily through multiplexing) which can be employed in the form of terminal equipment at each end of the trunk routes. The actual decrease in cost per circuit mile as a function of the number of circuits along one route is illustrated in Fig 3. The data represents relative cost of the different types of transmission facilities used in the Bell System.[1]

From the relationship above it would appear to be more economical to use few large switching centers with few

Fig. 2—Typical communication network.



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 for cables and radio relay systems and supervising radio communications engineering and development. In 1947 Dr. Guenther joined the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey and did consulting work for the Radio Communications Branch and General Engineering Branch in radio relay systems, radio propagation, special test equipment, and antennas. In 1952 he joined the Bell Telephone Laboratories doing systems engineering work and systems studies. Among other projects, he evaluated different bandwidth conserving systems for use on submarine cables and the use of active components for loading telephone cables with negative impedances. Dr. Guenther joined the Surface Communications Division of Defense Electronic Products in 1956 with the assignment to establish a system engineering capability for the Division. This activity led to the establishment of the Surface Communications Systems Laboratories with headquarters in New York City. The major responsibility of the Systems Laboratories is the development of advanced communications concepts and techniques, the development of systems design plans and the management of development type systems projects in the basic communications field. In 1963 he was made Chief Scientist, responsible for the applied research and technical planning of the DEP Communication Systems Division (successor to SurfCom). He is a member of the IEEE and the American Association for the Advancement of Science.

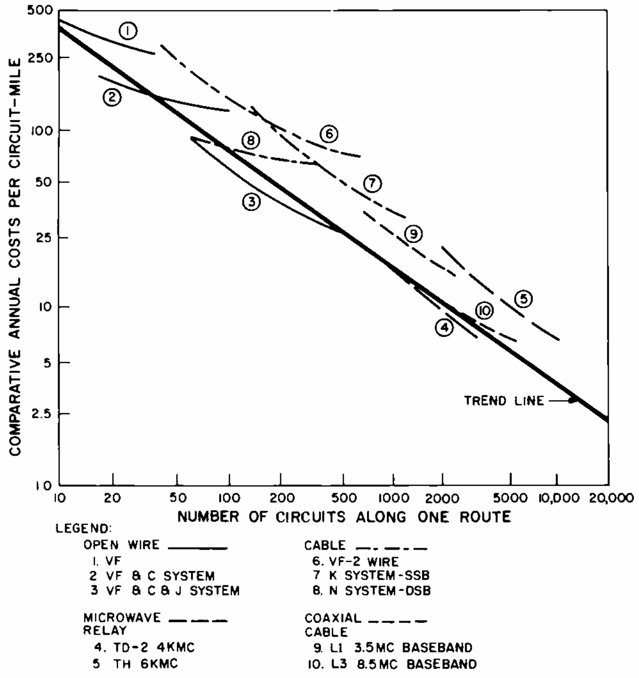


Fig. 3—Circuit cost vs. trunk cross-section.

heavy trunk routes between them; however, other considerations will put a limit on how far this is practical, as we will see later.

The topological structure of a communication network, shown in Fig. 2, is, of course, generally not unique and fixed, that is, the distribution of switching centers (*nodes*) and the choice of connecting trunk routes (*connectivity*) may have to be determined during the systems engineering process. The choice will depend obviously on the geographical distribution of the users, and the routing doctrine used in the switching centers. It is obvious that a change in the number of nodes and connecting trunk routes will affect the trunk cross section if the total traffic flow in the network is maintained constant. At the same time, the number and length of individual subscriber lines will be changed also. For example, fewer switching centers will require longer individual subscriber lines which would increase the cost of the subscriber complex, already a dominating cost factor. An extreme case would be the elimination of all switching centers and trunk routes, which requires subscriber lines from each user to every other user, an economic monster which no one can afford. Any practical system will have to represent a proper balance between the various parameters according to the weight attached to each one in the system evaluation.

From this general description of a general purpose communication system and its principal component parts, it is self-evident that engineering of such a system requires a systematic analysis of many aspects and variables in view of the operational requirements.

In special purpose systems, such as command and control systems or logistic support systems for military application, the operational requirements may be quite different from the described general purpose or common user case. These systems may have a very large amount of digital data traffic and may have to provide data processing functions, code and speed conversion, large scale information storage, information display and other special features, depending on the specific operational requirements. The main functions, however, are in all systems of the same type and can be summarized as follows:

1) subscriber sets (input/output devices)
2) local distribution (subscriber loops)
3) switching and routing
4) storage and processing (where needed)
5) long distance transmission (trunks)

It is the purpose of the following section to examine in greater detail some methods and tools available today to the systems engineer and how they can be used to design communication systems with the best balance of systems parameters.

THE BASIC TOOLS AND METHODS OF COMMUNICATION SYSTEMS ENGINEERING

First, a few words about the yardsticks used to measure the performance and effectiveness of communication systems.

One of the most important performance characteristics is the transmission quality from user to user once a connection is established. It is usually measured in terms of: 1) lower and upper cutoff frequency (*bandwidth*), 2) net loss in signal power expressed in decibels (where $1\ \text{db} = 10 \log_{10}$ [power in/power out]), deviation from ideal amplitude response and phase response (delay distortion). 4) and tolerable contamination with noise (*signal-to-noise ratio or noise power*)[2]. For most analog or continuous signals, such as voice, where an infinite number of different signal elements are possible, these performance measures are quite adequate. In digital systems with discrete signals, such as digital data, there is a finite number of possible signals and the most useful measure of performance in this case is the probability of errors (error rate). The transmission characteristics are primarily determined by the quality of local and long distance transmission media and the terminal equipment. Once each link of the system is designed to meet the transmission performance requirements, it can be counted upon, after a connection is established or a message is delivered to the user.

The design of the transmission subsystems is usually fairly straight-forward. Most commercial systems follow the standards recommended by the CCITT.[3] The Bell System has its own standards which differ, however, only in minor details from the CCITT recommendations. The

TABLE I—Transmission Standards for AIRCOM Reference Circuit

PARAMETER	Overall Reference Circuit 6000 nm (6 links)	Normally Assignable to:		
		Transmission Medium, Incl. Repeaters (6 links)	Multiplex Equipment (1 link only)	
Insertion loss-frequency, ref. to 1000 cps:				
600–2400 cps	+ 4.0–4.0 db		+0.7–0.7 db	
400–3000 cps	+ 9.0–4.0 db		+1.5–0.7 db	
300–3400 cps	+18.0–4.0 db		+3.0–0.7 db	
Differential time delay, 900–2500 cps, max	1000 μsec		160 μsec	
Median noise level, worst hour, worst month, from all sources (Note 1):			Term only=	Term & Inter-med=
Psophometrically weighed, at 0 TLP, pwp	25,000	20,000	475	815
Equiv. white noise, FIA line wtg. dbau	38.0	37.0	20.8	23.1
Harmonic distortion, 2 tones at 0 dbm0			–40 dbm0	
Gain change for output level increase from 0 dbm0, to: + 3.5 dbm0			0.35 db max	
+12.0 dbm0			6.0 db min	
Net loss variation, max at 1000 cps audio, or any baseband frequency	±2.0 db	±0.5 db	±0.2 db	
Level adjustability	±0.5 db	±0.5 db	±0.5 db	
Max overall change in any audio frequency	±2 cps		±2 cps	
Stability of multiplex frequency generator Initial setting to:			2 parts in 108	
Drift per month:			2 parts in 107	
Single tone interference	24 dba0			
Max data/telegraph levels, single channel high speed			(FSK)–13 dbm0 (AM)–10 dbm0	

military communication organizations usually have their own standards which are derived from the commercial recommendations, taking into account the special military operating conditions.

An example of the most important transmission standards used by the U. S. Air Force (AFCS) is shown in Table I. The transmission standards are usually broken down for each subsystem and equipment within the subsystem such as subscriber sets, distribution links, switching offices, trunk routes, etc. Once a system design plan is completed a detailed performance specification can thus be written for each equipment toward which the product design engineer can work, with confidence that his equipment, when completed, will perform in accordance with the overall operational concept of the system.

However, the transmission performance does not describe the overall systems quality of service such as the speed and reliability of establishing the desired connection or delivering the messages to the right user without excessive delays.

The latter performance is related to the grade of service the system provides when service is requested. This grade of service is usually expressed by the probability of not being able to reach the called party or addressee when the latter is free to receive a call or message. The Bell System, for instance, is engineered to provide not more than one miss out of 1,000 legitimate service requests under peak traffic conditions (10^{-3} grade of service). In times of emergencies (blizzards, floods, etc.) this grade of service will, of course, deteriorate considerably because all users have the same service privilege and will request service at a much higher rate than usual. For this reason, military systems require service according to established priorities which, for example, will give all users of highest priority service at all times without delay and lower priority users may encounter considerable delay during emergencies. The grade of service is primarily determined by the design characteristics of the switching facilities (*blocking* or *nonblocking switching matrix*), the number and the size of switching centers and their connectivity, the selected routing doctrine (*alternate routing*), and the capacity of interconnecting trunks (*trunk cross section*).

TABLE II—Switching Performance Standards for Automatically Switched Service

Automatic, shared-facility switched service is employed where the grade of service provided by cooperative utilization of trunks will meet the user operational requirements.

GRADE OF SERVICE

The grade of service will depend upon the classification of the user in the system. Where switched service is employed, minimum requirements shall be:

1) *Nonblocking*—Where needs demand nonblocking, users shall be provided nonblocking access to trunk groups.
2) *Lost call working*—Where lost call principles apply, the grade of service shall be 0.01 (i.e., the probability is that 1 call in 100 will encounter an all-trunks-busy condition under normal operating conditions).
3) *Delay working*—Where delay principles apply (this includes teletype, data, and facsimile) message preference is applied as below.

CLASS OF SERVICE

Message Precedence	*Allowable Delay*
Flash. Emergency	One message length plus the cross-office switching time (signaling time not included).
Operational Immediate	As for Flash and Emergency, except in the case of preemption by a higher precedence message. In any circumstances the delay shall not exceed 10 minutes.
Priority	Maximum of 1 hour.
Routine	Subject to delays as demanded by higher precedence messages but not to exceed 4 hours.
Deferred	Same as routine, except that delay may not exceed 12 hours.

A class A user (high priority, pre-emptive) shall have the equivalent of allocated service, regardless of whether the communication is subjected to switching or store and forward handling.

All these factors have to be related to the traffic requirements imposed on the system in terms of volume and pattern of flow. In addition to these factors, of course, are the equipment reliability considerations which have to be included in the overall grade of service evaluation and will have to include monitoring and maintenance procedures.

Almost any performance objective can be designed into a system if there are no economical constraints. Real systems, however, are subject to economical limitations. The systems engineering process has to find the optimum balance of parameters to provide the required transmission quality and the expected grade of service within the given economical limits.

In military systems there are frequently special requirements with respect to physical survivability and/or reliability under severe jamming, which adds another systems evaluation factor.

There are obviously trade-offs possible among these various factors and different operational requirements will attach different weights to each of them. For example, military systems usually weigh reliability and survivability much more heavily than cost.

Unlike the transmission performance it is much more difficult to assure compliance with respect to the grade of service, cost, or survivability of a system. One example of the U. S. Air Force requirements for grade of service is given in Table II.

A more detailed discussion will help to explain some phases of the system design related to the grade of service. The most important operational variable, of course, is the traffic concept. At the nodes of a typical communication network, as shown in Fig. 2, the traffic generated by all users connected to each switching center is being collected and routed to other nodes according to the routing instructions sent to the switching center with the service request and the routing doctrine used. The volume of traffic may be conveniently measured in call-minutes per hour, that is the minutes of information flow during the busiest hour of the day. Through special analytical tools[4] it is possible to analyze a given network configuration with respect to the traffic handling capability under peak load conditions. There exists extensive literature on maximum flow through networks, a survey of which was completed recently.[5] Computer programs can be written to determine the optimum connectivity with respect to such parameters as, for example, minimum number of total trunk circuits. In a more sophisticated program this analysis can be combined with the evaluation of the cost of transmission facilities so as to minimize the total cost rather than the total numbers.[6] In both cases the analytical process amounts to matching the requirements matrix of the network against the capacity matrix and minimizing the total cost of all connecting links. In the case where the number and location of the nodes are given, this optimization process is relatively simple. Using the notations from Fig. 2, the total cost of all trunk transmission circuits can be expressed by:

Total Cost of Trunk Transmission

$$= \sum_{x=1}^{n} \frac{c_x}{60} \frac{Cost}{Trunk\ Ckt.\ Mile} l_x$$

Where: c_x = call-minutes during busiest hour in trunk route x, and l_x = length of trunk route x.

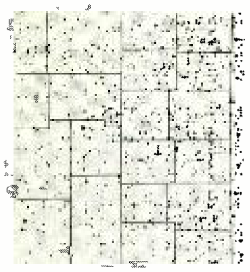


Fig. 4a—A geographical distribution of subscribers.

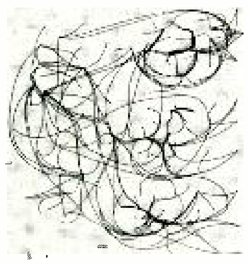


Fig. 4b — Examples of need lines.

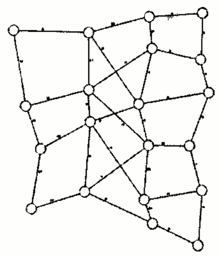


Fig. 4c—Resulting system for equal switching load.

In many practical cases both the location and the total number of nodes are not fixed and it will be necessary to determine them from the traffic generated by all users. The first step in such an analysis requires the determination of the location of all users. An example is shown in Fig. 4, which represents results obtained from a study of the Field Army Communications System requirements for a division area. (Performed under Contract DA-36-029-SC-80071 by Systems Laboratory, Communications Systems Division, DEP, Tucson, Arizona.)

The second step represents a tabulation of the user need-lines or traffic pattern which is illustrated in the example shown in Fig. 4b for the same division area.

With the additional information of the volume of traffic generated by all users, it is now possible to select the logical location of switching nodes according to a selected rule. For example, if the rule selected specifies equal traffic load for each switching center, the result would be a communication network configuration such as shown in Fig. 4c.

The areas covered by each center are outlined by squares of equal traffic load in Fig. 4a. The remaining optimization with respect to total number of circuits or costs may now follow the same routine as described before.

This example was based on a rather arbitrary assumption, namely, the equal traffic load. In a more sophisticated communication synthesis process, it would be desirable to have the traffic load for each center varied also to arrive at an absolute minimum of number or cost of transmission and switching equipment. This requires that an optimum balance between the number of nodes versus the number and length of trunk routes has to be found. This balance will depend on the relative cost of the equipment necessary to provide the transmission and the switching functions. For the hypothetical case of extremely low cost trunk transmission facilities, it would obviously be less expensive to use very few switching centers and fewer trunk connections with more circuits along each route.

As we have seen from previous information presented in Fig. 3, the increase of the number of circuits along each trunk route results in a further decrease in cost of transmission circuits. This reasoning would, however, lead to longer connections between the individual users and the local switching centers, the so-called subscriber loops, which are the most numerous part of the system and would tend to counterbalance the cost reduction. For an overall cost minimization it will, therefore, be necessary to balance the cost of loop transmission versus trunk transmission. The Bell System is conducting such a study (*loop* and *trunk study*) every 10 to 20 years to update the results according to the latest changes in the cost for the respective equipment and installations.

The overall cost of transmission for such an evaluation can be expressed in the following sum:

Total Cost of All Transmission

$$= \sum_{y=1}^{m} \frac{\textit{cost}}{\textit{loop-mile}} \times l_y + \sum_{x=1}^{n} \frac{c_x}{60} \frac{\textit{cost}}{\textit{trunk ckt. mile}} l_x$$

Where: l_y = length of loop y, l_x = length of trunk route x, m = total number of loops (or subscribers), n = total number of trunk routes.

The largest cost reduction in the past 30 years of transmission equipment development was realized in terminal equipment for multi-channel trunks which is very well summarized in Fig. 3 discussed before. It was possible to make full use of this reduction primarily because of the increased total traffic flow and demand which are still increasing. In contrast the subscriber loops which have to be provided on a per user basis, have not been decreased in cost considerably. Consequently, the trend is toward shorter loops and more switching centers. This trend will be even accelerated if, for instance, the use of solid state switching techniques will reduce the cost of future switching centers per line even further. With a known relationship of switching cost per line versus number of lines per switching center, the minimization of total cost may be computed from the following expression:

Total Cost

$$= \sum_{z=1}^{p} \frac{\textit{cost of switching center}}{\textit{line}} s_z + \sum_{y=1}^{m} \frac{\textit{cost}}{\textit{loop-mile}} l_y$$

$$= \sum_{x=1}^{n} \frac{c}{60} \frac{\textit{cost}}{\textit{trunk ckt. mile}} l_x$$

Where: s_z = number of lines in switching center z, and p = number of switching centers.

As mentioned before, in military systems very frequently vulnerability requirements are more important than the minimization of cost. The aforementioned analysis method lends itself also to the evaluation of physical vulnerability. A system can be designed, for instance, for normal grade of service to all users under normal conditions, and, in the case of specified percentage of damage or interference, normal service would be provided only for a restricted number of users and lower grade of service to all others. The percentage of users with full service under emergency conditions is, of course, related to the total cost of the system and has to be balanced according to operational and cost requirements.

In closing our treatment of systems evaluation, it is important to point out that a systems engineering effort, particularly for a new system or system to meet new requirements, is not complete without an evaluation of implementation techniques. The purpose of the techniques' evaluation is to assure the latest state of the art to be used in the optimization process because it will affect the balance between the various factors involved. For this reason the most effective integration between systems design and technique evaluation is mandatory. To assure an unprejudiced evaluation, the analysis should not be performed by the same team as the techniques development.

THE ROLE OF SYSTEMS TESTS

Earlier in the paper the major steps in the systems engineering process were summarized. It is self-evident from this summary that identification of the operational problems is to come first before a solution for an optimum system may be found. When the system design is completed, however, it is just as important to prove the validity of the system design plan. The only valid proving ground for a system design is, of course, an operational service test. Laboratory tests of individual parts of equipment or subsystems will never suffice because they never evaluate the function of each equipment as a part of an integrated systems operation. Full systems tests, however, are possible only in the fully implemented operational system so that the only operational evaluation during the systems engineering process is either a simulated test or computer simulation. Transmission media, for instance such as cables, can be easily simulated by R-C networks representing artificial lines which approximate very closely the transmission performance of real cables. Realistic noise sources may be injected into the artificial lines from recorded noise at any level required. Similarly, other more complex transmission media may be simulated by a more sophisticated apparatus. A good example is the SYSEC simulator shown in Fig. 5, originally developed by RCA Laboratories at Rocky Point, New York (now in Camden) to simulate the multipath medium prevailing for example in HF long distance transmission. This simulator was also used to evaluate three sonar communications systems in a time varying multipath channel environment (Navy Contract NOBSR 89119).

Other aspects of a communication system, such as the switching subsystem, lend themselves well to computer simulation. A general purpose digital computer can be easily programmed to handle each message or call according to its routing information on the way through a completely predetermined communication network with a given number of switching nodes and connectivity. Such a traffic simulation will evaluate the grade of service rendered by the analyzed system for a given traffic load. The computer can be interrogated to give actual traffic load data in any given part of the system to match it to the required load. A program of his nature has been written for the traffic analysis of the Field Army Communication System[7] and has proven an extremely powerful tool in the design of a complete communication network. It has been expanded later on to handle larger systems with more nodes at the price of giving up some detail. Field tests made on a small system performed by the U. S. Army at Fort Huachuca, Arizona, have confirmed the accuracy of the simulation program.

Fig. 5—System Simulator Evaluation Center (SYSEC) developed by RCA Labs., Rocky Point, N.Y.

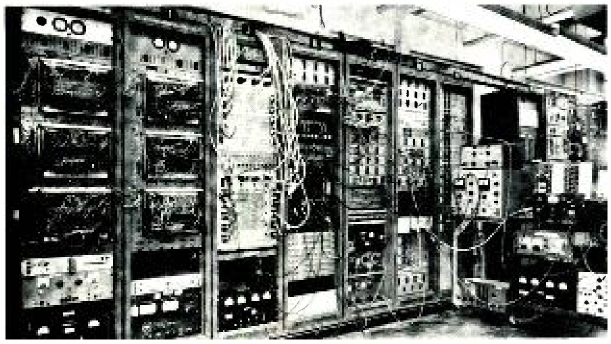
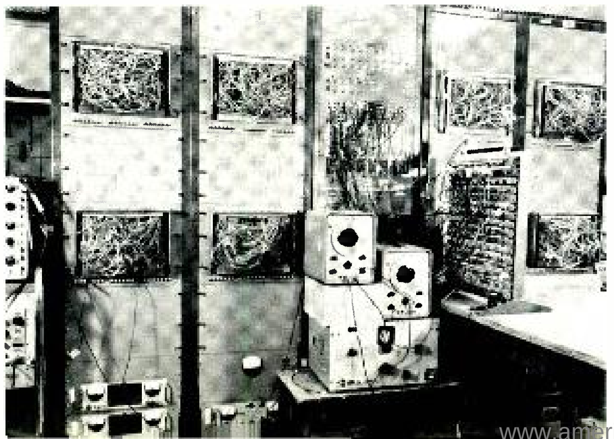


Fig. 6—Minuteman prototype system designed for maximum measurement flexibility.



Wherever possible laboratory systems tests combined with simulated facilities should be used for checking out the consistency and integrity of the design plan before large scale equipment design and production is started. A good example is the MINUTEMAN prototype system with programmable logic, a photograph of which is shown in Fig. 6. The MINUTEMAN prototype system was designed for measurement flexibility so that necessary changes could be introduced by reprogramming the logic. This permits the quick evaluation of changes in operational requirements and permits the complete debugging of the system without costly rewiring of nests and racks.

In many cases, a skeletonized experimental system is retained in the engineering laboratories for extended periods of time for product improvement work, factory follow-up, and continued product development as a very powerful experimental tool. Most larger communication laboratories have such complex equipments and subsystems available for extended performance tests and evaluation against established standards and new requirements.

THE ROLE OF SYSTEMS ENGINEERING IN BUSINESS MANAGEMENT

From these discussions it is evident that the systems engineering process includes far reaching and forward looking analyses which are also the basic inputs for long range business planning.

The operational analysis for instance leads to the best possible understanding of the customer's present facilities and/or future needs. This information is needed to direct the more forward looking research and applied research projects directed toward identifiable future need areas. The analysis and development of new techniques and concepts provides the information for a continuous matching process between the customer's operational requirements and the company's available technology to fill these requirements. The result of such activities has been proven to be extremely useful to guide marketing and promotional activities toward the most promising areas of new business and establish realistic company sponsored research and applied research programs directed toward the most marketable product lines.

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Systems Engineering was established within the Engineering Department of RCA Electronic Data Processing (EDP) in November 1961 as a formal organizational entity reporting to the Chief Engineer. This paper describes the nature of Systems Engineering in EDP; and the objectives which have guided and continue to guide the development, training, and staffing of that organization.

The Engineer and the Corporation

SYSTEMS ENGINEERING — THREE VIEWPOINTS

III—SYSTEMS ENGINEERING IN EDP

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The increasing complexity of automated operational systems as they affect the most basic facets of our daily lives is mushrooming at a rate that is almost unbelievable to even those of us who are in the midst of this fascinating process. This process owes much of its impetus to the pressures created by the immense socio-economic forces that have as their primary objectives: higher pay and less working hours for the working man. These objectives, in turn, are causes for lower profits and a corresponding effort on the part of management to reduce overhead and raise productivity. This regenerative cycle is and will continue to be a major cause for continued extensions in the application and use of computer automation.

Once computer automation is recognized as an *effect* rather than a cause, it becomes clear that the increased technological complexity must be dealt with in a positive and constructive manner if chaos is to be avoided in daily and long-term operations within industrial, military, and governmental organizational processes.

It is becoming increasingly evident that we are in a new and different kind of race today[1]. This race has two contestants—the rapidly increasing complexity of our technological civilization versus that group of people who are devoted to progress by reducing such complexities to simpler, more manageable, and more readily solvable elements.

The group of people referred to above are those who knowingly define and solve complex situations and problems through the application of systems methodology. We find numerous types of "systems people" in today's technical and administrative environments. While the specific technical specialties, objectives, and parent organizations of these systems people may differ, there is at least one important common denominator—the understanding of, and the ability and desire to apply systems methodology effectively.

In the field of electronic data processing, there are business systems analysts, programming systems analysts, management systems analysts, and systems engineers found in growing numbers. Regardless of the number, however, there are never enough. And, there is little reason to believe that this situation will improve without a major revamping of our educational curricula and a concerted effort by industry to train and encourage the development of systems methodology.

"SYSTEM" DEFINED

Before proceeding into the details of what a systems engineer is and what he does, it is necessary to define a *system*. A system may be broadly defined as:

> "Any entity, conceptual or physical, which consists of interdependent parts and displays some element of order".[2]

A system which displays activity is a *behavioral* system. The essential characteristic of a behavioral system is that it consists of dependent parts each of which displays behavior.[2] In EDP, we are concerned with systems that are subject to control by human beings. Hence, we deal with systems that are primarily tools for use by humans. Such systems are defined technically as *controllable behavioral* systems. The type of controllable behavioral system with which we are concerned is further characterized by the techniques and components which it encompasses. In computer systems, the techniques and components employed readily identify the technical disciplines required

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of EDP Systems Engineering as those associated with computers, logic, electronics, mechanics, mathematics, programming, etc.—disciplines with which we are well-acquainted.

Having defined the nature of a behavioral system, its relationship to the behavioral sciences becomes apparent. The latter include a number of disciplines such as anthropology, history, political science, sociology, and psychology. Related specializations based on the behavioral sciences which are often intermingled, overlapped and confused with systems engineering are management engineering, industrial administration, industrial design, and labor relations. Systems engineering does not usually deal with these areas directly. However, in EDP we *are* developing management information and control systems. We *are* concerned with *how* work is done within the industrial environment, and *how* the industrial organization functions. Our product *is* a form of automation and must have some effect on labor relations. Finally, RCA supplies computer products to industry that are purchased in part for their convenience of operation, ease of maintenance, and general appearance.

In any event, EDP Systems Engineering deals with problem-oriented solutions and the application thereof. We address ourselves to the problem and bring to bear upon that problem all of the knowledge at our disposal. We do not quarrel with whether it is a pure behavioral science, an element of management, or electronic design.

CLASSIC OR METHOD?

What then is systems engineering? Is it the *engineering of systems* as classic engineering would suggest, or is it a form of engineering which performs its work through the use of systems methodology? A closer examination of these two definitions shows that both apply equally.

If systems engineering is classified as a branch of engineering in the classic sense, such as electronic, mechanical and chemical engineering, then the *engineering of systems* includes: *research*, *development*, *design*, and *applications*. In this sense, EDP Systems Engineering indeed performs all facets of classic engineering, with the exception of systems research engineering which is performed by the RCA Laboratories.

When systems engineering is considered in the other sense—as *specialized method and discipline*—then EDP Systems Engineering is specifically concerned with the application of the systems method. Systems engineering, as a methodology, then includes:

problem definition	*evaluation*
objective establishment	*simulation*
analysis	*decision*
synthesis	*communication of result*

Hence, the systems engineer applies systems method together with the applicable classic engineering specialties. His systems method and approach is inherently identical to that of the business system analyst. Only the complementing technical specialties differ.

What, then, does a systems engineer do? A general and classic definition of what a systems engineer *does* is as follows:

> "A systems engineer applies scientific and engineering knowledge to define a problem, establish objectives; and plan, specify, and evaluate complex man-machine systems and components".

Hence, the systems engineer acts as an active bridge between what is needed in the market place and that which is technically feasible or financially practicable. A bridge between aspirations and possibilities . . . a translator of technical terms into technical objectives . . . and the span between what ought to be done and what can be done. This bridge is supported by two columns—our experience and our knowledge of the sciences, and is illustrated in Fig. 1.

INTERDISCIPLINARY NEED

Let us now examine those sciences upon which the EDP systems engineer draws during the course of his work. We would do well to look at the sciences and their general relationship to the total body of knowledge.

Fig. 2 illustrates the way in which one cybernetician has chosen to depict the relationship of the sciences, the arts, the technologies, and philosophy.[3] The various arts and sciences are distributed around the equator in a logical sequence. If we begin with the fine arts, we move through literature, language, logic, mathematics (which is depicted as the bridge between the arts and sciences),

Fig. 1—The function of systems engineering.

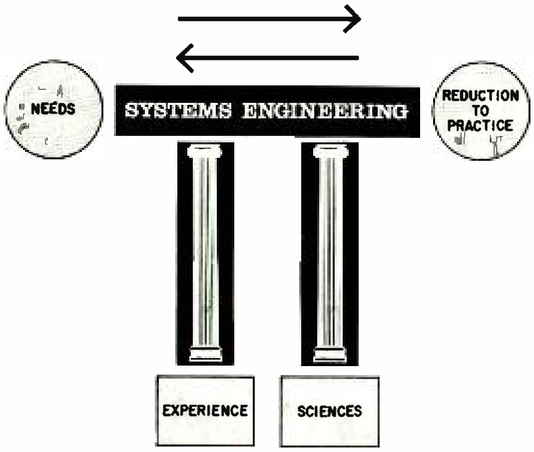
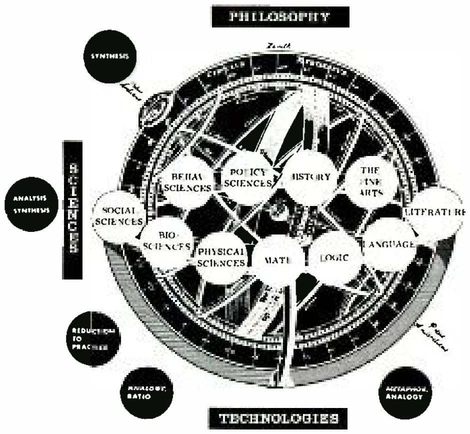


Fig. 2—Relationship of the sciences, the arts, the technologies, and philosophy. (Based on diagrams by Cassidy.[3])



into the physical, biological, social, and behavioral sciences before crossing through the humanities, as represented by the policy sciences and history.

Classically, we think of Engineering as functioning in the area of "analogy" and "ratio", "reduction to practice", and drawing from the classic engineering sciences of logic, mathematics, and physics. In systems engineering, however, we have introduced elements of the behavioral sciences. Systems engineering, thus, embraces the entire spectrum of sciences depicted.

In addition, we see that the tools of systems engineering are *analysis* and *synthesis*. Synthesis may involve hardware and hence reduction-to-practice in the technologies. It can also be synthesis in-the-abstract—in which case, we are dealing with philosophy. It is of interest that while computer systems are a direct product of the technologies, they have already found application in all of the arts and sciences depicted in Fig. 2.

ANALYSIS AND SYNTHESIS

In the description of systems methodology two terms are used often—*analysis* and *synthesis*. These are primary tools in systems work and deserve further elaboration. These tools are equally applied to a systems problem without any conscious demarcation. For the sake of demonstration, I would like to pursue the development of an automobile designed for competition by both:

analysis, optimization through the application of what exists, and

synthesis, beginning with the problem and pursuing the optimum solution.

The neighborhood hot rod will illustrate *analysis*. It is the result of taking the most available "main frame", some careful study of the wide range of shelf items available at the auto accessories store, Dad's allowance, and the part-time job income, and combining it all with a high degree of ingenuity and hard work. This is analysis and implementation—a hopped-up engine that has been ported and relieved, a hot cam, and a dynamically balanced crankshaft; topped off with a monstrous carburetion system. The frame has probably been lowered, and sway bars and special shocks have been added for improved cornering—and this car is capable of winning a race. But, it still bears a license plate and is permitted on city streets.

In contrast, the *synthesized* approach to competitive vehicles is *quite different*. Here, money is rarely the object, and the racing stables that produce these extremely sophisticated vehicles for the Grand Prix Circuit go out and study pavement materials, weather conditions, grades, embankments, lengths of straight-aways and examine the state of their particular art at that time. These have little interest in off-the-shelf engines. Instead, the latest combustion technology, the most recent advances in metallurgy, what the tire companies can do in an ultimate sense, the newest suspension concepts, and their possibilities are continuously examined. These vehicles start with four wheels because at the moment this is the best-known configuration. Otherwise, there is very little in common with the hot rod. And, this vehicle has no headlights, no luggage space, no radio, heater, or automatic drive.

EDP Systems Engineering methodology encompasses the whole spectrum of activity from pure analysis to pure synthesis. Two examples which further illustrate the application of the techniques of synthesis and analysis involve a general-purpose computer and a special-purpose computer.

In selling an RCA 301 System, a new computer is not designed for the customer's task. Instead, methods personnel including systems analysts are utilized to analyze the customer's problem and to apply the general-purpose computer system in the solution of that problem in the most efficient manner.

In the case of a specialized or a newly developed computer system, however, the process is reversed. We start with the problem and end up with a computer that does that job and preferably nothing more in order to optimize cost-performance ratio. This effect results from a purely synthesized approach.

Through *analysis* we usually apply some combination of standard or shelf items to a given problem. *Synthesis* usually results in new techniques or equipment to solve a given problem. Both methods are used individually or in combination rather freely in systems methodology.

THE BRIDGE BETWEEN

EDP Systems Engineering is a bridge between all things *system*. It is the interpreter of the needs of management, the customer and marketing, and of the goals of product planning to the technical organization. EDP Systems Engi-

Fig. 3—Organized relationship of systems engineering.

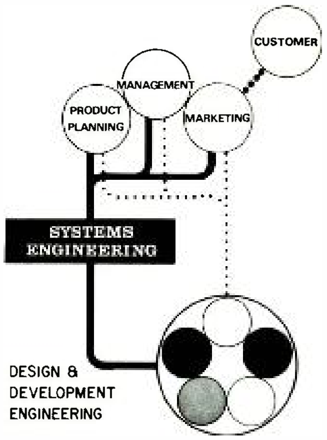
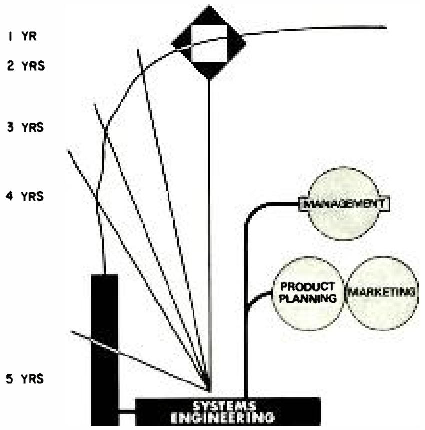


Fig. 4—Systems engineering and the concept of a new product.



neering, in turn, communicates to management, product planning, and marketing, (and the customer in isolated instances) on matters of what can be done, the strengths that should be promoted, and the weaknesses and limitations that should be corrected. This relationship is illustrated by Fig. 3.

It should be noted that each one of the organizational elements shown in Fig. 3 marketing, management, product planning and design and development engineering—have a set of organizational interfaces with the remainder of the organization which parallels this one. It is important to recognize that the role of the EDP Systems Engineering organization does not prevent or preclude normal communication between the design and development function and the nontechnical organizational elements. EDP Systems Egineering is present to assist, provide interpretation, liaison, and technical product supervision.

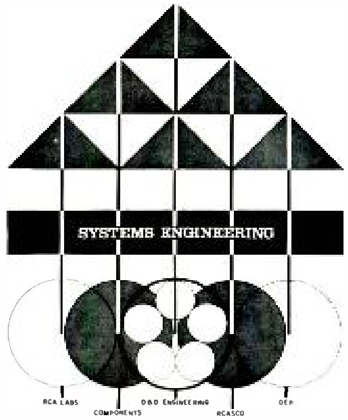
TECHNICAL PLANNING AND PRODUCT CONTROL

Fig. 4 illustrates the concept of technical planning, advanced project management, and product control. In the development of a new computer system, EDP Systems Engineering works from the inception of a project in assisting design and development engineering, product planning, marketing, and management to establish a *direction* and a *target*. Once the direction and the target have been established, EDP Systems Engineering assists the same functions in keeping the effort on the track, so to speak, aimed towards the selected target and providing vernier and/or major correction as our market studies, competitive situation, and technical progress change. Product control avoids costly tangents and ensures continued integration of the product lines over the length of the design, development, and product improvement cycle.

SYSTEMS TASK FORCE

Systems Engineering is a ready task force which may be brought to bear upon any problem whose solution requires its participation. This task force may apply to the members of the EDP Systems Engineering organization as well as to a combined task force including elements of the EDP Design and Development Engineering groups, and of other RCA organizations such as Defense Electronic Products, the RCA Laboratories and the RCA Service Company. This concept is illustrated by Fig. 5.

Fig. 5—Concept of EDP Systems Engineering combined task force that involve other RCA activities.



In this role, EDP Systems Engineering leads, coordinates, and assembles a closely-knit team designed to cope with systems problems and to provide quick reaction to unexpected competitive developments. It operates as an informed group of senior people whose work is accomplished through already established communication channels within EDP and as well as between EDP and cooperating RCA groups. The task force approach enables RCA to put its best foot forward in every instance requiring EDP-wide or Corporation-wide technical resources.

HOW SYSTEMS WORK IS DONE IN EDP

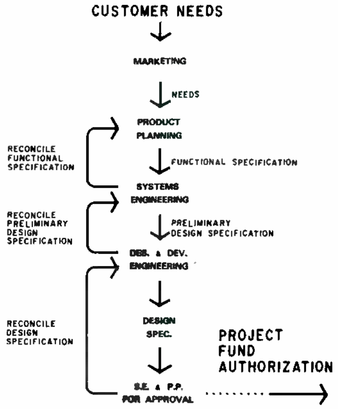
The manner in which an EDP product is developed is classically illustrated in Fig. 6.

Fig. 6 shows how a *customer need* enters the cycle through the EDP Marketing Department and emerges as a *requirement*, and how EDP Product Planning in turn creates a *functional specification*. The functional specification is often a joint effort between EDP's Product Planning, Systems Engineering, and Design & Development Engineering groups, but the responsibility and issuance of the document always belongs to Product Planning. Upon completion of the functional specification and prior to issuance, it is reconciled with the original requirement and need. If the two compare satisfactorily, the specification is then issued and forwarded to the EDP Engineering Department for preliminary design specification, cost estimating, and scheduling.

Systems Engineering then prepares a preliminary design specification with the participation of Design Engineering and Product Planning, which forms the basis for the engineering cost estimate and the technical specifications to which the product will be designed. The preliminary design specification then goes through an approval cycle by Product Planning and final reconciliation with the customer need, if applicable, prior to the authorization of the project and funds by the Marketing Department.

This, then, is a classic procedure in the development of an EDP product or product line. It doesn't really work this way, however, since these tasks are not performed in a serial, step-by-step fashion which is obviously inefficient and time consuming. Fig. 6 is really more of a description of responsibility and prerogative. To define the product development cycle in a more appropriate manner, better

Fig. 6—A classical illustration of the genesis of a new EDP product—emphasizing responsibility and prerogative.



real-time expression is needed to illustrate the concurrent rather than serial process which occurs in the real world.

Fig. 7 illustrates how a system is usually developed and specified. The time scale shown is general and is applicable to a period of 10 days, 10 weeks, 10 months, or 10 years. The events associated with the specification and initiation of a product cycle are shown to occur both serially and concurrently. This point is stressed to illustrate that Systems Engineering tasks, because of their inherent complexity. are of necessity group functions and in reality require people with the command of different technical disciplines working together. The PERT-type representation of Fig. 7 illustrates the manner in which multiple elements of the organization receive information regarding a customer need, and how all elements of the organization may be caused to function concurrently.

In the development of a large system, little inter-organizational activity occurs serially. Each organizational component has its basic responsibility. The PERT-type representation recognizes that each organizational element performs most efficiently *only* if it participates and has more information from an earlier date than a serial process allows. To this end, Systems Engineering provides a pivotal point for the transmission of data and specification between the Engineering Department and its interfacing functions within EDP.

SUMMARY

The traditional concept of the engineer as a person who deals primarily with the analysis of physical systems is rapidly changing so that at the present time the systems engineer is delving into areas that heretofore would have been considered outside the normal sphere of engineering activity.[4] He is concerned with the application of technical specialties that were once considered beyond the purview of a single individual.

The systems engineer is *not* a know-all. see-all, hear-all omnipotent, but rather a legitimate expert in the methodology and techniques applicable to the study of complex systems.[4] In concept, the systems engineer's methods are straightforward and direct. The application of these methods requires that he listen to symptoms of need, define the problem that exists from these symptoms, and establish suitable objectives. He analyzes the problem, the objectives, and potential solutions. Data are gathered for these solutions and multiple solutions are optimized for evaluation and comparison with the initial objectives and problem. He then either decides or provides the basis for a decision considering local or practical criteria—such as time, schedule, investment, manning, etc. Lastly, he *communicates* the results for decision and/or action.

Systems engineering then is an *attitude*—a positive solution-prone state of mental readiness to impose a given set of disciplines upon the unknown. The disciplines are the sciences, our experience, our knowledge of people and of the thinking process, what we know of organization. economics, and management. We must know about the real and the abstract—the possible and the practical. We also have the responsibility for self-discipline and organization. Finding the right people, keeping them stimulated by challenge and reward, maintaining objectivity, and combatting stagnation and reaction are requirements with which systems engineering management must concern itself at all times. A constant flow of challenges and a fresh spring of alert people is required to properly apply the systems methodology and to achieve the type of success that is necessary to meet our objectives.

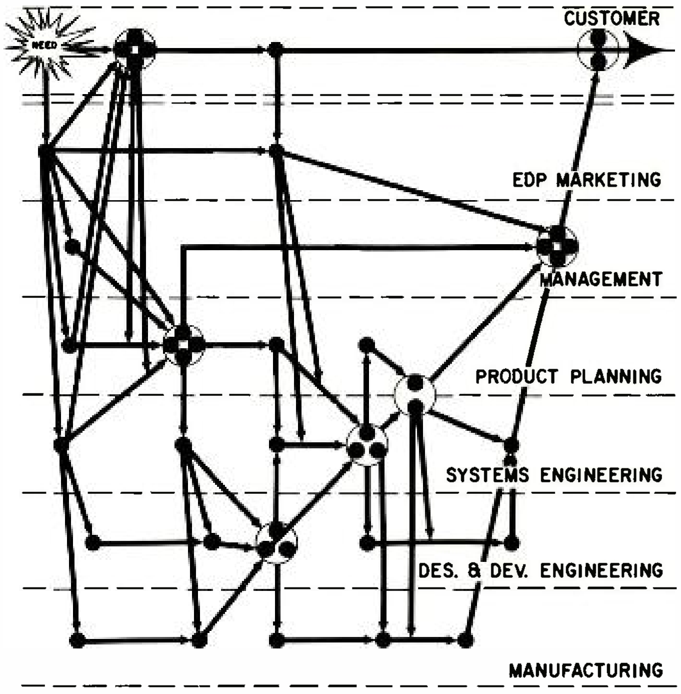


Fig. 7—A real-time illustration of the evolution of a new product. The time scale could be 10 days or 10 years. In contrast to the "ideal" progression suggested by Fig. 6, events are seen to occur both serially and concurrently, in actual situations.

It may be seen that complexity in itself is *not* a characteristic of the systems engineer's approach. Complexity *is*, however, a characteristic of the problems with which he is concerned—a characteristic whose reduction to more readily understandable, solvable. and manageable components requires all of the technical and human resources at his disposal. Those who are engaged in systems engineering activities know that the acquisition and maintenance of such competence is a never-ending challenge in itself.

ACKNOWLEDGEMENT

The many contributions of C. R. Coughlan to the study upon which this article is based are gratefully acknowledged.

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FOUR RCA MEN ELECTED IEEE FELLOWS

The four RCA men appearing on this page have been honored for their professional achievements by being elected Fellows of the Institute of Electrical and Electronics Engineers, an honor bestowed each year for outstanding contributions to the field of electronics.

LOREN R. KIRKWOOD

. . . for contributions to color television receiver design.

LOREN R. KIRKWOOD received his BSEE from Kansas State University. He joined RCA in 1930, and through 1941 worked on design and development of home radio receivers, a period during which he made important contributions to AM-FM receivers, early high-fidelity work, and early superheterodyne radios, among many others. Between 1941 and 1946, he engaged in engineering of communications equipment for the military. From 1946 to 1950, he worked again on home instruments, developing one of the first AC-DC, AM-FM home radios, and contributing to development of the 45-rpm record player. Between 1950 and 1959, he directed receiver activities and development for all RCA color television demonstrations and field tests, and contributed importantly to work on the performance and simplification of the color-TV receiver system. In 1951, he received the RCA "Award of Merit" for his work in color TV. Between 1959 and 1963, he was Manager of TV Product Engineering for the RCA Victor Home Instruments Division, now in Indianapolis, Indiana, responsible for all TV receiver engineering design. In 1963, he was named Chief Engineer of that Division, responsible for the engineering of the entire RCA home instrument product line.

ERIC McPHAIL LEYTON

. . . for contributions to the development of television transmitters and video tape systems.

ERIC McPHAIL LEYTON studied, from 1934 to 1938, at Faraday House College (part of London University), where he received the DFH 1938 (equivalent to EE). From 1938-1945 he worked at the Research Laboratories of the General Electric Company, Wembley, England. In 1945-1947, he worked for Rediffusion Ltd., Wandsworth, London, where he became Chief Engineer of the Industrial Division. From 1947-1953 he was with the Research Laboratories of Electrical & Musical Industries, Hayes, near London, England, in charge of development of television transmitters. During this period he was responsible for the Kirk O'Shotts and Wenvoe television transmitters of the British Broadcasting Corporation—the most powerful transmitters in the world. In 1953, he joined RCA Laboratories in Princeton, and until 1959 was a research engineer on color television, video tape recording, and on high-power radar transmitters. In 1959, he assumed his present position of Staff Engineer, reporting to Dr. George H. Brown, Vice President, RCA Research Engineering. He received the IEE "Premium Award" in 1951 and 1953 and RCA Laboratories "Achievement Awards" in 1957 and 1958.

WENDELL C. MORRISON

. . . for significant contributions to the fields of VHF, UHF, and color television.

WENDELL C. MORRISON received his BSEE and MSEE from the University of Iowa in 1940, and then joined RCA at Camden, N. J. Two years later, he became a research engineer at the RCA Laboratories, Princeton, N. J., where he was engaged in development work in such fields as UHF-TV transmitters, antenna pattern calculators, and color TV terminal and test equipment. During this period, became a Senior Member of the Technical Staff. In 1957, Mr. Morrison returned to Camden as Staff Engineer for the commercial product area and in 1959 became Manager of Engineering Plans and Services for the major RCA activity then called Industrial Electronic Products. Two years later, he transferred to DEP as Assistant to the Chief Defense Engineer. In October of 1963, he was appointed Chief Engineer, Broadcast and Communications Products Division, Camden, N. J., reporting to the Division Vice President and General Manager. He now directs the overall engineering activities for the Division and its product line, which includes radio and television broadcast equipment, microwave communications systems, scientific instruments, two-way mobile radio, Radiomarine equipment, and audiovisual products.

DR. J. TORKEL WALLMARK

. . . for contributions to the concepts of integrated electronic devices and field-effect transistors.

DR. J. TORKEL WALLMARK was one of the early contributors to integrated electronic circuits. He received the degree of Civilingenjor in Electrical Engineering in 1944, Teknologie Licentiat in 1947, and Teknologie Doktor in 1953, all from the Royal Institute of Technology, Stockholm, Sweden. From 1943 to 1953 he was, at intervals, a research assistant at the R. I. T. working on various electron tube and gas discharge problems, particularly the trochotron, a decade counting tube using magnetron principles. Inbetween, he spent a year as a vacuum and gas tube designer with A. B, Standard Radiofabrik and on other assignments concerning semiconductor devices and research administration. In 1947-1948, he spent a year with RCA Laboratories as a trainee under the auspices of the American Scandinavian Foundation, taking part in the development of broad band amplifier tubes using secondary emission multipliers. In 1953, he returned to RCA Laboratories and has been active in magnetrons, color television tubes, photocells, semiconductor devices, and integrated circuits. He is a co-author of "Microelectronics" and is now head of Solid State Device Technology. In 1957 and 1962 he was the recipient of RCA Laboratories "Achievement Awards."

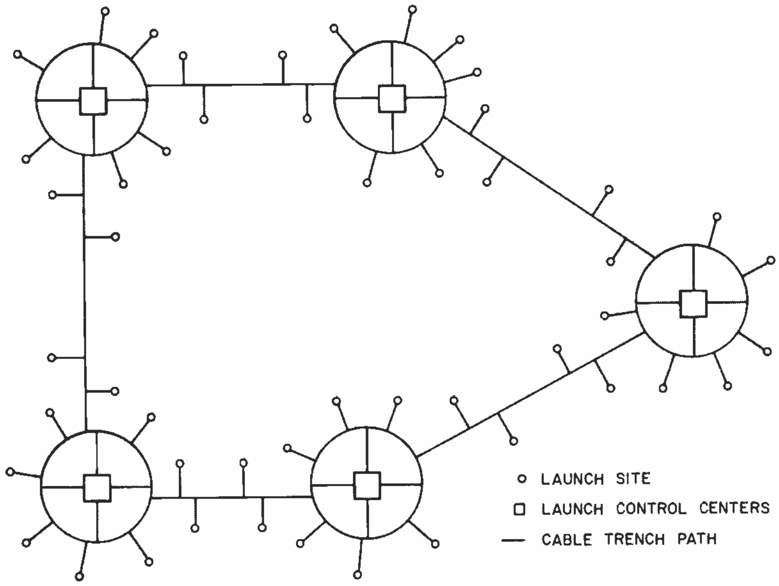

Fig. 1—MINUTEMAN squadron cable trench pattern.

SYSTEMS CONSIDERATIONS FOR ICBM COMMAND AND CONTROL

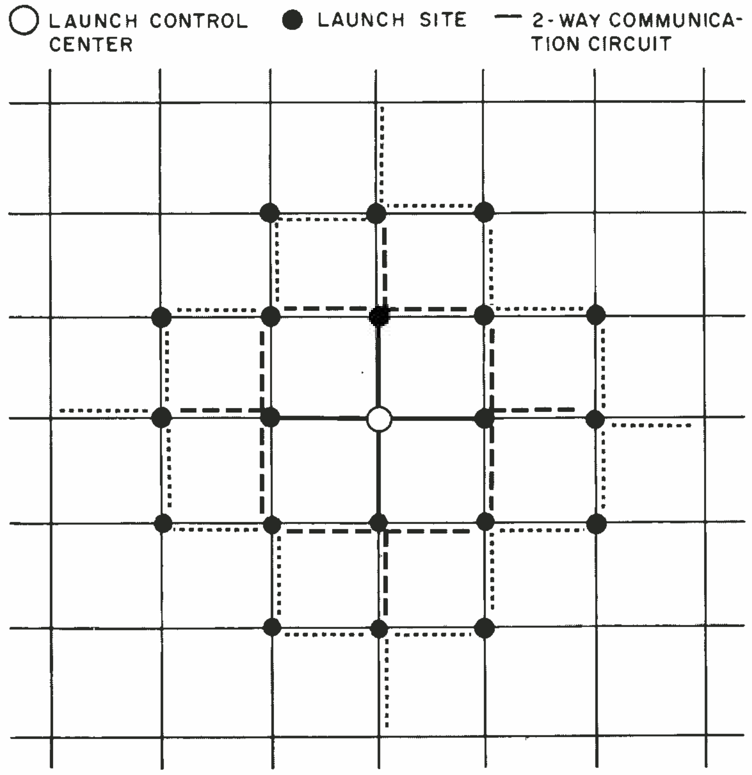

Fig. 2—Command message propagation diagram.

In modern ICBM weapon systems, the launching sites may be either unmanned and located remotely from their control centers, or locally manned and controlled. But in all cases, an order to launch must be authorized from an executive level in the government or military. A command and control system tying together the missile site and the appropriate executive authority is, therefore, a key part of modern ICBM systems. Because of the large destructive power (megatons) and the range (in excess of 5,000 miles) of a single ICBM, the proper performance of command and control system is abnormally critical.

C. G. ARNOLD, Director
Systems Engineering
MINUTEMAN *Program*
Management Office
Communications Systems Division
DEP, New York, N.Y.

C. G. ARNOLD received a BSEE degree from Pennsylvania State University in 1942. He has completed graduate work in Electrical Engineering at Stevens Institute of Technology. After graduation, Mr. Arnold joined Bell Telephone Laboratories, Inc. Here he was concerned with equipment design and development of aircraft radar equipment. After World War II he was concerned with the design of the coaxial carrier systems and radio relay systems for common carrier application. Mr. Arnold joined the Surface Communications Division Systems Laboratory in 1956. Initially, he was concerned with the development of the AN/GRC-50 Radio Relay Equipment. During 1958 he was project manager of the MM-600 System development program, a high-capacity microwave, radio relay system. He is currently Director, Systems Engineering (PMO) on the Minuteman Communication System project whose responsibilities include: 1) Definition and interpretation of customer criteria; 2) Performance of analytical studies on vulnerability, operations, maintenance and transmitter performance, 3) Definition of Communications Systems concept; 4) Generation of equipment requirements; 5) Design of new techniques; 6) Conduction of system tests; 7) Support of equipment design, production, and field test programs. He has also served as a consultant on several other communication projects in RCA.

IN THE implementation of an ICBM command and control system (CCS), the key system factors that must be considered are:

1) *Availability*—the probability that a function will be performed in accordance with specifications at any point in time.
2) *Functional Capability*—assuming no equipment malfunction, the ability of equipment to satisfy operational requirements.
3) *Security*—the capability of the implementation to adequately insure that launch occurs only when properly authorized.
4) *Cost Effectiveness*—the optimum balance of cost and performance.

The CCS is the nervous system of the weapons system. It provides the means by which the *launch* command is conveyed to the weapon; it provides status information as required from the weapon to operational and maintenance centers; it provides necessary data processing for weapons systems operation; and it provides maintenance and administrative communications to maintain the system in operational readiness. It is, therefore, as essential to weapons systems as the weapon itself (particularly, in those systems where launch sites are unmanned). In general, the weapon and its characteristics are defined first, and the communication system required for its operation must then be tailored to properly support a specific weapon-system use. The characteristics of the weapons system having greatest impact on the CCS are its *deployment* (land, water, fixed or mobile), its *operational mission* (i.e., retaliatory or attack), manned or unmanned *launch sites*, and the *reaction-time* characteristics of the missile itself.

The systems engineering of a CCS is a complex problem. A multitude of interrelated factors must be kept under constant attention as decisions are made. The problem is further complicated by the fact that operational requirements are often crystalized concurrently with the equipment design program, and changes in direction may be encountered throughout the research, design, test and evaluation period. International politics have major impact on the CCS for an ICBM. This factor is not a stable one. It is therefore necessary to anticipate possible future requirements so that retrofits may be integrated into an already operational system.

WEAPONS SYSTEM CHARACTERISTICS PERTINENT TO CCS

Deployment

Currently, ICBM's are located on land (fixed and mobile) and in submarines. It is recognized that the POLARIS missile is not catalogued as an ICBM; however, for the purpose of this discussion of CCS, no distinction is made. Considerations are now being given for future systems to employ fixed underwater and surface vessel locations. The missile sites on land are both hardened and soft, fixed and mobile, manned and unmanned. The aircraft and submarine installations are, of course, manned and their hardness is obviously no greater than that of their carrier. The carrier may be located almost any place on the globe when communications to it may be required.

The scope of the communications problems is clearly tremendous in satisfying command and control requirements. To limit the scope of this paper, only hardened, ground-based systems will be discussed in any detail. The general aspects of all systems are the same; however, the implementations differ markedly with each weapons system.

Retaliation

By national policy, ICBM's armed with nuclear warheads are to be used only as a deterrent and retaliatory weapon. To satisfy this requirement, some weapons systems have been designed to withstand attack by hardening of fixed installations. Since a complete system is no better than its weakest link, the CCS must be at least as invulnerable as the weapon system itself. In other words, the communciation system must be designed to withstand any threat that might be postulated for the missile sites themselves. It must therefore be hardened, adequately redundant, or an appropriate combination of both. In addition, of course, it must resist typical threats to communications, such as covert activity, jamming, etc. Another aspect of the deterrent concept is that of reaction time of weapons system. Minutes and even seconds are important to some war strategies. The design of the CCS is affected by this factor. For example, a high transmission rate may well eliminate several communication techniques from consideration.

Unmanned Missile Sites

For economical reasons, missile systems have been designed and are in operation which employ unmanned and remote missile launching sites. All command and control is exercised via communications systems from remote control centers which may be 100 miles away. Since this system is completely automatic, absolute protection against accidental or unauthorized activities, which could result in launch, must be provided.

Weapons Systems Costs

All ICBM systems are expensive. The monies which can be allocated to the communication system are directly related to the cost and effectiveness of the weapon itself. The need for communications must unequivocally be satisfied; however, well-considered judgments must be made regarding the levels of performance that are to be provided. A given level of effectiveness of a weapon system may be attained at a fixed cost, either with a limited number of missiles with high availability or larger numbers with a lower capability of command and control.

CCS CONSIDERATIONS

Availability

Availability implies more than is normally attached to the word *reliability*. In the weapon-system field, it encompasses survivability as well. As stated earlier, it is the probability that a given function will be performed as specified at any point in time. Availability, A, is usually expressed mathematically by:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MDT}}$$

Where: MTBF = mean time between failure, and MDT = mean down time after failure occurs before repair is completed.

In the case of MINUTEMAN, for example, the missile sites are hardened and dispersed to withstand overt and covert attacks ranging from enemy ICBM's to covert agent activities. The launch sites are unmanned and are operated completely automatically from launch control centers. The primary transmission medium employed between the launch sites and control centers is currently buried cable. The layout of the cable plant has been carefully engineered[1] to withstand the same attack that might be directed at the sites themselves as well as such threats as jamming, which might be directed only at the communications system itself. The classical cable trench pattern for a MINUTEMAN squadron (50 launch sites and 5 control centers) is shown in Fig. 1. War games and Monte Carlo techniques, solved on computers, have been employed to evaluate this and many other possible configurations. Only the cable trenches are shown in Fig. 1. It can be noted that some cable trenches are redundant. Also, both launch and control sites are located off the main cable trench. This arrangement insures that if there is damage to one site, transmission between other sites will not be disrupted. In addition to the trench redundancy, though not illustrated in this figure, there are many redundant command pairs running through the cable sheath. Connected to each launch site there are as many as 6 two-way circuits, all going to different sites in the network. At the control centers, there are 10 two-way circuits connected to 10 different launch sites.

Command messages are transmitted throughout the squadron network in a unique manner which makes maximum use of the available connectivity. The routing concept for the command message can be best illustrated by the use of the equilateral matrix shown in Fig. 2. Assume that at each line intersection there is a launch site and that the solid lines represent a two-way communication channel. The solid circle represents a control center where *launch* commands are initiated. Command information is transmitted in digital, secret, encoded messages of adequate length to prevent inadvertent or unauthorized launch. When a message is initiated, it is transmitted on all transmitting lines (10 in an actual network, 4 in the illustrative Fig. 2) emanating from the site. These are shown in heavy solid lines. This message is received at each of the adjacent sites or modes, checked for validity and retransmitted again to all adjacent sites except those from which a message has just been received. Such a process is repeated—on lines designated—ad infinitum until a message once initiated has permeated the network over all communication links that are undamaged. There exists, therefore, many redundant paths by means of which a message may get from one site to another. In fact, communications will always be provided between any two sites, if there exists an undamaged path, however, circuitous it may be. The above discussion partially illustrates one aspect of the impact of the survivability requirement on the communication system for Minuteman.

This discussion has centered around only a small portion of the total CCS for MINUTEMAN. The communication system discussed above is completely contained within the weapon system itself. Extensive communications are also required to provide the link from the executive command hierarchy to launch control centers. This function is exceedingly difficult to implement with adequate survivability characteristics. It must provide access points at all key military and government locations throughout the United States. Its area of coverage is as vast and almost as complex as the existing commercial communications systems. In fact, commercial systems are used extensively to fulfill this military communications need. Additional military links are then provided as a backup to insure survivability in a post-attack period.

The MINUTEMAN weapon system is only one of several ballistic missile systems. The POLARIS weapon system (submarine) is more of a problem to the communicator in some respects. It is mobile, global, and underwater. The primary communication problem here is not one of survivability, but one of range and the capability of transmitting through seawater. This subject will be discussed in some detail later.

More important than the survivability characteristics of a communication function is its reliability. Reliability can be divided into two areas: 1) equipment and 2) transmission.

The reliability of equipment is generally measured in terms of time between failures. It can apply to a single component or a complete system. More than normal attention has been devoted to the reliability of equipment in some of the weapon systems—in particular, those systems which employ unmanned missile sites. Equipment must operate in these locations over extended periods without maintenance. Ultrareliable components are used. Further, various techniques are employed to provide *alarm* indications when any failure occurs which would render the site inoperative. This alarm information is transmitted automatically from the unattended location to control centers where appropriate maintenance action can be initiated. The operational capability of the equipment at the unmanned site is determined by the provision of self-checking routines and the use of test messages which exercise the equipment and command status information to be returned to the manned control centers.[2]

The effect of poor transmission reliability on operational performance is similar to equipment malfunction. It results in *no-go* conditions. The use factor for the command link for an ICBM is very low. As we all know, a CCS has never yet been used to perform its prime function, that of initiating a launch. In fact, our ICBM systems will have accomplished their original, basic objective if they are *never* fired.

In determining the transmission reliability of a normal communication system, performance over a long-term period is assessed on a statistical basis. The same procedure is followed for evaluating some of the functions performed by the CCS; however, not the command function. If ever used for transmission of the command message, it will be in use for only a few seconds out of the life of the weapon system (which may be 10 years). However, in order that the operational use of the weapon system not be restricted in flexibility, good performance must be provided at any point in time on a demand basis. In systems where digital messages are used, bit error rates of the order of 1 in 10^4 are commonly required. It should be appreciated that this is not a long-term average, but a performance which must be available for any short interval of time, when launching of missiles is required.

All factors which have been mentioned above have impact on the total availability of the CCS and ultimately the availability of the weapon system. The availability requirement for the CCS is keyed to the performance of other portions of the Weapons System. Since the CCS generally occupies the role of a support function, its performance is normally established at a level an order of magnitude better than the performance of the total weapon system.

Functional Capability

In concept, the prime role of the CCS is a simple one. *It provides a means for operating remotely a single-pole switch.* In satisfying all the needs of an ICBM system, this command function is not a simple one and many additional functions must be performed. The basic functions performed are: 1) *command* communications, 2) *status* communications, and 3) *maintenance* communications.

The command function provides the means for conveying the launch command from control centers to the missile sites. The extent of this communication system has already been illustrated. It may extend from key points in the United States to any point on the globe. It is usually made up of several communication links in series which may employ a variety of communication techniques (cable, radio, sonar, etc.). To satisfy survivability requirements, parallel and redundant systems are also provided. Both voice and digital systems are used. Due to the sensitivity of the information transmitted, the message must be encoded and secure.

Because of the large missile force which exists and the variety of strategies which might be employed in a given situation, the capability of transmitting and decoding a large number of commands must be provided. Even within a single weapons system, MINUTEMAN for example, as many as hundreds of different launch commands may be required. In addition to launch commands, test and calibrate orders are also often required to keep the missile in operational readiness. Such commands are circulated within the confines of a weapons system and are a matter of concern to personnel associated with that weapons system only.

A status system provides information as to the operational capability of a weapons system. Such information is of prime importance to those responsible for planning war strategy and of course for maintenance purposes. In a system where launching sites are manned, the operational status of the equipment and missiles is observed locally and transmitted rearward, generally by telephone. In systems where the sites are unmanned the status system between these sites and the control centers is relatively sophisticated. Means are provided for automatically reporting trouble conditions whenever they occur over digital links. Audible and visual indications are provided. The *go, no-go* status is sent rearward and local maintenance activities are initiated to correct trouble conditions. In general, the status information is sufficiently detailed to permit trouble isolation remotely. Maintenance personnel can then be dispatched with spare equipment for that which has failed and the site can be repaired in one trip. Major reductions in maintenance cost are thereby realized by the provision of a good status system.

The maintenance communications systems are commonly voice systems which provide intra- and inter-site links. They can usually be provided at minimum cost by the dual use of the same transmission medium provided for command and status.

Security

The problem of inadvertent or unauthorized launch of an ICBM must receive constant attention in the development of a CCS. Because of the sensitivity of this subject and the classification applied to pertinent information, this discussion will be limited. It can be stated that this problem can be divided into the following four categories:

1) Protection against equipment failure or malfunction;
2) Protection against inadvertent action initiated either by natural or manmade causes;
3) Protection against defecting authorized personnel; and
4) Protection against the activities of unauthorized personnel such as covert agents

The first item is the most tractable to deal with. Studies can be made of final equipment designs to determine the impact of single and multicomponent failures. Computers may also be gainfully employed, particularly to assess the performance of digital systems. The corrective means used to strengthen the weak spots in a system are 1) long and redundant code formats; 2) special equipment designs (e.g. interlocks, use of ultrareliable components, redundancy, electromechanical logic as well as solid state); and 3) completely separate overlay systems which parallel the normal command system and which must be operated to enable the command system to complete its mission.

The second item is similar to the first in that it can also be classified as unintentional. High levels of noise in the command transmission system typically represent the problems encountered here. Poor signal-to-noise performance in a system causes errors in signal transmission and may either cause one message to be translated into another or cause a valid message to be developed from a random source. Another class of problems included in this item is represented by unintentional actions of maintenance personnel — dropping of screwdrivers, failure to follow specified procedures in the handling of secure coding equipment, etc. In general these problems are solved by steps described above for equipment failures.

It is extremely difficult to protect against defecting and knowledgeable individuals. There are basically only two ways to control a defector: 1) to establish operational procedures and designs that require joint action by more than one person to effect launch and 2) to provide facilities which monitor an individual's actions and permit corrective countermand action to be taken prior to any catastrophic development.

The problem of sabotage by covert activities which will prevent a system from performing its mission is not new. It is always a military problem. The situation which is new and which must receive attention in ICBM systems is the possibility of a covert agent willfully launching the missile. The methods which are employed to protect against such an occurrence are those already mentioned. The optimum solution to the problem of unauthorized and inadvertent launch is a compromise between procedures and equipment and systems design.

Cost Effectiveness

The ultimate objective of an ICBM weapon system is to destroy enemy targets. From a military point of view, therefore, the justification for implementing any function within a weapons system should be based on a final "yardstick" of least dollars per enemy target destroyed. This measure of value neglects the political, security and safety aspects which must be measured against other criteria. Quite obviously, if security and safety provisions are to be emphasized, additional costs are involved and very likely operational flexibility and reaction time will be degraded.

The measures of effectiveness for a CCS must be evolved from those established for the overall weapons system. Measures of effectiveness must be established for all the major requirements of the CCS and in addition the relationships between these yardsticks. It is quite obvious that the optimizing problem is very complex, when many factors are involved. Nevertheless, it is the role of systems engineering to develop the optimum configuration that will maximize the aggregate of all relevant values at minimum cost.

CONCLUSION

ICBM systems have been in development and operation for several years. Each new system contains improvements and more sophistication. Until recently, primary emphasis has been placed on the nuclear warhead and its vehicle. With increased automaticity in missile launch and operational capabilities and with increased dispersal of launch sites, the importance of the role played by the command-and-control system in the overall weapons system has increased. For modern ICBM's the command-and-control system is as significant in influencing overall effectiveness as any other key portion of the weapons system.

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DESIGN OF A DATA COMMUNICATIONS COMPUTER SYSTEM

W. A. LEVY and A. E. DIMOND

*Electronic Data Processing**

Camden, N.J.

A data communications computer system must respond to whatever load the outside world has to offer and, therefore, has to handle difficult peak period conditions with random inputs. Some data-communications systems solve this problem through use of equipment which is auxiliary to the central processor.[1] The virtue of this arrangement is that the computer program is substantially relieved of the burden of processing random inputs. The system described in this paper treats the problem differently. There is a simple and direct link between 100 full-duplex telegraph lines and the central processor memory. There is no auxiliary buffering, so the program is designed to respond quickly to substantially unpredictable load impacts. To achieve the desired flexibility, the program is equipped with a control system which is adaptive to short-term variations in the traffic load. The system is thus characterized by its emphasis on software coupled with a relatively simple equipment configuration for a large-scale data communications application.

THE integration of a computer with a communications system presents an interesting combination of problems to the system designer. Along with the normal difficulties of solving a major problem by use of a computer, there is an additional level of complexity because the system must operate in real time. The computer does not receive work in convenient batches but must respond to whatever the outside world has to offer. The system must be able to escape from error situations or momentary overloads without losing data or halting. Generally speaking, the system must be capable of responding quickly to the widest possible range of circumstances—wide both in kind and in frequency of occurrence.

RCA Electronic Data Processing has recently completed the engineering and manufacture of a computer-communications system of this sort. This particular system was developed to meet RCA communication traffic specifications and was purchased and installed by RCA Communications, Inc., in New York City. It was designed to switch telegraph messages through the RCA Communications Central Telegraph Office, and is currently being cutover to live traffic. This paper will describe the design techniques utilized in developing this system. Specific information about the application is offered only insofar as is thought necessary to illustrate technique. (An earlier paper[2] described this system from the applications viewpoint.)

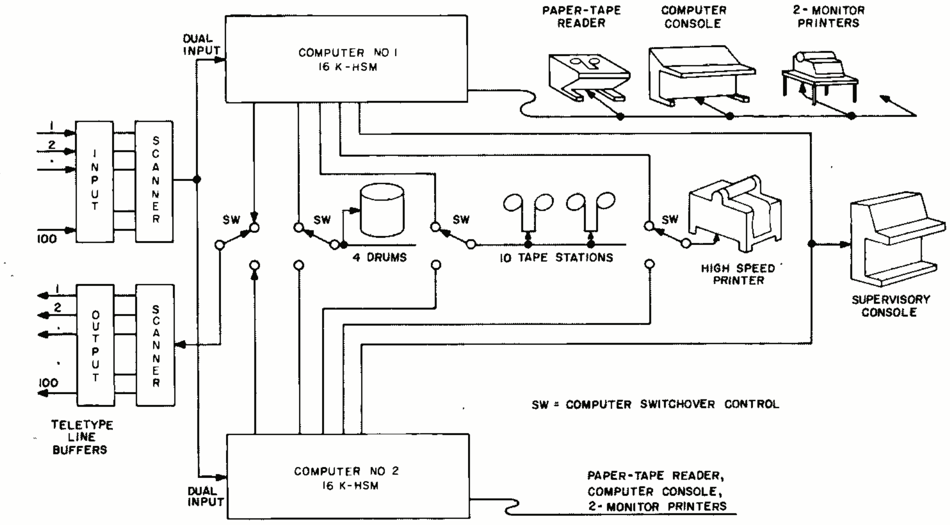

Fig. 1—System block diagram. Sw = computer switchover control.

BACKGROUND OF THE APPLICATION[2]

RCA Communications, Inc., operates a commercial telegraphic service which functions principally as a gateway for message traffic between the United States and the other nations of the world. An important portion of the RCA Communications operation is the public message service wherein RCA Communications accepts a written message from a subscriber and transmits it to an associated common carrier overseas who forwards the message to its final destination. (The reverse path is, of course, equally likely in this service. This type of service is quite distinct from the RCA Communications TELEX service, wherein RCA Communications furnishes two subscribers a direct international circuit connection and the customer is responsible for the preparation and transmission of the particular messages which may be exchanged over the connection.)

In the United States, one may enter a message for overseas transmission through RCA's public message service at branch offices in New York and other major cities, by a telephone call, via private tie-lines to the RCA Office, or by filing at an office of another common carrier who will use the RCA facility to get the message overseas. RCA's linkages with the various foreign telegraph administrations consist of radio-telegraph or cable circuits which originate in the RCA Plant in New York City and usually terminate (after connection via leased line and radio transmitter or cable) in a major foreign city where there will be a connection into the foreign telegraph system.

All public message traffic passes through RCA's Central Telegraph Office (CTO) where three basic functions are performed:

1) The messages are switched from the U.S. to the overseas circuits (or vice versa);
2) The messages are logged (and the logs checked) to guard against losses;
3) Accounting information is collected about each message to implement customer billing.

In addition to these basic functions, the CTO performs a variety of services for customers such as retrieving copies of messages, exchanging service messages with overseas administrations to verify messages which appear to contain errors, and maintaining a technical and operational liaison with the overseas administrations and telegraph operating agencies.

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* The authors participated in this work and wrote the initial draft of this paper while with EDP; since mid-1963, they have been with the DEP Communications Systems Division.

ALFRED E. DIMOND graduated from Indiana University 1948 with a BS in Business Administration. His programming experience dates back to 1954 and he has programmed for equipment with cathode ray tube memory, acoustical delay line memory, drum memory and core memory. He joined RCA-EDP in 1961. His assignments have been AUTODIN and RCA Communications, in the area of systems analysis and integration of program functions. On the RCA Communications project he was acting leader of programming and was responsible for the final systems analysis, programming and checkout of the program system. In mid-1963 he transferred to the DEP Communications Systems Division.

WALTER A. LEVY received his BSEE in 1952 and his MSEE in 1953 from New York University. He joined RCA-EDP in 1959 and was Project Engineer for evaluation of the AUTODIN System. He was responsible for system engineering of the RCA Communications, Inc. Switching Center. He has conducted studies in real-time computer system design and is active in the field of data-communications. In mid-1963 he transferred to the DEP Communications Systems Division, and has recently been engaged in the AADS-70 Study program. He represents RCA on Task Group 5 of the ASA X3.3 Sub-Committee on Data Communications. He is a member of Eta Kappa Nu and the ACM.

Co-authors W. Levy (left) and A. E. DiMond

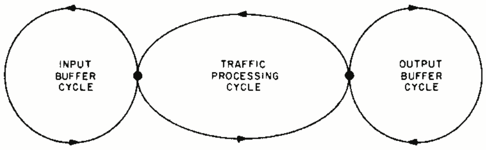


Fig. 2—Interlocked program cycle.
Timing of cycles:

Cycle	Frequency, msec	Elapsed Time, msec	Basis for Initiation
Input Buffer Cycle	465	30	Machine Interrupt
Output Buffer Cycle	232	8	Machine Interrupt
Traffic Processing Cycle	variable	variable	Completion of last traffic processing cycle.

Prior to the introduction of the system being described in this article, the RCA Communications CTO had been essentially a manual operation. Procedures had been developed over the years in accordance with the day-to-day needs of the business.

The actual mechanism for switching messages from one circuit to another was a highly refined manual "torn-tape" center. Messages would enter this center and be punched out on paper tape at receiving positions, with the text of the message typed along the edge of the tape. Operators would read the front portion of each message as it entered the system, tear off the tape when the message was finished, and carry the tape to the appropriate transmitting position. At the transmitting position the operator would either place the message tape directly into the tape reader, or if the circuit was busy, insert the message tape into a holding clip, to await its turn for transmission. While certain operators serviced the incoming traffic as described above, others would monitor the transmitting positions, moving new messages from the holding clips to the paper tape reader in accordance with the age and precedence of the messages in the backlog.

Messages entering the system were identified by a prefix and sequence number corresponding to the inbound circuit. Messages leaving the system were given a prefix and sequence number corresponding to the outbound circuit. Checklists were maintained by which the input and output numbers could be correlated, and operators performed this task periodically as a means of insuring against the loss of a message on its way through the center.

Accounting information was collected from page printed copies of the messages by clerks and transcribed to punched cards. Accounting and billing information was developed by conventional tabulating-machine methods and, more recently, by processing on an RCA 501 system.

The computer system described here is replacing this manually operated torn-tape switching center. This transition is quite extreme, bypassing completely several intermediate levels of automation in the form of semi-automatic or fully automatic, relay-transistor, logic-actuated, teleprinter switching systems.

The stored program computer approach was chosen since any of these intermediate measures would not have been able to provide the type of performance which RCA Communications required. Much more is involved than the simple switching of messages from one teleprinter circuit to another. The message formats are quite complex, growing out of years of international experience, and do not permit routing code detection by simple relay logic. The computer can provide a variety of data-processing services such as message retrieval, extraction of accounting information, multiple-precedence level message processing and editing of message content—all of which are essential to the RCA Communications operation and beyond the capability of any less powerful type of system. The computer system also provides a substantial amount of reserve capacity for future expansion of traffic and services.

SYSTEM FUNCTIONAL CAPABILITY

The computer system provides a variety of functions. Chief of these is, of course, the basic function of switching messages from one circuit to another. The actual rules which govern message switching are sufficiently complex to be classified as a set of system functions, and there are in addition many other functions which the system performs to support the basic flow of traffic. The following enumeration gives an indication of the system's functional capability.[2,3]

1) The system receives messages simultaneously and independently on 100

TABLE I—Characteristics of the RCA Communications Data Processor

The RCA CDP is a multi-programmable real-time computer developed for AUTO-DIN. It is a modular system consisting of a basic processor, 1 to 4 banks of memory and 1 to 16 transfer channels through which a full range of standard EDP peripheral devices and communications channels may be controlled.

Memory Parameters:

Each bank of high-speed memory consists of 8,196 words, each of 56 bits with a read-write cycle of 1.5 μsec.

A memory word consists of 2 half-words, each containing 24 data bits, 3 tag bits, 1 parity bit.

The memory is addressable by word, half-word, 3, 4, 6, 8 bit character.

Instructions:

Instructions are variable in length and may have 0, 1, 2, or 3 addresses.

There are 97 standard instructions providing word, half-word, and character operations, binary and decimal arithmetic.

All instructions are sub-routines of Elementary Operations (EO's). New instructions may be developed for any particular application without involving hardware changes.

Address Control:

Multi-level indirect addressing plus incrementing or non-incrementing address modification is individually applicable to any or all addresses of each instruction. Addresses may be assumed from previous instructions.

Interrupt System and Real-Time Features:

Simultaneous operation of several transfer channels. Automatic back-logging of instructions for busy peripheral devices.

Termination of peripheral device instruction causes program interrupt at which time program change may be made.

Program interrupts may be caused by errors, external signals, millisecond clock, or program operations.

Two levels of interrupt: 1) Servicing Peripheral Devices: by short service routines which interlace but do not disrupt main program. 2) Program interrupts and switch-over which require exchange of contents of all machine registers.

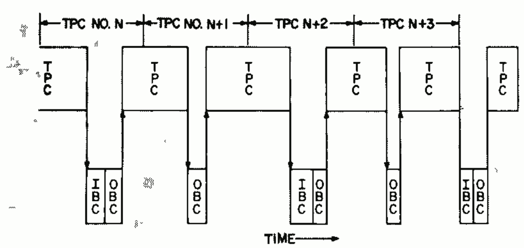


Fig. 3—Interlacing of program cycles. TPC = traffic processing cycle, IBC = input buffer cycle, OBC = output buffer cycle.

telegraph channels, stores them, and then releases them simultaneously and independently on 100 telegraph channels. Messages are received whenever offered, and delivered without delay, whenever the output channels will accept them.

2) Traffic is routed to selected output channels on the basis of information whose exact position within the message is quite variable. The system recognizes a number of different formats, some of which have several items which might be the source of routing information. The routing information, once extracted from the message, must be compared against an index with over 10,000 entries in order to select the proper output channel. Auxiliary routing information may be obtained from this index and inserted in the message.
3) Messages are separated into three priority classes and delivered to each output channel first-in-first-out by priority.
4) Messages are protected against loss in the center and between the RCA Communications Center and other telegraph systems by sequence number checks. The system will alert a supervisor if a message sequence number check should fail. Messages are also recorded on magnetic tape for protection and retrieval.
5) Considerable supervisory control is permitted hy the system without interruption to traffic. Inquiries will be answered concerning messages which may be stored in the system, or which have been transmitted. Messages may be retrieved almost immediately if they are still in active storage, or with little difficulty if they are available only on magnetic tape. Backlogs can be monitored, the distribution of channels can be changed in accordance with traffic requirements, and channels can be opened and closed—all without disturbing normal traffic through the system.
6) Accounting information is automatically extracted from each message and transcribed into a form suitable for billing operations performed on the RCA 501 facility.

EQUIPMENT CONFIGURATION

The heart of the system is a large-scale general purpose computer, the RCA Communications Data Processor (CDP). This machine and some of its peripheral equipment was developed for the Auto-Din program,[6] recently completed by RCA. Table I contains a detailed list of the machine's principal characteristics.

Fig. 1 is a block diagram of the system. Information flows between the computer and the RCA Communications Plant serial-by-bit on 100 duplex telegraph lines. These lines terminate at a relay rack which is connected to the computer through 200 serial/parallel telegraph line buffers* (100 for each direction). Data is exchanged directly between the computer's main high-speed memory and the telegraph line buffers under the control of an electronic scanner. The data path between the computer's memory and the buffers provides code conversion between the 5-level baudot line code and a 6-level nonambiguous internal machine code, but otherwise lacks special features.

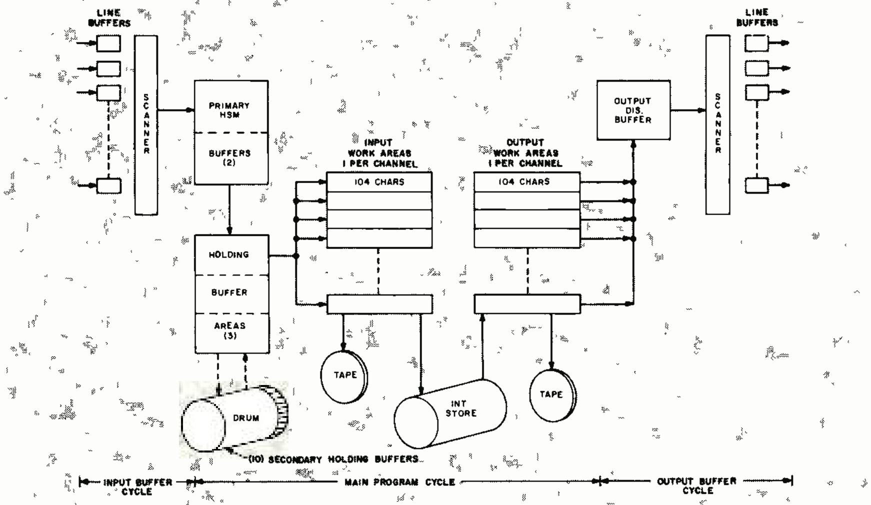
The computer system utilizes four large-capacity-fast-random access drums for storage of messages in transit and tables of routing information. Each of these drums has a capacity of 436,000 characters (6 bits each) and an average access time of 33 msec. Data on the drums is generally organized in 112-character blocks. This drum is furnished with a particularly powerful *scatter-read-gather-write* feature which permits reading or writing up to 120 randomly located 112-character blocks within the time of a single drum revolution, 67 msec. This feature yields an effective access time per block of $67 \div 120 = 0.56$ msec under maximum load. This very high random-access rate capability is essential for data communications applications unless the traffic load is extremely light. RCA 581 tape stations are used to accumulate copies of all messages passing through the system and to perform a variety of system support functions. The tape stations are used as a source of information for message retrieval as a customer service, for preparation of accounting information utilized by the RCA 501, and for recovery of traffic in case of a system failure.

Printing equipment is provided to furnish the system supervisory personnel with information relative to the status of the computer system and to answer inquiries about traffic. A 600-line/min printer and two 10 character/sec monitor printers handle this task. Typical information printed out includes tape-station swap instructions (automatically), traffic backlogs by channel (by request) or copies of messages stored in the system (by request).

General supervision of the system is accomplished by means of a special console known as the traffic-facilities-control position. This console contains automatic supervisory capability as well as indicators and a command insertion panel for use by the supervisory personnel. Through use of the command insertion panel and a paper tape reader. the status of the system can be modified without interfering with the flow of traffic.

In order to provide the system with 24-hour operation, the computer is duplexed. All of the peripheral devices are switchable between the two computers. The input telegraph line buffers feed both computers simultaneously while the output buffers are switchable between them. The supervisory console automatically monitors the computer which is processing the traffic by means of a fail-safe elapsed-time alarm. If this alarm should be set, the supervisory logic will cause the second computer to take over traffic processing with a few milliseconds, which is fast enough to prevent any loss of traffic.

Fig. 4—Traffic flow through the system.



(**The term* buffer *is very badly overworked in the jargon of computer systems. Generally, a buffer is any type of device, or portion thereof, which holds information for some specified period of time. In this article it will be used to refer to transistor registers, tape stations, drums, various portions of high speed memories—each time in combination with some hopefully less ambiguous adjective.*)

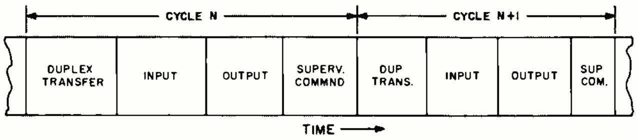


Fig. 5a—Normal sequence of traffic processing program.

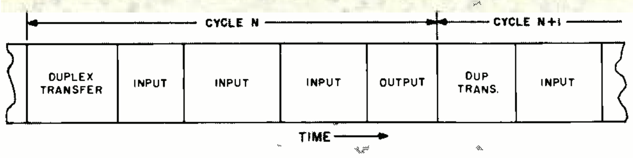


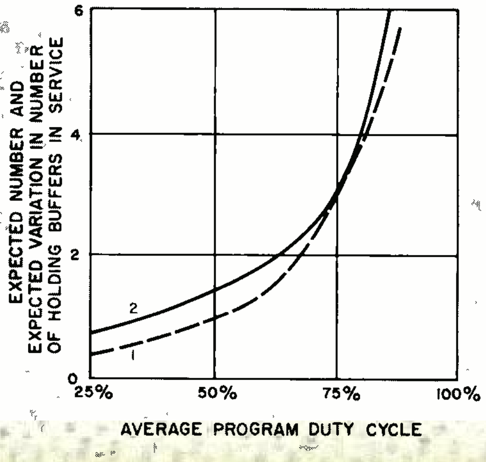
Fig. 5b—Short-cycle sequence of traffic processing program due to input data surge.

ORGANIZATION INTO PROCESSING CYCLES

The program is organized into several cycles (Fig. 2). The cycles operate independently of each other, yet are interdependent, the failure of any cycle to be completed causing a loss of traffic processing capability.

1) The input buffer cycle is the link between the input scanner and the high-speed memory, and thereby is the link between the incoming traffic and the traffic processing program. This cycle is fixed in length of execution and the cycle occurs at fixed intervals of time. The elapsed execution time is 30 msec and this will occur every 465 msec. This cycle is automatically entered as a result of a signal from the computer logic indicating that a primary high-speed-memory buffer has been filled with incoming data. The signal will lead to interruption of whatever program was in execution at the time, followed by a jump to the input buffer cycle.
2) The output buffer cycle is the link between the traffic processing cycle and the output scanner. It will supply outgoing data to the scanner, if the scanner is capable of receiving data, and if data is available for transmission. It is entered automatically as a result of a signal generated by the computer logic. This signal occurs at a rate set fast enough to assure that the output channels will be kept efficiently loaded. The output buffer cycle occurs every 232 msec and takes approximately 8 msec to execute.
3) The traffic processing cycle is the major production program element. It has several functions, namely:
   a) It is the link between the input buffer cycle and the output buffer cycle.
   b) It is the cycle which examines and processes the traffic, validates the messages, routes the messages, extracts information required for ledgering, etc.
   c) It is the link between the high-speed memory and the system peripheral devices. This cycle is variable in length of execution and is in action whenever no other cycle is active. The variability is based upon traffic load, peripheral device requirements, and external stimuli.

Fig. 6—Holding buffer requirements, estimated by use of poisson queue relations. (1) This is E(n), ½ the square root of the variance of the number of elements in the queue. It is reasonable to expect occasions when there will be E(n) + V(n) ½ elements in the queue.



It is essential for good system design that the traffic processing cycle be allowed to vary with load and this is achieved by isolating this cycle from actual momentary traffic demands through use of the input and output buffer cycles. The interlacing of the three program cycles is illustrated in Fig. 3.

TRAFFIC FLOW THROUGH THE SYSTEM

Fig. 4 illustrates traffic flow. The traffic enters the system with the scan of the telegraph line buffers. The scanner samples each of the telegraph line buffers and delivers the data, if present, to the primary buffers in the high-speed memory of the CDP. From there, the data is moved by the input buffer program into one of the holding buffers for use by the traffic processing program. This scan is repeated continuously and delivers a primary high-speed-memory buffer area to the input buffer program every 465 msec. It is well to point out that, although some circuits in the system may have channel coordination procedures, these procedures terminate prior to the line buffers and are not available to the traffic computer program. This places the program in a real-time environment with a requirement to accept data from the scanner every 465 msec. To accommodate this requirement and not impair the system, three holding buffers are provided to back up the primary buffer. Should the holding buffers be full, a portion of a drum is reserved as a secondary holding buffer area.

The traffic processing cycle is initiated by transferring data from the holding buffer area to a work area referred to as a *line slot.* One such area is assigned to each of the 100 input lines. The message is reconstructed in this area. As the message is being reconstructed in the line-slot area, validity checks are performed, routing is determined, and priority is determined. When the line slot area for a message is filled (up to 104 characters) or if the end of message is reached, the message segment is written to the intermediate storage drum. When the end of the message is reached, the message is linked into the proper output queue by priority. As each message segment is written onto the intermediate drum, the segment is also copied onto the recovery tape to provide a back-up copy of the message which will be recoverable in case of a system failure.

When the start-of-message segment is detected, a determination is made as to whether overflow conditions exist or are imminent. If the intermediate drum or output queue table is reaching saturation, the message segment, and all continuing segments, will be written to the overflow tape. Messages written to this tape are re-entered later when the traffic load is low.

After a message is linked to its proper output channel queue it is available for transmission. Transmission is accomplished on a first-in, first-out basis within priority class. As each data block from the intermediate drum is placed into a work area (called the *output line slot area*), the output buffer cycle control is set so that line-slot areas containing data will be examined for output by the output buffer cycle and data delivered to the output distribution buffer area, thence to the scanner and on to the telegraph line buffers. After each message segment is transmitted, a copy of the segment is written to the journal tape to provide a record of each transmission. At the end of each message, a ledger record is written to the number list tape to provide a correlated record of each message received and transmitted.

In addition to handling the normal flow of traffic through the system, the traffic processing cycle executes various commands called for by the supervisor. These commands may require the program to produce status reports or to change certain internal tables, thus modifying future program behavior. An important function in this category is the rerunning of recently transmitted messages (or the production of printed copies of messages stored in the system). To accommodate these demands a re-run or short-term queue is provided, messages eligible for retention in this queue being transferred to this control after completion of initial transmission. This queue is cyclic in its use, and a fixed number of messages are contained in the area at all times. When the queue space allocated to a message is pre-empted by another message, the drum store associated with the pre-empted message is released for re-use in the system.

ORGANIZATION OF THE TRAFFIC PROCESSING PROGRAM

In a preceding part of the paper, reference was made to the *variable cycle* of this program. A detailed description of

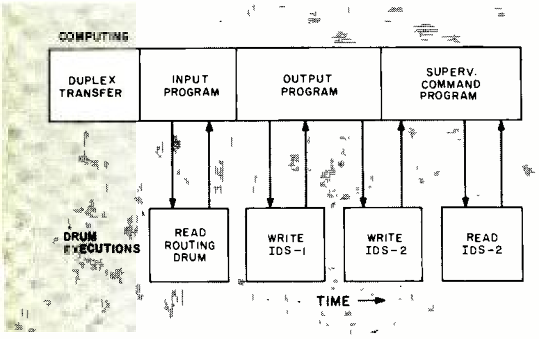


Fig. 7—Typical traffic processing cycle illustrating scheduling of drum execution events simultaneously with computing.

this cycle will point up the need for this variability and the benefits derived from the completely variable cycle length. The traffic processing program is made up of five program segments: 1) *control,* 2) *input,* 3) *output,* 4) *supervisory command* and 5) *duplexing.*

Control Program

This program segment is. as the name implies, the portion that is cognizant of the entire cycle and causes the other program segments to be entered in sequence, providing all the criteria for entrance are satisfied. In addition, the control program is charged with the movement of all data between buffer areas, work areas and the various peripheral devices. With the movement of data come the various and multiple levels of interrupts which enable the RCA Communications ETS System to function as a real-time computer application. From the interrupts and the knowledge of the availability of the various buffer and work areas, the control program is able to determine the criteria for entrance into other program segments and thereby control the cycle length. These criteria, when analyzed, constitute the feedback information which lead to variability in cycle length. The details of the feedback control will be discussed after development of the normal organization of the program cycle.

Input Program

The input program performs all message recognition, validation and routing, and it provides the recognition of the overflow criteria. The input program recognizes and processes three basic types of traffic message formats as well as various formats associated with service type messages. The program provides the linking of completely received messages by outbound destination—such linking being done in a manner consistent with the system requirement of out-transmission first-in, first-out by priority class. As the inbound messages are being reconstructed in the input line slot area, the input program scans each of the 100 channels to process the data as it is present. The program is constructed so as not to be data sensitive, but rather to be able to receive data at any rate from 45.5 baud to 150 baud.

Output Program

The output program has the prime responsibility of keeping all circuits, for which traffic is in the system, busy to the maximum extent possible. Each traffic message transmitted is numbered for record purposes and subject to the various ledgering and recording requirements of the system. The output program scans each of the 100 output channels to determine if servicing is required and determines the requirement to be satisfied, i.e., to select the next message to be transmitted, to send the appropriate *start-of-message* header, to send *end-of-message* sequence, to edit and schedule writing of the ledgering information. Due to the possibility of input data surges the output program is not guaranteed to be entered every program cycle; but if the output program is entered, all channels are serviced. (This program, as any other program segment other than the control program, is subject to interrupt by the termination of a peripheral device, the input buffer cycle, or the output buffer cycle. After any interrupt, the control program performs whatever processing is required and then returns control to the interrupted program.)

Supervisory Command Program

This is the program which interprets the supervisory commands and produces the desired end result. These commands range from production of traffic statistics to changes in the hardware assignments in the system. This program is entered if time remains in the basic traffic cycle or if the program is waiting for any of certain criteria to be satisfied for entrance to a given program segment. The ultimate accomplishment of a given supervisory command may require several traffic processing cycles. This program is the prime initiator of commands to the printing devices (the high-speed printer, the slow-speed monitor printers). These devices are utilized to acknowledge commands, report on status of messages, indicate supervisory controlled hardware changes, etc.)

Duplexing Program

As mentioned previously, the system has two main computers duplexed. Should a failure occur in the on-line computer when two are available, the alternate computer will be in a position to take over traffic processing without the loss of traffic. This is accomplished by providing dual input from the input buffer to both the on-line and the stand-by computers. With both computers receiving the same basic raw data from the telegraph line buffers the only further requirement is to provide a means for the stand-by computer to make the transition from raw data to that which has been accumulated in the intermediate store by the on-line computer. This is accomplished by allowing the on-line computer to process the raw data into message segments, and to periodically update the standby computer so that it is cognizant of the processing to the point of updating.

At the beginning of every major program cycle, the standby computer is updated by means of a computer-to-computer transfer of all dynamic tables. The standby computer accumulates the raw data between update transfers and is able to process this raw data when required, as though no failure has occurred. Should the standby computer be directed to go on-line, it begins to process data as of the last transfer of updated dynamic tables. This will usually involve duplicating work done by the previously on-line computer, but the standby computer will catch up quickly and, in taking over the load, it assures against loss of inbound data and minimizes duplicate transmission from the system.

Normal Execution of the Traffic Processing Cycle

From the previous description it can be seen that the traffic processing cycle will normally perform all program functions in the sequence listed below:

1. Transfer of duplexing information to the standby computer
2. Input processing
3. Output processing
4. Supervisory command processing

The control program is always utilized, interlaced throughout the entire traffic processing cycle.

Adaptive Control of the Traffic Processing Cycle

The normal sequence of events in the traffic processing cycle is not unconditionally followed. Fig. 5 shows the normal and modified flow of the traffic-processing cycle. Characteristics of this variable processing will now be discussed.

The control program monitors the status of the system at several points and adjusts the mode of operation to best accommodate the current load. Principle decisions which are made in this manner follow:

1) *Duplex Transfer Control.* At the start of the traffic processing cycle the control program checks to see if the alternate computer is in the standby mode. If so, the duplex transfer program is entered to update the standby computer; if not, this element of the work is bypassed.

This is not a trivial decision, for several reasons. Firstly, the alternate computer may very likely *not* be in the standby mode as it could be performing off-line functions or it could be down for maintenance. Secondly, the transfer of updating information between computers takes a significant amount of time and the system should not go through this exercise needlessly.

2) *Entrance to Input Program (Normal).* At the normal entrance to the input program, the control program first checks to see if there is data available for the input program and if all peripheral devices required have terminated previous instructions and may be utilized. If either of these conditions is not met, the control program will determine if there is a lower priority program which could be executed in the meanwhile. Should this be so, as for example a supervisory command which has not been executed, then the control program will cause an appropriate transfer to occur. Any interrupt (usually caused by a peripheral device instruction terminating) will cause the system to return to the control program where a new attempt will be made to enter the input program.

3) *Exit from Input Program.* Each time the input program is completed (which means basically processing the data received from one holding buffer), the input backlog is examined. Should there be input data accumulated in more than two of the 13 holding buffers (three in high-speed memory, ten on the drum), control will be returned directly to the entrance to the input program, which will repeat its cycle. This short cycle will continue until the input backlog is eliminated.

This technique provides instant response to input data surges. The system adapts itself to the changing character of the load. Granting the input function top priority assures against loss of incoming data at the expense of slowing the output and deferring execution of supervisory commands. In this particular application, such a decision is correct as message integrity is the primary standard. In another type of application, such as process control, a different standard would probably apply. When the input program is completed, and there is no backlog of data remaining, control is transferred to the output program.

4) *Entrance to Supervisory Command Program.* As previously mentioned, the traffic processing cycle normally includes duplex transfer, input, output, and supervisory command programs. Under normal conditions this sequence of programs should approximately synchronize with the input buffer cycle which occurs every 465 msc.

The supervisory command programs are classified as lowest priority compared with the input and output programs. Since these commands are introduced by a human operator, it is unimportant whether or not the command is executed instantly or takes several program cycles. The control program, therefore, allocates time to supervisory command program execution in a manner consistent with relative priorities.

A timer is used to assure entrance to the input program roughly every 465 msec. Each time that the input program is entered, this timer is set to 400 msec (rough value). When the output program is completed, control is returned to the control program which determines whether to enter the supervisory command program or to initiate a new traffic processing cycle. The supervisory command program is entered only if the timer has not elapsed. Similarly, any time during execution of the supervisory control program, when there is an interruption due to a peripheral device termination, the control program senses the elapsed time indicator to decide whether to return to the supervisory command program or to initiate a new traffic processing cycle.

QUANTITATIVE ASPECTS OF PROGRAM DESIGN

In order for a real-time computer program to handle its load, three major factors must be correctly treated:

1) The computing time requirement per unit of load (messages) must be consistent with the expected traffic load.
2) Peripheral device utilization must be efficiently scheduled.
3) The logical sequence between computing routines and peripheral device utilization must maximize simultaneous operation of the system in order to maximize total efficiency (connectivity).

The system which results from consideration of these three factors may be properly classified as a queueing process whose service time is a function of all the possible program sequence combinations which may result in the course of processing traffic. While the situation is far too complex to permit one to actually write expressions for the service time as a function of traffic, it is possible to discuss this area qualitatively with some benefit.

Suppose we consider, mathematically, a very simple classical queueing problem[5] and intuitively extend the principles found therein to the more complex case in question. Let the process be a single-server queue with Poisson (random) arrivals at an average message rate per unit time of λ and with an exponentially distributed time, with an average processing rate of μ messages per unit time. If n represents the number of messages queued up for the process (including a message which might be in process), then the following expressions hold, provided $(\lambda/\mu) < 1$:

$$p(n) = \left(1 - \frac{\lambda}{\mu}\right)\left(\frac{\lambda}{\mu}\right)^n \qquad (1)$$

$$E(n) = \frac{\lambda}{\mu - \lambda} \qquad (2)$$

$$\mathrm{Var}(n) = \left(\frac{\lambda}{\mu - \lambda}\right)^2 + \frac{\lambda}{\mu - \lambda} \qquad (3)$$

Where: λ/μ = ratio of input to output load, or the duty cycle of the process; $p(n)$ = probability of there being n elements in the queue at any given instant of time; $E(n)$ = expected value of n; and $\mathrm{Var}(n)$ = variance of n. For $(\lambda/\mu) \geq 1$, the system is unstable.

While it is intuitively obvious without recourse to formal reasoning that any system must possess an average processing rate capability greater than the average message arrival rate, it may not be intuitively clear that even a lightly loaded system can develop substantial queues.

Suppose we assumed that these equations were an adequate mathematical model of the holding buffer system shown in Fig. 4. We could then find the expectation and variance of the number of holding buffers in use as a function of the duty cycle of the system. Fig. 6 shows plots of these functions. From these plots it is clear that even at duty cycles below 50% there will be frequent use of the holding buffers.

Peripheral Device Utilization

In the RCA Communications ETS System extensive use is made of the drums. While a drum instruction may be executed simultaneously with computing, only one drum may be accessed at a time. Efficient scheduling of drum utilization was, therefore, given primary consideration in the system design. Table II lists the various program requirements for drum utilization and indicates average execution time per program cycle of nominally 465 msec. Fig. 7 is a time-domain diagram of a typical program cycle illustrating the overlap of comput-

TABLE II—Drum Utilization Units During Typical Program Cycle

Symbolic Name for Drum Unit	*Average use per program cycle*	*Purpose*	*Average time per program cycle, msec*
WIDS-1	regular once	write inbound line blocks to drum #1	75
WIDS-2	regular once	write inbound line block to drum #2	75
RIDS-1	regular once	read outbound line block from drum #1	75
RIDS-2	regular once	read outbound line block from drum #2	75
RRD	regular once	read routing table segment from drum to memory	40
BUFW	small	write input surge to buffer on drum	—
BUFR	small	read data from buffer drum back into memory	—
RDVT	small	read drum vacancy table entries into memory (input)	—
WDVT	small	write released drum vacancy table entries onto drum	—
		Total Elapsed Drum Time = 340 msec/cycle average	

ing and drum instructions. Since the elapsed time requirement for drum instructions can easily reach 340 msec per program cycle, connectivity considerations may cause the cycle to extend beyond the nominal maximum of 465 msec.

The load per program cycle was estimated from traffic predictions furnished by RCA Communications. Because of their extensive experience with international telegraphic traffic it was possible to obtain relatively good estimates of the daily message rate, peak hourly message rate, and average message length. Minimum and maximum message length were determined from procedural considerations. Since growth capacity was one of the system's objectives, a goal was established for a message processing rate substantially higher than specified.

A design objective was established at 7,200 messages per hour (peak-hour) with an average length of 400 characters (or four line-blocks). This corresponds roughly to an average load of one message per program cycle. Since the input load on the system comes from one hundred essentially independent channels, and the output is delivered to one hundred essentially independent channels, a more precise statement of the average load per program cycle would be:

1) One of each event which occurs on a per-message basis, both input and output-wise.
2) Four incoming line-blocks written to the intermediate drums from four different channels and, likewise, four line-blocks read from the drum for four different output channels.

Since the loads are imposed by 100 independent channels, the binominal distribution applies as a means of estimating the possible variations in load that can occur in any given program cycle during the peak hour. Table III indicates the characteristics of the important loads on the drums under peak hour conditions. As can be seen from Table III, there may be many occasions during a peak hour when the instantaneous load per program cycle is such that the cycle cannot possibly be completed in 465 msec. At these times, the input buffer program absorbs the input data, holds it until the main program can catch up, and then feeds it back to the main program.

While statistical analysis can be applied to estimation of reasonable variations in load, the system designer cannot ignore the possibility of worst-case hits. Unlikely as it may be, the situation may arise where all 100 input channels present demands for access to the routing drum and the intermediate drums during the same program cycle, etc. The program handles such situations by short-cycling until the load is absorbed.

TABLE III—Characteristics of Load on Major Drum Utilization Units

Symbolic Name for Drum Unit	*Utilization by System (Work Units)*	*Average Load Per Cycle*	*Time to Execute, msec*	*Maximum* likely load per program cycle*		*Maximum** likely load per peak hour*	
				Work units	*Time, msec*	*Work units*	*Time, msec*
WIDS-1	1 to 10 line blocks per drum revolution	2 Line Blocks	75	6 Line Blocks	75	10 Line Blocks	75
WIDS-2	1 to 10 line blocks per drum revolution	2 Line Blocks	75	6 Line Blocks	75	10 Line Blocks	75
RIDS-1	1 to 10 line blocks per drum revolution	2 Line Blocks	75	6 Line Blocks	75	10 Line Blocks	75
RIDS-2	1 to 10 line blocks per drum revolution	2 Line Blocks	75	6 Line Blocks	75	10 Line Blocks	75
RRD	one access per message	1 Accesses	40	4 Accesses	160	7 Accesses	280
Totals, msec			340		460		580

* Max. no. of work units with $P = 0.996$, in a single program cycle.
** Max. no. of work units with $P = 0.94$, over 7,200 consecutive program cycles.

CONCLUSIONS

A real-time computer program must be written with careful consideration of uncertainty. The program has to be designed with adaptive features and, generally, should initially be able to operate at a relatively low duty cycle. Statistical methods are very important in providing insight into the quantitative aspects of system behavior, but features for treatment of worst-cases must still be provided.

Real-time system design is an art still in its infancy. There are, as yet, no simple analytical techniques to solve these problems. One must depend upon brute force analysis of the particulars of each application coupled with an essentially descriptive approach to system organization. Technique is best developed out of experience and it is hoped that this paper, essentially a case study, will contribute to an improved understanding of these problems.

ACKNOWLEDGEMENTS

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THE DYNAMICAL DESIGN OF THE RELAY SATELLITE

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The RELAY program is a NASA-sponsored experiment to gather data for use in the design of operational, low-altitude communications satellites for TV, telephony, and telegraphy. This paper discusses the dynamical design considerations occasioned by the presence of sensitive components and their positioning, the various static and vibratory loads, the limitations on total weight, etc.

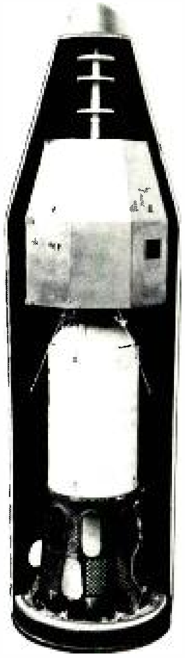

Fig. 1—Satellite within fairing (to show relationship of satellite and fairing dimensions).

The analysis of the Relay mission took the usual form of the reduction of the general requirements to payload equipment capabilities. These requirements for the equipment were in the nature of such parameters as antenna gain, transmitter power, etc. These generalities were further reduced to specifications; and such accessory information as size, weight, special orientations, and temperature limits were added.

The astronautical requirements were expressed in terms of the time and spatial relationship of the payload with respect to the Earth and Sun. Designing for these requirements then led to definition of the orbit with immediate corollary requirements on the number and location of ground stations, and upon the weight capacity of the launching vehicle. Another line of relationships connected the size, as well as the weight, of the payload to the launching vehicle, since its choice also defined the fairing and thus an envelope which bounded the payload externally (Fig. 1). Still another line of relationships involved such orbital parameters as altitude, inclination, and time in the sun with payload surface area, means of stabilization, and antenna patterns.

Thus, the constraints on the dynamic and structural design of the Relay payload included:

1) Fairing envelope.
2) Axial, transverse, and torsional loads from each stage of the booster.
3) Dynamic balance limits.
4) Spin-axis runout limits.
5) Temperature limits.
6) Vibrational loads.
7) Weight limit.
8) Spin stabilization.
9) A maximum area for solar cells.

The equipment list for the spacecraft, including radiation sensors, totaled 39 components or "black boxes". General prior knowledge of communications equipment capabilities, and elementary geometry, indicated that the payload would weigh at least 125 pounds and require, when used with conventional ground stations, an altitude of about 2,500 miles.

SATELLITE CONFIGURATION

The configuration of the Relay payload had first, and simultaneously to satisfy the primary conditions of: 1) spin stabilization, 2) compatibility with an existing fairing, and 3) maximized surface area. Basic control of the attitude of the spin axis in inertial space required that the mass distribution *must* be that of a disk, whatever the external shape of the payload. Dynamically, the ratio of the mass moment of inertia about the spin axis to the maximum inertia about any transverse axis must be greater than one; that is, $(I_{spin}/I_{trans}) > 1$, or $I_{spin} > I_{trans}$. Control of this parameter was necessary; otherwise any unbalanced moment at separation or dynamic unbalance would lead eventually to tumbling, with concomitant nullification of the antenna directionality.

The major problem in the achievement of a component arrangement to provide this inertia condition was the fixed maximum diameter of the fairing. The problem was solved by establishing a basic cruciform structure of four vertical elements carrying most of the components in shear mounts, and an equatorial belt, or ring, of the four heaviest components (Fig. 2). The two battery packs, the wideband receiver, and the encoder—totaling some 50 pounds and mounted in or on beam structures—were each located as a bridge between two adjacent cruciform elements. Longitudinally, this assembly was placed at the plane of the center of gravity. Since the final weight and center-of-gravity location of the individual components was uncertain, a margin of +5% was arbitrarily added to the theoretical $(I_{spin}/I_{trans}) > 1$; i.e. 1.05 min. A bifilar pendulum with a demonstrated accuracy of 0.3% maximum was used to measure the inertia ratio of Relay I as built: the value was 1.038. The high accuracy and consistency of the pendulum measurements lent confidence to the acceptance of the number. Additionally, Relay I carries a precession damper and a magnetic-torquing coil for the correction of any slow drift of the attitude of the spin axis due to perturbation, particularly that arising from a non-zero value for the residual magnetic dipole moment.

The third condition, maximized surface area, was only a maximum in terms of an area of silicon solar cells to support a given power requirement. Relay was not basically a power-limited design; the balance of limitations was well established among such items as power, temperature rise of the TWT, altitude, weight, and mutual visibility time. But to provide the power for the duty cycle required extensive design attempts to attain sufficient area within the fixed values of diameter and inertia ratio. An arrangement of solar cells, shingles, electrically parallel strings of cells, and supporting panels was finally established resulting in, basically, a number of panels and a panel length to meet the power requirements. It was then found that a slight margin of power (area) could be provided by extending the

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length without violating the dynamic-stability criterion of the inertia ratio.

The dynamical design of RELAY to account for the other six constraints involved the disciplines of stress analysis and sizing of structural elements to meet both static and vibratory loads (which is discussed further in some detail); the detailing of the location of components, as masses, to minimize both the added mass for dynamic balance and the degradation of the inertia ratio; plus the continuous vigilance necessary to control the growth of the total weight.

DESIGN OF VIBRATION DAMPING DEVICES

The physical arrangement of electronic components to meet the inertia ratio required by spin stabilization was basically that of a tube. This placed the component masses at the maximum possible radius, and at the minimum displacement from the plane of the longitudinal center of gravity; that is, to make a short ring. The solar-cell panels appeared as the exterior shell, and the majority of the 35 "black boxes" were shear-mounted on the cruciform elements. The controlling (heaviest) components to obtain an inertia ratio of at least 1.05 were the wideband receiver, the encoder, and the two battery packs. Their optimum location (at the longitudinal center-of-gravity plane and at maximum radius) was attained by developing their local enclosures as box beams that bridged circumferentially between adjacent elements of the cruciform.

Both the receiver and encoder showed considerable sensitivity to the high forces in vibration testing. The vibratory input forces at the separation ring were multiplied some 12 to 16 times by the transmissibility of the structural path from the ring up through the vertical legs of the cruciform and along the bridge beam. The battery packs did not show a similar sensitivity, the nature of the component allowing a very rugged beam to be made by riveting cover plates to a pair of channels and epoxy-bonding the individual cells to these covers. The receiver and encoder required access for adjustment and alignment after assembly, resulting in a number of unsymmetrical openings. In fact, the wideband receiver was actually a pair of receivers back to back—an arrangement resulting in a beam structure whose lack of symmetry made analysis rather difficult (Fig. 3).

Of the several vibration tests on the components and assemblies, the qualification test had the most severe inputs. This was a sine-wave test with the following levels and durations (only the longitudinal, or thrust, direction are considered here):

Frequency Range (cps)	*Acceleration (g, 0-to-peak)*	*Duration (minutes)*
5-50	2.3	1.66
50-500	10.7	1.66
500-2000	21.0	1.00

Because the first natural frequency, or resonance, of the entire assembly as a mass-spring system turned out to be 110 cps, the frequency of greatest interest was the 50-to-500-cps range, with its 10.7-g input.

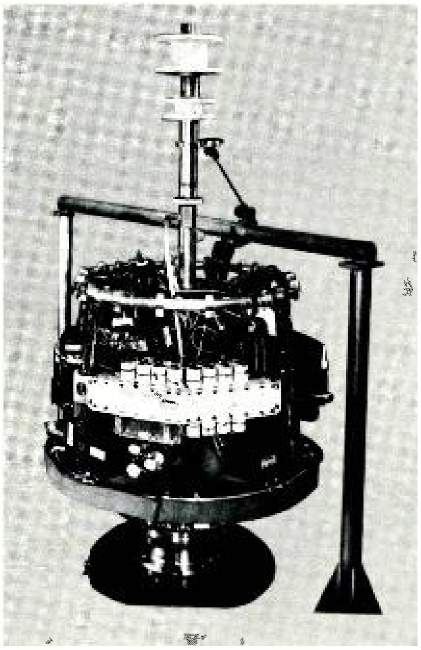
With the electronic design of the receiver and encoder already well established, exploratory vibration tests on the components (separately) indicated that they could probably survive 80- to 100-g peaks and, during the test, they would "see" these high inputs only as the frequency sweep passed through their local resonance. Thus, they would absorb relatively small amounts of energy. Vibration tests on the components had indicated that these resonances occurred at approximately 160 cps. The problem appeared, then, in the form of a constraint on transmissibility of the 10.7-g input at the separation ring to a value of 10 or less in the frequency range which included both 110 and 160 cps.

During vibration tests on the assembly, the relative stiffness of the beams was higher than that of the cruciform elements, the beam motion being nearly that of a rigid body. Redesign of the cruciform with the increased stiffness necessary to get the resonance of the cruciform-beam system significantly above the 110-cps fundamental resulted in an inadmissable weight increase. To lower the stiffness and resonant frequency of the cruciform-beam system was not at all attractive because of the potential of buckling in the cruciform skin. The general approach of isolating the entire satellite from the booster with a spring was invalid because of the tremendous displacements involved and the indefinite change imparted to the separation velocity.

A lossy element was introduced between the booster and payload—the four foot-blocks which form the contact and load-carrying elements between the separation ring and cruciform were redesigned using structural plastics having high compressive strength but low elastic modulus, chiefly the epoxy-bonded glass laminates. Although this reduced transmissibility only slightly, the substitution of this material for the original aluminum was made for a minor saving of weight and improved thermal isolation of the ring.

It was decided to limit the vibration amplitude at the center of the cruciform beam by decreasing its span with a brace

Fig. 2—Component arrangement in satellite (to show how disk-like mass distribution is obtained).



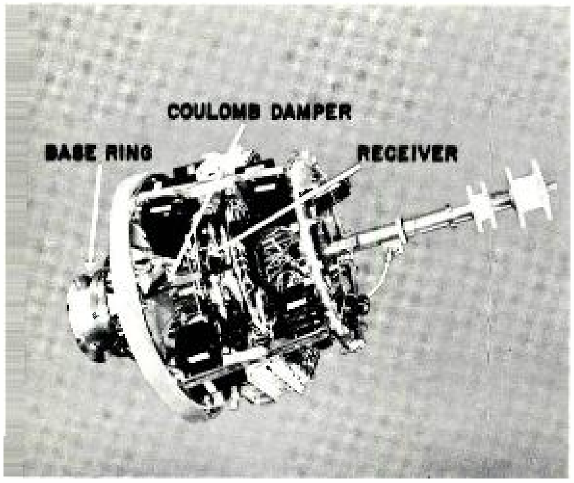


Fig. 3—Receiver and supporting structure.

from the beam center to the separation ring and, at the same time, reducing the force input to the beam and its electronic component by making a lossy element out of the brace.

The use of viscous friction as a means of energy dissipation was denied by the project specification, which prohibited the presence of any liquids outside of sealed containers. Thus, Coulomb, or dry-friction, damping was the most practical means available. The dimensions of the physical arrangements were such that a column brace of reasonable slenderness ratio L/r could be designed without undue weight increase for the total satellite (Fig. 4). In choosing the materials, the paramount consideration was the retention of the initial friction load throughout the operating life. This was taken as 100 times the duration of the vibration test, or about 3 hours. As the required friction force, or load, was not known precisely, the design of the damper included a means for adjusting this force. Consideration of all the requirements led to the choice of a polished, phenolic, fibreglass rod sliding in a stainless steel tube (Fig. 4). The tube was longitudinally slit in the region of the overlap.

As mentioned previously, vibration tests indicated that the maximum allowable transmissibility for the receiver and encoder was about 10 for a 10.7-g input in the 50-to-500-cps band. Therefore, the design goal of the damper was a transmissibility between 3 and 5 for a narrow band which included the resonant frequency.

DESIGN APPROACH

The general design approach is based on Den Hartog[1] and may be used for any type of damping as long as its action can be expressed either analytically or graphically. For forced vibrations with nonlinear damping the differential equation of motion is

$$m\ddot{x} + f(\dot{x}) + kx = P_o \sin \omega t \qquad (1)$$

Where: $f(\dot{x}) \neq c\,\dot{x}$ for linear damping. The motion is not harmonic because of the nonlinear term $f(\dot{x})$. An exact solution for this equation is known only for the case of Coulomb or dry-friction damping, where $f(\dot{x}) = \pm F + c\dot{x}$. Even though the damping for this design is greater than that usually assumed for this approach, the curve of motion is sufficiently close to a sinusoid to base an approximate analysis on it. The analysis assumed basically that equal work per cycle will be done in both the sinusoidal and in the equivalent system. The term $f(\dot{x})$ is replaced by an equivalent $c\dot{x}$, and an "equivalent damping constant" c is determined such that the actual damping force, $f(\dot{x})$, does the same work per cycle as the equivalent damping force $c\dot{x}$. The term c is then not strictly a constant, but a function of ω and of x_o. Thus the nonlinear Coulomb system represented by the differential equation can be replaced by a linear one, with the concomitant approximation.

The motion is given by:

$$x = x_o \sin \omega t \qquad (2)$$

The work per cycle v_1 of the general damping force $f(\dot{x})$:

$$v_1 = x_o \int_o^{2\omega} f(\dot{x}) \cos \omega t \, d\omega t \qquad (3)$$

The work per cycle v_2 of the equivalent damping force $c\dot{x}$:

$$v_2 = \pi \, c \omega x_o^2 \qquad (4)$$

The equivalent damping constant c is found by equating equations 3 and 4:

$$c = \frac{1}{\pi \, \omega x_o} \int_o^{2\pi} f(\dot{x}) \cos \omega t \, d\omega t \qquad (5)$$

And, the amplitude of the now-linearized system is:

$$x_o = \frac{P_o}{k} \frac{1}{\sqrt{\left[1 - \frac{\omega}{\omega_n}\right]^2 + \left[\frac{c\omega}{k}\right]^2}} \qquad (6)$$

The amplitude is found by substituting the value of c from Equation 5, but first the integral must be evaluated. From a plot of damping force and velocity versus ωt, it can be observed that the integral consists of four equal parts:

$$4\int_o^{\pi/2} F \cos \omega t \, d\omega t = 4F. \qquad (7)$$

Thus:

$$c = \frac{4F}{\pi \omega x_o} \qquad (8)$$

And, substituting c from Equation 8 in Equation 6 yields:

$$x_o = \frac{P_o}{k} \frac{\sqrt{1 - [(4/\pi)\,(F/P_o)]^2}}{1 - \left(\frac{\omega}{\omega_n}\right)^2} \qquad (9)$$

With Coulomb friction in the region of $F/P_o = \pi/4$, the amplitude at resonance is infinite and independent of the damping.

This "linearized" approach is applied in the design of the Coulomb damper as a single-degree-of-freedom system at resonance. Thus, critical damping at resonance is required.

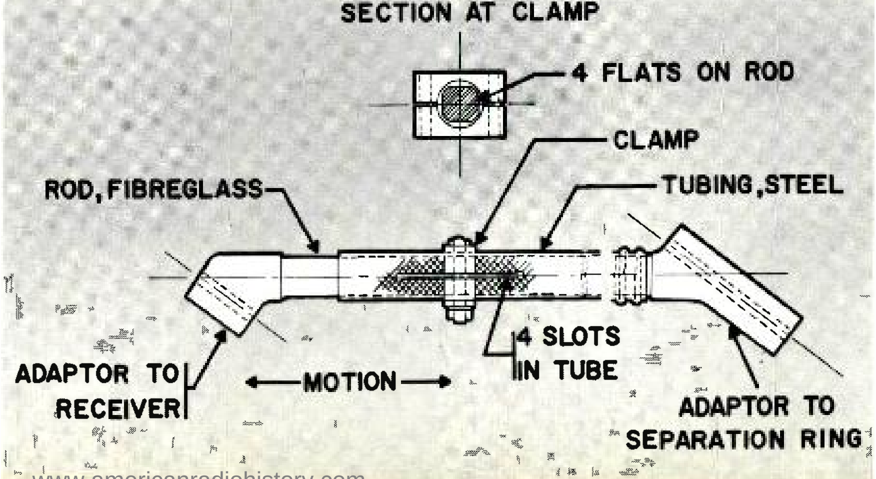
Preliminary vibration experiments were performed to determine the natural frequency of the encoder (as typical of these components) on a rigid brace, resulting in a value of $f_n = 160$ cps. The weight of the encoder is taken as 11 pounds, and the critical damping at resonance c_{cr} is:

$$c_{cr} = \sqrt{\frac{4kW}{g}} = 2\,w_n \frac{W}{g} = 2(2\pi f_n)\,\frac{W}{g} \qquad (10)$$

$$c_{cr} = 54 \text{ lb-sec-in}^{-1}$$

Assuming now that the force on the center of the encoder beam from the brace is relatively high and the beam thus acts as a rigid body, and taking the transmissibility value as 5 for a trial, the acceleration at the encoder center and the velocity across the friction elements are found. The acceleration a = *input* × *transmissibility* = 53.5g; and the velocity $V_o = a/\omega = a/(2\pi f_n) = 22$

Fig. 4—Coulomb damper.



in-sec.$^{-1}$ The critical friction force at resonance is then $F_{cr} = V_o c_{cr} = 1190$ lb. This critical-friction force must be developed by the normal force acting through the coefficient of friction at the interface between the fibreglass rod and the steel tube. It is not necessary to know the value of the coefficient of friction, but it is required that the friction force and the break-away force not be widely different. It is also required that the wear and surface characteristics of the mating materials be such that the friction force remains reasonably constant for the operating period, a condition best demonstrated by experiment. The combination of fibreglass and stainless steel proved admirable. No detectable wear nor change in friction force was evidenced during the extensive experimental operations. The slits in the tube and the adjustable clamp provided the means of setting the normal force and, through it, the friction force.

The proper value of the friction force is found through the use of the damping ratio:

$$\frac{F_{FR}}{F_{cr}} \approx \frac{c}{c_{cr}} \qquad (11)$$

Since the amplification is to be 5 or preferably less, the value of the damping ratio may be read as 0.13 from standard resonance curves for a linear system.[2] Then, from Equation 11, $F_{FR} = 0.13\, F_{cr} = 150$ lb.

The clamp on the brace is torqued to provide the corresponding normal force, and the axial friction force is measured by experiment. A relationship between this axial friction force and clamp torque was set up so that the experimental measurement could be omitted in future production.

Direct use is made of the rigidity inherent in the brace even though its major function and design are those of a damper. The introduction of the axial force essential to the dissipation of input energy acts to increase the stiffness of the encoder support and thus to raise its natural frequency. This overall action (i.e., to reduce the energy input to a sensitive component and to move its resonance away from the frequency of maximum energy input) is, of course, the chief reason for using the damper.

The amount of increase in stiffness is difficult to calculate because of the unknown spring rate—the k of Equation 9—of the supporting cruciform elements in the region of the ends of the encoder. The overall spring rate for the cruciform assembly had been determined during static load tests to be approximately 200,000 lb/in which correlates reasonably well with the value of 211,000 lb/in derived from the experimental data of an 110-cps resonance at 172 pounds load.

The displacement of the encoder, without the brace, would be about 0.0004 inch. With the brace added, the new displacement is about 0.0060 inch. However, the displacements with the brace had been measured at about 0.0010 to 0.0015 inch, for a ratio of, say, 6/1.2 or 5. Since the natural frequency is related to the square root of the spring constant or displacement, the change in frequency would then be expected to be about 2.2. The results of vibration testing (Fig. 5) show an increase in the resonance from 150 cps without the damper to 215 cps after its introduction, for a ratio of 1.4. No particular precision was expected of these calculations, but it was important that the inevitable increase in stiffness due to the additional force of damping be accounted for by approximating the increase in resonant frequency.

The major benefit gained by the installation of the damper is readily seen by comparing the transmissibilities at resonance: without the damper it is 12 at 150 cps; with the damper it is only 7 at 215 cps. The latter value permits only those peak force inputs to the encoder which are within its capacity of about 10 transmissibility at 10.7-g input. The secondary peaks, for both conditions, near the 100-cps region were excited by the resonance of the entire assembly and represent a similar reduction in force. The wideband receiver responded even better to the same treatment, the transmissibility at resonance being reduced from 16 to 6.

The data gathered during the tests was used to calculate the actual damping and transmissibility. The damping ratio was found to be 0.1, which, when entered on standard resonance curves, indicates a transmissibility of about 6—comparable to the measured value of 7. The energy dissipated per cycle was calculated as $= 2 \times 10^{-6}$ in-lb/cycle, a reasonably acceptable value.

Improvement in the design of such dampers is being studied, mainly in the form of a search for materials and combinations which should yield a small difference between break-away force and friction force, and high friction force with good wear characteristics.

OTHER METHODS OF TRANSMISSIBILITY CONTROL

Other methods of providing control of transmissibility were studied, chiefly the effects of various modes of fabrication of essentially all-metal structures. The stiffness requirements for most spacecraft usually dictate that their basic structures be built of a high-modulus material, and the general shape, size and strength requirements lead to use of the metals and their alloys. Castings, forgings, rolled or extruded sections and parts machined from solid metal form the basic elements from which an assembly may be fabricated. While a number of available alloys (Nivco and Mn-Cu alloys, highly stressed and at correspondingly high plastic strain) can provide damping to an extent of one to two orders of magnitude greater than aluminum or magnesium alloys, their stiffness/density characteristic is completely unfavorable for the design of lightweight spacecraft. It follows, then, that normal "material" damping will be present in all assemblies and that the degree of damping from the material will not vary significantly among the possible choices of constructional alloys of reasonable stiffness/density characteristic.

Another means of damping control, and therefore transmissibility control, open to the designer is the mode of fabrication in terms of the loss of vibratory energy in the joints. Intuition and experience both strongly indicate that the metal forms (i.e., castings, forgings, machined-from-the-solids, and mill sections) generally arrange themselves into levels of transmissibility related to the methods of joining. Welding and brazing result in high transmissibility; riveting and bolting result in medium transmissibility; and adhesive bonding results in low transmissibility.

Additionally, the geometric form of both the structural element and of the assembly has a strong effect on the damping, the transmissibility, and the resonant frequencies. Quite apparently, a column of large slenderness ratio has a larger amplitude of lateral vibration than one of smaller ratio for a given input, irrespective of the material and the details of the end joints. Honeycomb plates, bonded or brazed, have lower resonances and greater damping than solid plates of the same bending stiffness. These geometric and stiffness factors arise from the topology of both the detailed part and the entire assembly, and are connected in an essentially indeterminable manner. But they, and their relationship, are constant for a given design. Thus, an approach to the problem through consideration of the various modes of fabrication is possible.

Starting with the most highly desirable condition of high damping and low transmissibility, the RELAY structural layouts were evaluated for the possibility of using adhesive bonds, but the method was rejected because there were many joints which had to be open for component accessibility during much of the assembly sequence. Going next to the conditions of medium damping and transmissibility, the same layouts and assemblage of mill sections were considered for riveting and/or bolting. The previous evaluation as to accessibility—in terms of which were the last items in the assembly sequence—was given special attention, as were the practicalities of structural sub-assembly fabrication and its scheduling. The combination of riveting for all structural subassemblies in conjunction with bolting for component mounting and for one or two special cases, such as the separation ring and center fitting joints, was adjudged the best. One exception to this choice was the joining of the upper and lower panel-mounting rings. In these, the circumferential joint in the rolled tubing was formed by an epoxy bonded sleeve, but this was done for practical shop purposes rather than to obtain more damping at this non-critical location.

The cruciform subassemblies were of such shape and design as to lend themselves readily to fabrication by the welding or brazing of square tubes. But this method appeared to have no other advantages, and it did promise high transmissibility, as well as high cost due to the fixturing and post-joining heat treatment required. Semiquantitative curves are given (Fig. 6) as a means of comparing the transmissibility of these modes of fabrication. This is not a plot of the response of the RELAY structure, but only of structural elements (beams mostly) made up by the different methods of fabrication. (Data from Barry Controls, Inc. Watertown, Mass. for beams with trapped viscoelastic layers is included.) The basic material was aluminum of the 2024-T3 or 7075-T3 type alloys, fabricated by normal shop methods for the making of joints and the trapping of the viscoelastic layers. The major point of the comparison is the reduction of transmissibility, and thus of deflections and stresses, at the fundamental frequency and its first few harmonics. The comparison really only illustrates the well known concepts that the introduction of joints in a vibrating system inevitably causes loss of input energy, and that certain classes of materials have higher internal losses than others, as the rubbers versus the metals.

While the curves are not particularly precise, nor suitable for extrapolation without regard for the great variation in the geometrical factors among different designs, a general design of a spacecraft in aluminum with riveted joints should yield transmissibilities not much over 10. If the configuration permits some degradation of dimensional stability and locally large displacements, the introduction of adhesive joints may reduce transmissibilities to a value of 5 or even less at the first resonance.

Riveted and bolted construction—used for in the RELAY spacecraft—usually can introduce sufficient Coulomb friction to keep the transmissibilities below a tolerable limit. The amount of damping from this source is relatively small and rarely causes difficulty due to fretting. Fretting usually arises in those cases of excessive stresses and local displacements. Rivet damping, for whatever benefit it will provide, can be included in a design essentially "for free," in that no weight or reliability penalties are involved. If the geometrical layout, or the assembly sequence and accessibility, provides the opportunity, an even more advantageous situation could be designed through application of adhesively bonded joints.

In the RELAY spacecraft, the presence of rather sensitive components plus the configuration forced by the dynamic-stability criterion required additional damping, which was furnished by the specially designed, large-capacity Coulomb dampers.

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1. Den Hartog, J. P., *Mechanical Vibrations,* Fourth Ed., McGraw-Hill, 1956.
2. *op. cit.,* Fig. 22a.

Fig. 5—Transmissibility test results with and without damper.

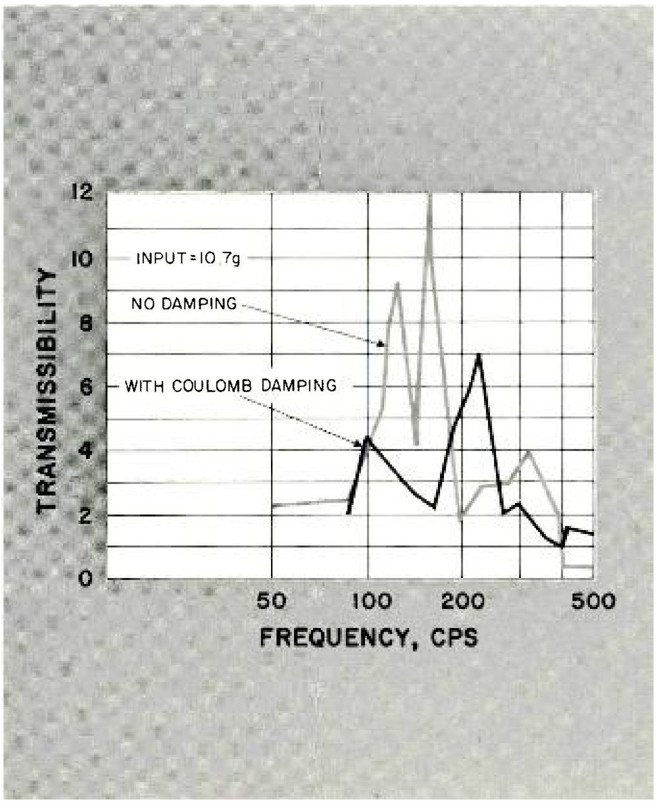
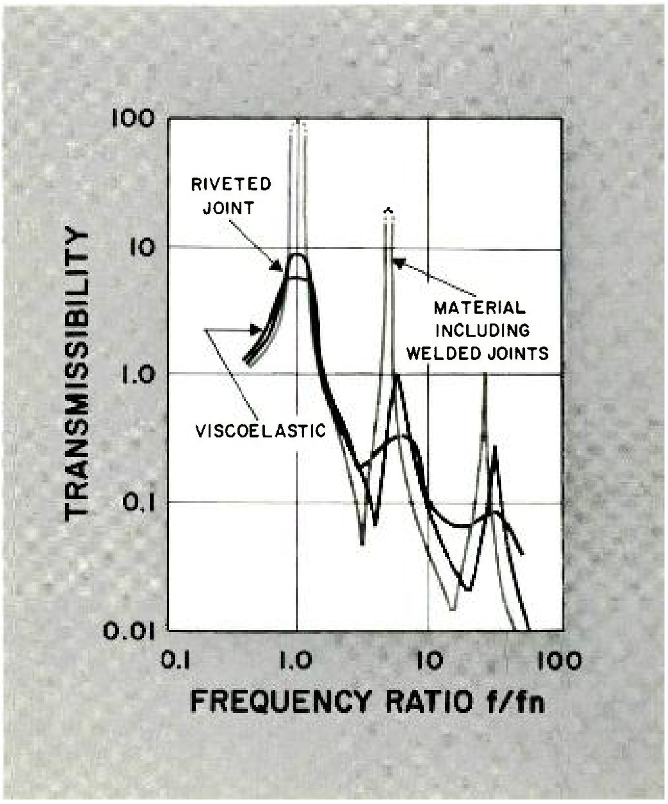


Fig. 6—Transmissibility curves for several modes of fabrication.



REVIEW OF ELECTRIC PROPULSION

Electric propulsion—a term that includes electrothermal, electrostatic, and plasma propulsion—differs basically from a chemical rocket system in two major ways: 1) The charged electric particles (i.e., the propellant) obtain their energy for acceleration from a separate energy source to achieve a propulsive effect, while a chemical rocket obtains its energy by virtue of the chemical energy inherent in a fuel-oxidizer combination—a propulsive effect then being achieved with a nozzle that directs the flow of kinetic energy, and 2) the electric propellant can be kept from significant contact with the engine walls (e.g., by electric and/or magnetic focussing) thus avoiding the heating problems of a chemical rocket. This paper explains, tutorially, the concept of electric propulsion, compares its performance with other means, and reviews the operation of current engines and engine mechanisms. A considerable advance in power and propulsion technology is needed to realize full benefits of electric propulsion. Nevertheless, only electric propulsion will make practical the more-ambitious space missions, such as manned interplanetary vehicles. For more-detailed reading, a bibliography of source literature is included.

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A COMPARISON[1] between the electric-propulsion and the chemical-propulsion concepts is shown in Fig. 1. Both the chemical and electric rocket engines operate by direct ejection of mass. In chemical systems, the expellant is energized by a thermochemical reaction between a fuel and an oxidizer. The product of this combustion is the expellant. A nozzle is used to convert the random thermal energy to directed kinetic energy of the beam. In electric systems, charged particles are accelerated by electric fields, or electric and magnetic fields, and expelled. The substance expelled does not contain the energy for its own acceleration. (This energy, for the case shown, is supplied by a nuclear reactor with a turbo-generator power-conversion system.)

A fundamental difference between chemical and electric propulsion lies in the separation of the energy source from the propellant. For the latter, energy is provided by solar or nuclear power supplies. Thus, in principle, extremely large amounts of work may be accomplished since the energy source is, to a first approximation, nearly infinite. In effect, we are conserving on propellant by continuously expending energy. Unfortunately, the conversion of this energy to the electric form for acceleration purposes is not an unmitigated attribute, since the weight penalty of the conversion system must be considered in evaluating the gains provided by use of high exhaust velocity. A second fundamental difference between electric and chemical propulsion is the possibility that exists with electric propulsors of reducing the interaction of the propellant with the walls. Because of the intimate contact of the reacting fuel with the walls in chemical propulsion, heat transfer to the walls is pronounced. In electric propulsion, the propellant can be uncoupled from the walls by electrostatic focusing or by magnetic fields.

FUNDAMENTAL CONSIDERATIONS

To clarify some fundamental considerations, a simple mathematical analysis is in order. If we let M be the rocket mass; $\dot{M}$ the time rate of change of the rocket mass; c the effective propellant exhaust velocity relative to the rocket; and F the thrust force due to the rocket engine; then:

$$F = -\dot{M}c \qquad (1)$$

The thrust force per unit mass f of the rocket is given by:

$$Mf = F \qquad (2)$$

Letting a represent the acceleration, and if all forces except the thrust force are ignored, it follows that:

$$Ma = -\dot{M}c \qquad (3)$$

It should be noted that $a = f$ when no other forces are acting. Equation 3 is the well-known rocket equation. For the case where the velocity, direction, and rate of propellant flow are constant, Equation 3 can be written as a scalar equation, and integrated immediately to obtain:

$$\Delta v = v_b - v_o = c \ln \frac{M_o}{M_b} \qquad (4)$$

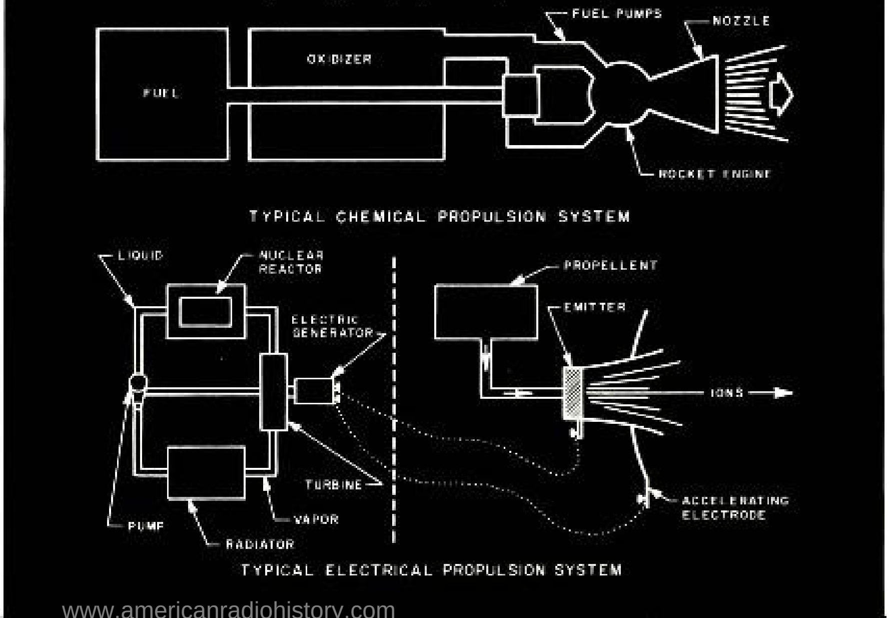
In Equation 4, the subscripts o and b refer to the initial and burnout values, respectively; v is the velocity; and Δv is called the characteristic velocity or velocity increment; M_o/M_b is called the mass ratio. The specific impulse I_{sp}, which is a measure of the velocity of the particles leaving the propulsor, may be expressed as:

$$I_{sp} = \frac{F}{\dot{w}} \qquad (5)$$

Where: $\dot{w}$ is the weight flow of the propellant. Since $\dot{w} = \dot{M}g_o$, it follows that:

$$I_{sp} = \frac{c}{g_o} \qquad (6)$$

Fig. 1—Typical propulsion system concepts.



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Equation 4 may then be written:

$$\Delta v = g_o I_{sp} \ln \frac{M_o}{M_b} \qquad (7)$$

It is seen that the specific impulse is a measure of the effectiveness of the propellant in developing thrust. Further, specific impulse and exhaust velocity are related by the conversion factor g_o. It is clear that, if the propellant can be ejected at high velocity, it is very effective in producing thrust.

An approximate indication of the terms on which propellant can be exchanged for specific impulse for a given characteristic velocity can be obtained from Equation 7. In general, a slight change in the specific impulse can be balanced only by a large change in the mass ratio. For electric propulsion systems, the specific impulse ranges approximately between 1,000 and 20,000 seconds; for chemical systems, the specific impulse is under 500 seconds. Thus, for a given Δv, the electric system requires considerably less propellant mass than a chemical system. Equation 7 also shows that when extremely large Δv's are required (typical of ambitious space missions) the use of very high specific-impulse electric systems is the only way by which impossibly large mass ratios can be avoided.

However, the conclusion that the payload is larger for an electric system than for a chemical system is not always valid, because for an electric system, the mass M_w of the power source and acceleration system is a limiting factor. The parameter used for this factor is the specific mass γ, which is expressed as:

$$\gamma = \frac{M_w}{P_j} \qquad (8)$$

P_j is the jet power, expressed as:

$$P_j = \frac{-\dot{M}c^2}{2} \qquad (9)$$

Or, from Equation 1:

$$P_j = \frac{Fc}{2} \qquad (10)$$

The values of γ that are currently considered realistic range from 5 to 50 kg/kw.

Considerable mission analyses[1,2,3] have been performed that show the regions of applicability of the various types of thrustors. The three trade-off parameters are 1) payload weight, 2) travel time and 3) cost per unit weight of delivered payload. One such analysis for cases in which the first two parameters are considered for a variety of missions is that of the Jet Propulsion Laboratory.[3] Their result, which is typical, shows that for missions more ambitious than a Mars orbiter (Such as Venus orbiter, Saturn probe, Mercury orbiter, etc.), electric propulsion is not only applicable *but in many instances is essential.* The influence of the third parameter and its significance with respect to the first two is currently not clear since costs for these systems are difficult to estimate at this time. However, the use of electrical propulsion for missions of even shorter distances, such as for lunar logistic ferries, has been proposed as economically feasible.[4]

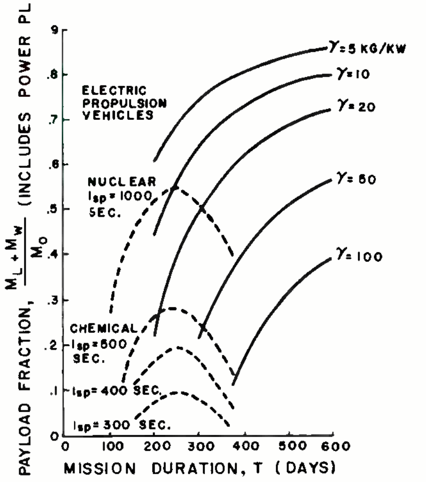
Of particular significance is the limitation on the thrust-to-weight ratio inherent in the electric propulsion system and the resultant mission transfer time. This is best illustrated by substitution of Equations 8 and 9 into Equation 3, which results in an expression of the form:

$$a = \frac{2}{\gamma c} \frac{M_w}{M_o}$$

For a practical ratio of $M_w/M_o = 1/4$, with $\gamma = 5$ kg/kw and a specific impulse of 5000 seconds, the thrust-to-weight ratio is only 2×10^{-4} g's. It is thus shown that electric propulsion is only applicable for those missions requiring very low accelerations. Fortunately, since real space exhibits no friction, very low thrust forces are usable. Although the thrust level may be low, a considerable amount of energy transfer can be accomplished in moving through a gravitational field because of the large distance and time involved.

A comparison of electric propulsion with chemical and nuclear propulsion for a one-way Earth-Mars mission, where the electric power plant is considered part of the payload, is presented in Fig. 2.[5] Such a consideration would appear reasonable, because considerable

Fig. 2—Comparison of payload capabilities for electric, chemical and nuclear propulsion vehicles on a one-way Earth-Mars mission, with electric power plant considered part of the payload.



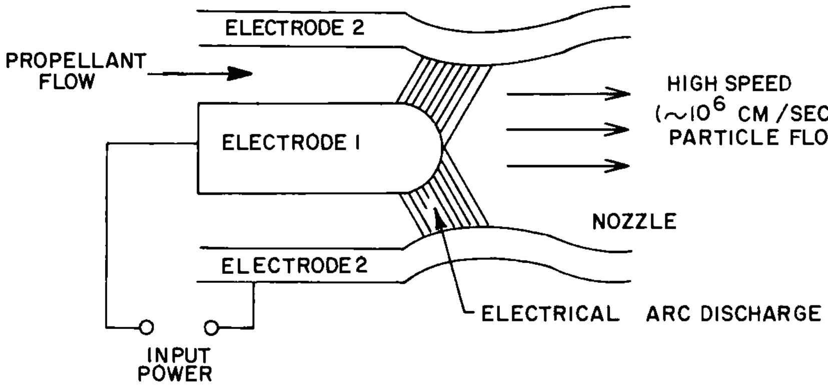


Fig. 3—Electrothermal accelerator, arc jet concept.

power will be required in any event once the target planet is reached. The curves are presented with the specific power of the power supply as a parameter. It is apparent that electric propulsion is superior on a maximum payload basis provided a power-supply specific power of 20 kg/kw can be achieved. This is one of the basic reasons for the current emphasis on developing lightweight power sources. Further, it can be seen that the electric propulsion system is potentially superior to nuclear rocket propulsion for mission durations greater than 200 days provided a power-supply specific power of 5 kg/kw can be achieved.

VARIOUS ACCELERATION MECHANISMS—GENERAL REMARKS

As stated earlier, the production of effective thrust arises from the directed flow of particles at high velocity. Such an energetic flow may be produced by the absorption of electrical power with flow directivity provided by nozzling (as in chemical propulsion systems), or by the direction of the applied electrical and/or magnetic fields. The usual nomenclature for various categories of electric propulsion mechanisms is *electrothermal*, *electrostatic*, and *plasma* propulsion.

Electrothermal propulsion utilizes electric fields as a means of providing energy to the propellant through ohmic heating; however, directivity of the beam is obtained by means of mechanical nozzling. Electrostatic acceleration makes primary use of electric fields to direct and to furnish energy to particles of one electric-charge type. After acceleration of the particles, introduction of oppositely charged particles into the beam is needed for electrical neutralization. Beam neutralization is required in order that the propulsor not charge to a potential such that beam flow is altered during operation. Because of the great difference in mass between ions and electrons, a method of insuring both charge and current neutrality represents a problem of significant concern. Plasma acceleration utilizes electric and/or magnetic fields to cause high velocity flow in the same direction for particles of both electric-charge types—the so-called plasma.

One measure of electric propulsor performance is power efficiency which is the ratio of the beam power to the applied electrical power. The power efficiency for electrothermal acceleration is about 60% at a specific impulse of about 1,000 seconds and greater than 80% at specific impulses higher than 5,000 seconds for electrostatic accelerators. Plasma accelerators offer the potential of maximum efficiency for specific impulses between 2,000 and 4,000 seconds with a value of about 40% having been obtained under certain laboratory conditions. This efficiency must be improved in order to capitalize adequately on this type of propulsion.

ELECTROTHERMAL PROPULSORS

In terms of specific impulse, the electrothermal propulsors rank next above chemical rockets. If one excludes nuclear rockets (in which particles obtain their energy from reactor heating), then electrothermal devices represent the only propulsion system in the range of from 500 to 2,000 seconds upon which any sizable amount of development has been done. The arc jet concept of this electrothermal accelerator is illustrated in Fig. 3.

As in the chemical rocket, the electrothermal rocket derives its motive powers from the expansion of hot gases through a nozzle. Unlike a chemical rocket, however, the enthalpy of the propellant gas in the electrothermal rocket is obtained not from an exothermic chemical reaction but from the ohmic dissipation of electrical power in the gas. This ohmic dissipation is brought about by one of two mechanisms at present:

1) *The Thermal Arc Jet.* In this mechanism, a large electric current is caused to flow through the gas. The fluxes of high currents through the gas are produced when the gas undergoes a dramatic reduction in electrical resistivity by virtue of its having been partially ionized. A 30-kw engine built by Plasmadyne[6] has achieved efficiencies of 45% at a specific impulse of 1,000 seconds with hydrogen as the fuel. On the other hand, at an I_{sp} of 2,000 seconds, the power efficiency drops to 20%.
2) *The Resistance-Heated Jet.* In this mechanism, the gas is made to flow through tungsten tubes that are electrically heated. Propellant temperatures of about 2,800°C have been achieved, which (for hydrogen as a propellant) is equivalent to a specific impulse of 1,000 seconds. In actual practice, Jack and Spisz[7] of NASA report an efficiency of about 50% for a specific impulse of 850 seconds.

Because higher specific impulses demand increased propellant enthalpies, the losses resulting from such operation increase. Two important sources of loss are: 1) the ionization and dissociation remaining in the gas after expansion in the nozzle (*frozen flow*) and, 2) the heat flux to the walls. Associated with this heat loss is electrode erosion which affects the useful life of the device. Continued work on electrothermal devices will be directed primarily towards reducing losses which will permit efficient operation at the higher specific-impulse levels and in addition will reduce erosion problems and thus increase engine lifetime. Even with marked improvements, it appears that electrothermal devices will be limited to missions requiring specific impulses of less than 2,000 seconds.

ELECTROSTATIC PROPULSORS

Ion Accelerators

Historically, it has developed that electrostatic propulsors are classified primarily according to the method of ion production. Almost without exception, the ion sources used are 1) contact or surface ionization of cesium on refractory metal surfaces and 2) electron bombardment or impact ionization of the propellant atoms in a low-pressure gas discharge. In the surface ionization of cesium by a porous refractory metal, the cesium vapor is fed into the rear of a heated tungsten plug and migrates along the capillary-like pores to the front surface where it is evaporated as a cesium ion. The ionization near the surface is nearly 100% because the work function of the tungsten is higher than the ionization energy of the cesium atom and, thus, a cesium electron finds a lower energy state within the tungsten. Of the two well-developed contact-ionization type devices today, one uses an annular geometry for the porous tungsten source. (The diameter and thickness of the annulus can be varied within limits to permit operation at various power levels.) In the second type, small (3/16-inch-diameter), porous tungsten buttons are arranged in closely packed hexagonal order to produce a multiplicity of ion beams.

In the electron-bombardment type ion source, an electron-emitting filament is situated near the axis of a hollow cylinder whose radial and axial dimensions are approximately equal and the walls of which are at a positive potential with respect to the filament. An axial magnetic field is impressed on the system, which causes the electrons to spiral on their way to the anode and thus increases their lifetime. Ionization of the propellant gas takes place by electron bombardment.

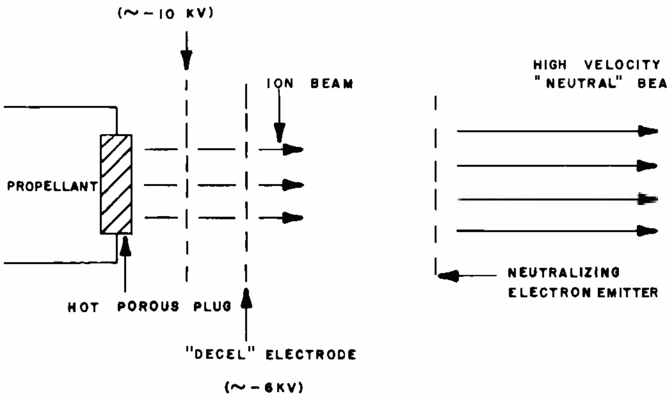
In all devices utilizing either of these ion sources, electrodes are arranged to accelerate the ions to high velocity. The amount of current that may be drawn is limited by space charge. In order to overcome, to a degree, this limitation, an *accel-decel* system of electrodes can be used. The particles are accelerated to energies higher than those finally desired in order to increase the flux of ions from the source. Then a decel electrode at less potential is utilized to bring the particle velocity down to the desired specific impulse. Such an accel-decel arrangement also prevents the neutralizing electrons from reaching the ion source. The current densities available from the above devices are of the order of 10 ma/cm^2 for specific impulse levels of from 5,000 to 10,000 seconds.

The ion optics associated with the electron bombardment system present greater problems regarding engine life than with the surface ionization system. This is due to the fact that in the porous plug ionizer, the ion-producing surface is well defined while in the electron bombardment source, the ions are extracted from a plasma sheath whose shape is a function of the engine operating parameters. This particular phase of development is extremely important because of its effect on erosion of electrodes and, thus, on the lifetime of the engine. At present, such engines have operated as long as several hundred hours, which is only a small fraction of the time required to justify the use of electric propulsors.

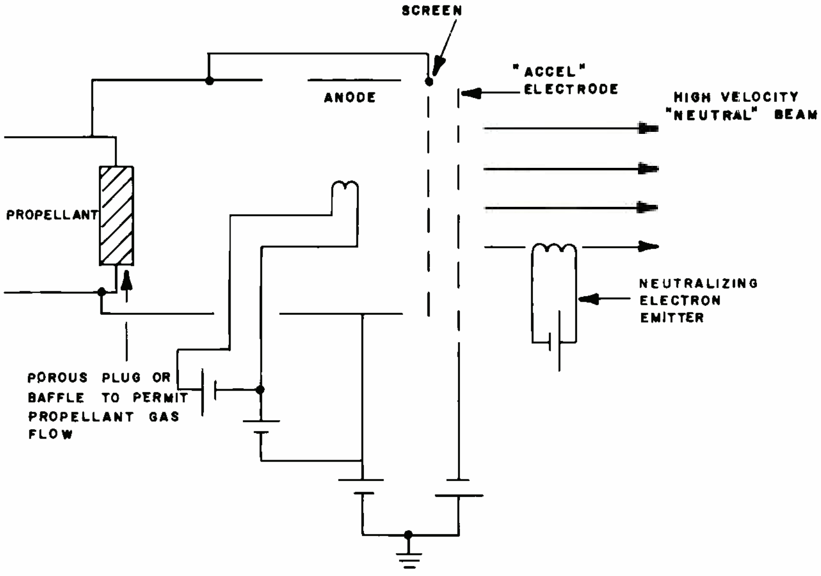
As mentioned earlier, it is essential that the thrusting beam be neutralized in order that the engine and vehicle potential remain constant during operation. Immediately following the electrode that adjusts the ions to the proper velocity is placed a source of electrons for neutralization of the beam. Because of the low mass of the electron, the velocity of the electrons produced thermionically is much higher than that of the ions. Thus, injection of electrons into the ion beam for neutralization does not imply motion of both charged particles at identical velocities nor does it imply a recombination process. Electrons are injected into the ion beam and oscillate continuously therein. Microscopically, the beam is a mixture of negative and positive charges with the electrons spending most of their time near the radial edges of the ion beam; macroscopically, however, the beam appears neutralized. Although convincing experiments[8] have been performed that indicate that neutralization will not be a serious problem with electrostatic devices, some concern about this possibility remains. One of the main objectives of the first space flight of such engines is to test the neutralization problem. The Astro-Electronics Division has the responsibility for the NASA program to test ion engines in space. It is anticipated that the vehicle (SERT) containing both an engine of the contact ionization type (Hughes Aircraft) and one of the electron bombardment type (Lewis Research Center of NASA) will be launched during 1964. Conceptual drawings of both the contact ionization and the ion bombardment accelerators are given in Fig. 4.

Present ion engines exhibit efficiencies of from 70 to 90% at specific impulse

Fig. 4—Ion accelerator concepts.



(a.) CONTACT IONIZATION TYPE



(b) ELECTRON BOMBARDMENT TYPE

values above 5,000 seconds. The maximum efficiency is limited by the energy lost to ionization:

$$\text{LIMITING EFFICIENCY} = \frac{V\ accelerating}{V\ accelerating + V\ practical\ ionization\ values}$$

And thus, as the specific impulse is decreased, the contribution of the loss factor of ionization becomes more significant. Thus, the efficiency of ion engines decreases as the specific impulse decreases. At present, even though ionization potentials may be about 15 volts/particle, the amount of energy actually utilized for ionization is in the order of 1,000 volts/particle.

This limitation in ion engine efficiency at lower specific impulses has been considered in the development of at least two concepts currently being investigated. One concept makes use of massive particles rather than single ions to provide the thrust. Thus, much higher accelerating potentials than for ion acceleration are required to reach desired specific impulses. Thus, the contribution of the loss factor due to ionization becomes less significant. Also, with a more massive particle, the thrust per unit area obtainable for equal number density will be higher. A second concept to improve ion engine efficiency at the lower specific impulses is one that is currently being investigated at AED. This concept called the Neutralized-Ion Cascade Engine (NICE) makes use of the charge-exchange principle to produce a greater mass flow of high speed neutral particles in the efflux than in the entering ion current.

Massive Particle Acceleration (Colloid Propulsion)

The advantages colloid accelerators hold in principle over their ionic counterparts include 1) the capability of efficient operation in the very important 1,000-to-5,000-second specific-impulse range, 2) the ability to provide useful thrust levels at low-aspect ratios (i.e., relatively small ratio of the beam diameter to the acceleration distance) thereby somewhat easing neutralization requirements, and 3) the possibility of continuously variable charge-to-mass ratio, which would permit a continuous variation of specific impulse.

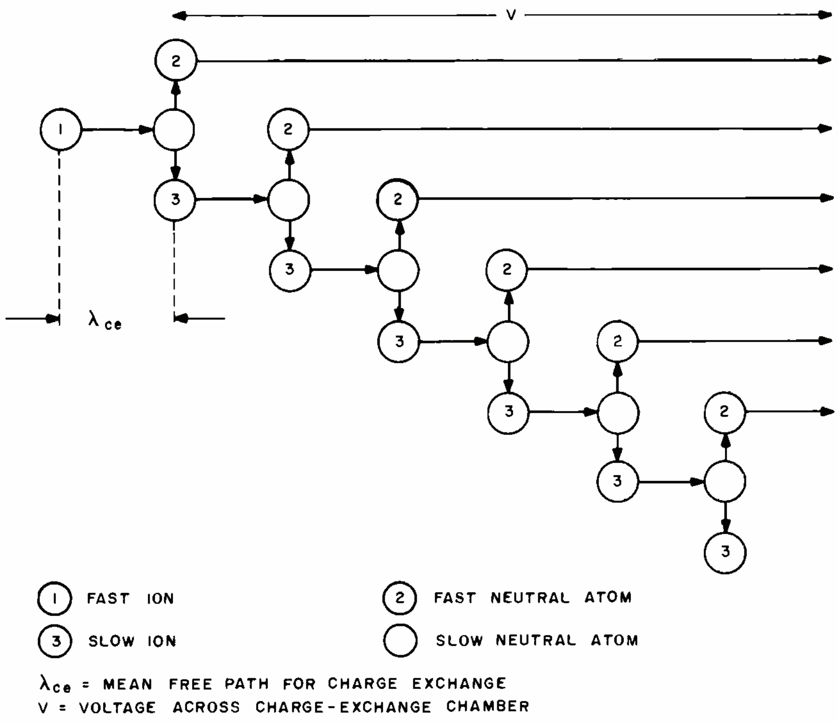
The above represent distinct advantages. However, at the present time, they are merely possibilities, rather than achievements. While the state-of-the-art of ionic propulsion has advanced almost to the operational stage, heavy-particle propulsion[9] is now being confronted with difficult problems in its infant stage.

Efficient operation of colloid propulsors is possible only if the exhaust beam is characterized by a single velocity. In order to obtain a high efficiency, it is, therefore, necessary that the beam consist of particles, all of which have nearly the same charge-to-mass ratio. The charge-to-mass ratios useful for colloid propulsion extend from about 200 to 10^5 coulombs/kg. The problem of generating sufficient numbers of particles satisfying the above conditions is presently the largest obstacle to progress in colloid propulsion. The undesirable effects encountered include the production of large amounts of atomic ions in addition to the desired colloids, the fragmentation of particles upon charging, the agglomeration of very fine particles, and broad distributions of charge-to-mass ratio. Many of these adverse effects may be attributed to the very high accelerating potentials (about 100 kv) required for accelerating the colloids.

Neutralized-Ion Cascade Engine

An engine utilizing a charge exchange concept achieves its thrust by ejecting fast neutral atoms, in contradistinction to more-conventional ion accelerators that eject fast positive ions whose charge must be neutralized later by mixing with electrons. If a high-velocity ion flows through a cloud of atoms of sufficient number density, the ion will pick up with little momentum change an electron from a neutral atom by a process called charge exchange. In the cascade concept, this process is utilized in a serial fashion to multiply the neutral output beam current without an increase in the input ion current. The fast neutral atoms are engendered in "charge exchange" between fast atomic ions and slow neutral atoms. The slow neutral atoms exist as a cold background gas. The charge exchange process converts the fast ion to a fast neutral atom moving in the same direction as was the ion; simultaneously, the slow background gas atom is converted to a slow (essentially zero velocity) ion, which—like the original ion—is accelerated and made to yield a fast neutral atom by means of charge exchange. This possibility of obtaining many fast neutral atoms per original ion (the cascade property) makes such a device inherently more efficient and capable of more thrust per unit area than conventional ion engines, especially at the low specific-impulse levels. The operation of this concept is shown, diagrammatically, in Fig. 5. The attractiveness of this concept relies on the high ratio of charge-exchange cross-section to scattering cross-section. For example, if the ratio is 15, then on the average, it would be possible to adjust the ambient background pressure to a value such that 15 charge-exchange reactions occur for each scattering reaction. Thus, if the process were cascaded 10 times, the geometric spread in the beam efflux due to scattering should be insignificant. To date, some joint experiments on charge exchange, involving AED groups and the DEP Plasma and Space Applied Physics group, have been performed. In these,

Fig. 5—Neutralized ion cascade engine concept.



argon has been used as the propellant. The information on scattering that has been obtained is consistent with that developed from the theoretical investigations. Multiplication experiments are currently underway.

PLASMA ACCELERATION

While plasma acceleration offers the potential of: 1) relatively high efficiency of operation at specific impulse levels of from 2,000 to 5,000 seconds; 2) high thrust-to-beam-area ratio (as a result of freedom from space-charge limitations); and 3) a greatly reduced neutralization problem, the problems of effecting such a practical device are quite serious. Some of the problems are those involved with achieving coupling between the energy source and the plasma, with obtaining high conductivity of the plasma, and with reducing losses caused by diffusion phenomena.

Many schemes for accelerating plasma have been investigated. The best known are those that utilize the interaction of a crossed current and magnetic field to produce a force at right angles to both current and magnetic field which is in the same direction for particles of both charges.

The so-called Hall current accelerators[10] are receiving increased attention as a concept that appears attractive for plasma propulsion. In addition to investigations specifically oriented to exploiting this Hall mechanism, investigations concerned with devices of other titles such as the oscillating-electron ion engine and the magnetic annular arc operate in regimes similar to that of Hall accelerators.

Experiments have been performed by AED and the RCA Laboratories on a concept of accelerating plasma by an RF electric-field gradient, with no need for application of magnetic fields.

At the present time, AED research is pursuing work directed toward utilizing the electron cyclotron resonance phenomena to accelerate plasmas.

$j \times B$ Acceleration

Acceleration of charged particles can be accomplished by the application of Lorentz type forces. This concept is illustrated in Fig. 6. Experiments have been performed in which operation is pulsed or continuous and in which the current that interacts with the *B* field flows because of an applied *E* field or because it is induced from a pulsed or traveling magnetic field. In all cases, the interaction of the current *j* with the *B* field causes the charged particles to flow at right angles to both *j* and *B*. Because of the relatively high density of the gas, the charged particles that are accelerated by this $j \times B$ force collide with and transfer their momentum to neutral particles in the plasma. Thus the bulk plasma is accelerated. Excluding the power losses encountered in producing 1) *the plasma*, 2) *the magnetic field*, and 3) *the anode-cathode current flow*, joule heating of the plasma is the limiting factor that determines the maximum theoretical efficiency of the device.

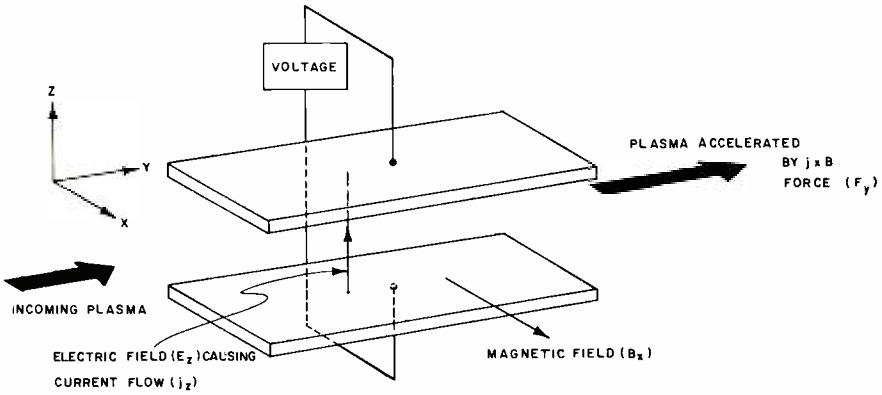


Fig. 6—Concept of $j \times B$ acceleration

Experimental results which have been reported and which appear to demonstrate high performance are those of Demetriades,[11] who uses a thermal arc jet as the plasma source. He introduces this jet into a region of applied electric and magnetic fields, and observes the $j \times B$ acceleration. At a specific impulse of 2,400 seconds, an acceleration efficiency (which does not include, among other items, the energy needed in the arc jet for ionization of the particles) of 54% has been reported.

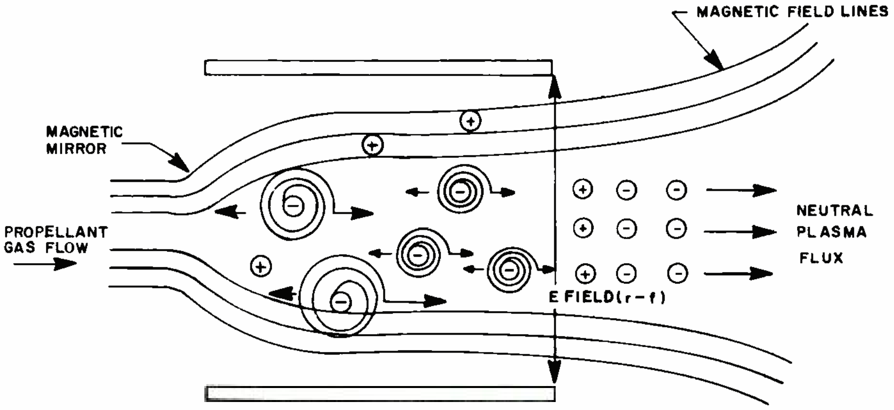
Capacitor Discharge Devices

The operating principle of the pulsed plasma guns[12] is based on the application of the $j \times B$ forces. Recent experiments[13,14] have shown that space-charge effects set up after discharge between the rapidly moving electrons and the slower ions also contribute significantly to the accelerating effect. One type of plasma gun consists of a pair of coaxial cylinders connected to the terminals of a capacitor. When gas is admitted, a discharge occurs, and a high-speed plasma blob issues forth. Instead of coaxial cylinders, metal rods or rails[15] may also be used for directing the plasma pulse produced at capacitor discharge. Bostick[16] is responsible for plasma guns of the button type. The pinch-plasma engine[17] is a pulsed device similar in operation to the guns mentioned above. It has been developed (under government support) to the stage where it can soon be tested in space.

RF Gradient Field Plasma Accelerator

An interesting experiment conceived by G. Swartz of the RCA Laboratories is that of the acceleration of plasma by an RF electric field gradient. Experiments were performed at the David Sarnoff Research Center in a joint program by AED and the RCA Laboratories that demonstrated the accelerating effect of such fields. Experiments[18,19,20] were performed

Fig. 7—Electron cyclotron resonance accelerator.



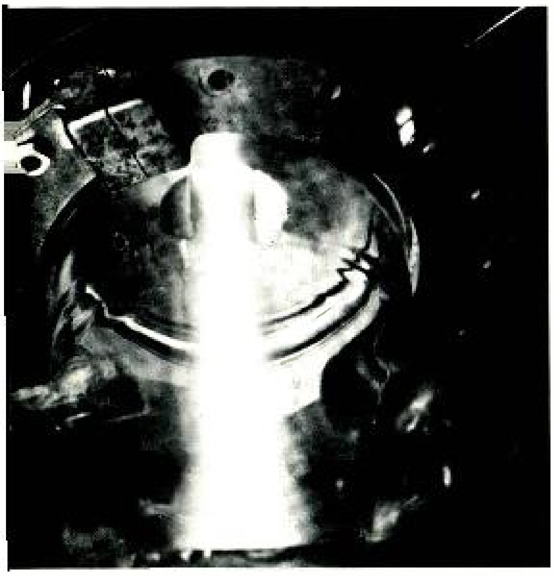


Fig. 8—Mercury plasma beam issuing from equipment presently in use.

at 140, 330 and 2,450 Mc using mercury propellant in the pulsed mode and cesium in the continuous mode. Velocities as high as 2×10^6 cm/sec were observed and various results were consistent with the theory. The mechanism did not appear, however, to be adaptable to a practical device.

Hall Accelerators

A number of accelerating mechanisms have been reported that are based on electrostatic acceleration of ions with simultaneous neutralization of the current-limiting space charge. Assuming that ions are to be accelerated efficiently in a neutralizing background of electrons, the electrons must be prevented one way or another from being accelerated in the opposite direction. This can be effected by imposing a magnetic field at right angles to the direction of acceleration. For conditions where $\omega \tau > 1$ (ω is the cyclotron frequency and τ is the time between collisions), the electrons are bound to the magnetic field whereas the ions can be accelerated, since their Larmor radius is much greater than both the electrons' Larmor radius and also the length of the accelerating region.

Many plasma propulsion concepts have evolved which make use of the Hall acceleration principle[21] but continue to retain their original name such as the magnetic annular arc[22] and the oscillating electron ion engine.[23] Experiments using a modification of a hot-cathode Penning discharge have produced plasma beams of density about $10^{10}/\text{cm}^3$ at velocities up to 3×10^6 cm/sec for argon. This arrangement (usually called the oscillating electron engine) has the advantage, as far as a practical device is concerned, of using all DC potentials; however, it suffers from deterioration of the electron emitter by ion bombardment.

Electron Cyclotron Resonance Plasma Accelerator

At AED, an investigation of the acceleration of neutral plasmas has grown out of earlier work on high velocities of ion pulses caused by space-charge effects occurring after capacitor discharge. The ion energy was obtained by transfer from the electron's original energy in the discharge. Efforts were then directed 1) toward operation on a continuous, rather than a pulsed, basis and 2) toward feeding in relatively high energy to the electrons in the plasma. Deviating from the more standard pattern of acceleration of the ions, this method[24,25] initially raises the energy content of only the electron gas by selective transfer of RF energy to electrons at cyclotron resonance. The electrons leaving the accelerator set up space-charge fields that accelerate the ions in a fashion very similar to the oscillating electron engine mentioned earlier. The RF energy serves the purpose not only of feeding energy to the electrons at cyclotron resonance but also of ionizing the supply gas. The cyclotron resonance accelerator arrangement is shown as a schematic diagram in Fig. 7. Mercury ion energies ranging from 50 to 135 ev at densities of nearly $10^{11}/\text{cm}^3$ have been obtained. Measurements have shown that the velocity distribution of particles in the beam is rather narrow (the width of distribution at half maximum equals ± 6% of average energy). Current experiments being performed with RF fields at 2450 Mc are being directed toward measuring efficiency, studying diffusion effects especially transverse to the magnetic field, and testing methods to reduce losses and thus increase efficiency. A photograph of a mercury plasma beam issuing from the equipment in use at present is shown in Fig. 8.

Table I—Probable Performance Range of Various Thrust Units

Engine	*Specific Impulse (sec)*	*Efficiency (%)*	*Power-to-Thrust Ratio (kw/lb)*
Resistojet	<1000	<70	50
Arc Jet	1,000 to 1,500	50 @ 1,000 sec	100
Ion Accelerators	5,000 to 10,000	60-90	300
Continuous Plasma	1,500 to 4,000	40	50
Pulsed Plasma	5,000 to 8,000	40	350

ESTIMATED PERFORMANCE OF PROPULSION DEVICES

Table I contains an estimation of the probable performance of the various propulsive devices discussed previously. It is apparent that the ion accelerators are currently by far the most efficient. On the other hand, they have yet to demonstrate adequate life for satisfactory use in space. If the efficiency of the plasma devices can be increased to a value comparable to the ion devices, then the higher thrust-to-area ratio of the plasma devices will make them more attractive. One possible contender not presented in Table I, but mentioned previously, is colloid propulsion. Although attractive in concept, practical devices still await invention. Therefore, an estimate of performance has not been made. The right hand column of the table defines the power-to-thrust ratio expected of these propulsors. This is a most significant parameter since in effect it sizes the power supply required to develop a unit of thrust and hence sets practical limits on the thrust-to-weight ratio of the system.

POWER SUPPLY CONSIDERATIONS

Although considerable developmental effort is presently underway, there are no power supplies currently available that are suitable for an electrically propelled vehicle. It is, nevertheless, prudent, from a planning viewpoint, to summarize and compare the expected performance of various classes of power supplies that may be applicable to electrical propulsion.

The summary presented is based on the results of a previous survey[2] and the intuitive feeling of the authors for advances in performance. The converters surveyed have been classified into either the static or dynamic category. The static converters considered were: *thermionic*, *thermoelectric*, and *solar cells*. The dynamic systems were: *turbomachinery*, *Sterling cycle*, and *magnetohydrodynamic* (MHD).

For all of the above systems (with the exception of the solar cells) the limiting factors, as the power requirements increase, are the size and weight of the radiator. The large area required for heat rejection makes packaging difficult and increases the probability of micrometeorite penetration. For the nuclear-powered systems, the shielding requirements introduce a secondary limiting

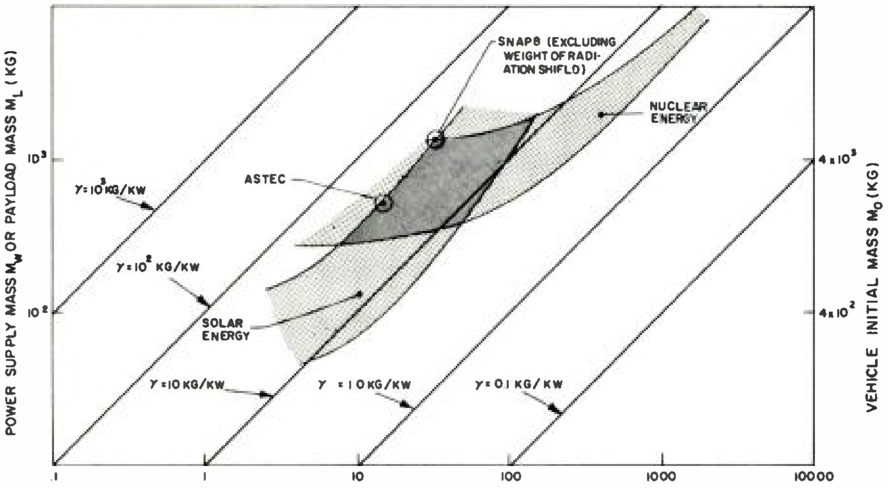


Fig. 9—Regions of application for nuclear and solar propulsive power sources.

factor. For the solar-powered systems, the primary limiting factor is the size of the solar collector involved.

It is difficult to select power levels for electrical propulsion without a specific mission analysis. However, for the purpose of establishing a preferred power range, 30 kw-elec SNAP 8, has been selected as a lower limit on usefulness, with 10 Mw-elec as a possible upper limit. Weight is also a difficult limitation to establish, especially since it is a nonlinear function of power. However, for interplanetary missions an upper limit on specific weight of approximately 50 lbs/kw-elec is still considered usable, with 10 lbs/kw-elec much more desirable. It is expected that the life must have a mean time-to-wear-out failure of the order of 10,000 hours or greater. The corresponding reliability must obviously be high, but such a projection can only be accomplished on a subjective basis at this time.

The over-all results are summarized in the curves of Fig. 9.[2] Shown is a plot of power supply mass versus electrical power out. It has been shown that for most missions optimum transfer is accomplished when the power supply mass is equal to the payload mass. The remaining mass is then allocated between the propellant, tankage, and structure. Under these conditions the right hand ordinate of the plot of payload versus power has been adjusted to indicate the total vehicle mass. Superimposed on this general plot are the regions of application for solar energy devices and nuclear energy systems. Since it was necessary to use many assumptions in the study the results are presented as broad bands. The upper limit represents pessimistic assumptions while the lower limit represents optimistic assumptions. By way of a check point, the SNAP 8 system is shown spotted on the upper limit line for nuclear power and the ASTEC (Advanced Solar Turbo Electric Concept) system is shown spotted on the upper limit line for solar power. It is anticipated that advances in the state-of-the-art will permit a reduction in the weights of these systems. Unfortunately, experience to date has not been encouraging. The curves shown indicate that nuclear-heat sources at the present time outclass the solar devices in the high-power ranges that are of primary interest in electric propulsion. This conclusion could be changed if ultralightweight solar cells become practical; however, additional development remains to be done before such cells can be included in this comparison. In any event, it is apparent that a considerable advance in power and propulsion technology is required before the full benefits of electric propulsion can be realized. However, it should also be made clear that only by using electric propulsion will it be practical to accomplish the more ambitious missions.

ACKNOWLEDGMENT

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SEER

Systems Engineering, Evaluation, and Research

DAVID SHORE received his BS in Aeronautical Engineering from the University of Michigan in 1941 and his MS in Physics from Ohio State University in 1950. From 1941 to 1954, Mr. Shore was with the USAF Wright Air Development Center, advancing to Assistant Chief of the Systems Planning Office, Weapon Systems Directorate in 1950-54. He joined the RCA Missile and Surface Radar Department in 1954 as Project Manager and directed several complex systems studies. He then had responsibility for all BMEWS systems engineering. In 1958, he was appointed Associate Director of DEP Advanced Military Systems. In August 1960, Mr. Shore took charge of all RCA studies on Satellite Inspector systems. Upon receipt of the SAINT contract, he was made SAINT Program Manager. In June 1962, Mr. Shore was made head of the new SEER group, responsible for studying and proposing new military and NASA systems. Also, since April 1963 he has been Technical Director for the RCA AADS-70 effort.

D. SHORE, Chief Systems Engineer

SEER
Defense Engineering
DEP, Moorestown, N.J.

GROWTH of corporations such as RCA has led to the formation of decentralized divisions operating as essentially separate businesses. While greater efficiency is achieved within the divisions, it is at the expense of effective multidivisional efforts on major systems.

In Defense Electronic Products, the Systems Engineering, Evaluation, and Research activity (SEER) was activated in October 1962 to remove this drawback of corporate size (Fig. 1). The first challenge for SEER was:

1) *Provide the leadership for companywide efforts on complex new systems.*

To provide such leadership requires more than creative systems engineering. The Department of Defense emphasis on cost effectiveness, program management and the introduction of the program-definition phase resulted in the second challenge for SEER:

2) *Provide project management "know-how" in new systems efforts.*

This is, perhaps, the greatest innovation in the SEER concept. Experience of past major programs in RCA has emphasized the need for technical continuity in a major system — from concept through test and evaluation. The third challenge for SEER was:

3) *Provide the key project and systems personnel to establish and run projects resulting from successful SEER efforts.*

This first anniversary of SEER is an opportunity to assess how the above three challenges were met.

Certainly the most significant event was the LUNAR EXCURSION MODULE (LEM) effort with Grumman Aircraft which culminated in the award of this phase of APOLLO to Grumman.

The SEER team on LEM was made up of men whose background had been on ground-based defense systems, with a heavy emphasis on radars. This team had been "re-tread" over a period of time into the developing field of space.

The value of the concept of an RCA team effort led by SEER was proven. Three major RCA divisions and other RCA organizations participated. The experience of the DEP Aerospace Systems Division on the USAF SATELLITE INSPECTOR program and of the DEP Astro-Electronics Division on TIROS, RELAY, and many other satellites was integrated into the attack against the staggering new problems of manned lunar landing and return. Team effort on LEM was a process of learning to work together as members of RCA — not of subordinate divisions. *The process was painful at times, but we all learned by experience how partisanship could be overcome.* SEER was able to demonstrate RCA competence — not just utilization of RCA products. Realistic cost and schedule estimates were the product of extensive effort by SEER's project engineering personnel.

Recently, LEM was established as a program for hardware implementation in the Aerospace Systems Division. SEER personnel who headed the proposal effort now direct the program.

Since then, SEER-led efforts have found increasing support in the divisions. The period of achieving acceptance by our colleagues in the product divisions is over.

Other programs since LEM which have continued this success pattern include:

1) Verification of a basically new antimissile discrimination technique.

2) Quantitative assessment of antisatellite surveillance systems (an ARPA contract).

3) Evaluation of Navy antisatellite concepts (a Navy contract).

4) Design of a command center for the military communication satellite system (an Army contract).

5) Application of certain radar techniques to sonar for antisubmarine warfare (a Navy contract).

6) Evaluation of nuclear effects (an ARPA contract).

The recital of these contracts is to emphasize the diversity of SEER activities, not just to indicate its acceptance by the government. It should be clear that these projects represented the culmination of company sponsored efforts averaging almost a year each.

. . . We resist most strongly against falling into the trap of the "proposal mill"—We do not seek contracts until we have done our homework.

These policies continue as we now expand our efforts into the fields of general-purpose forces, mobile command and control, and new space systems.

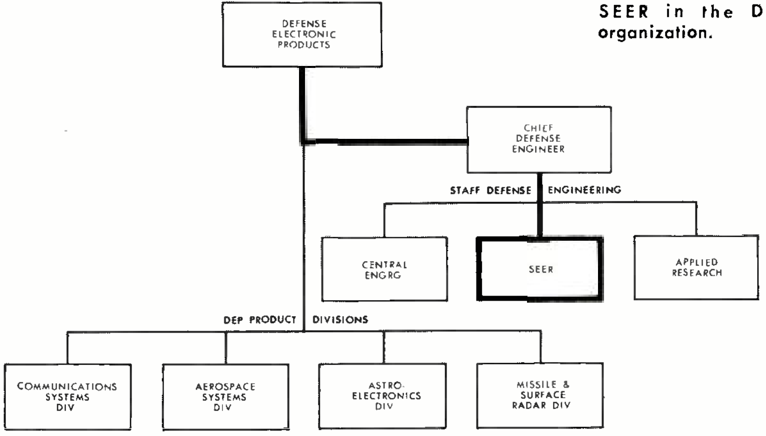

Fig. 1—Position of SEER in the DEP organization.

TOOLS AND TECHNIQUES FOR SPACE SURVEILLANCE STUDIES

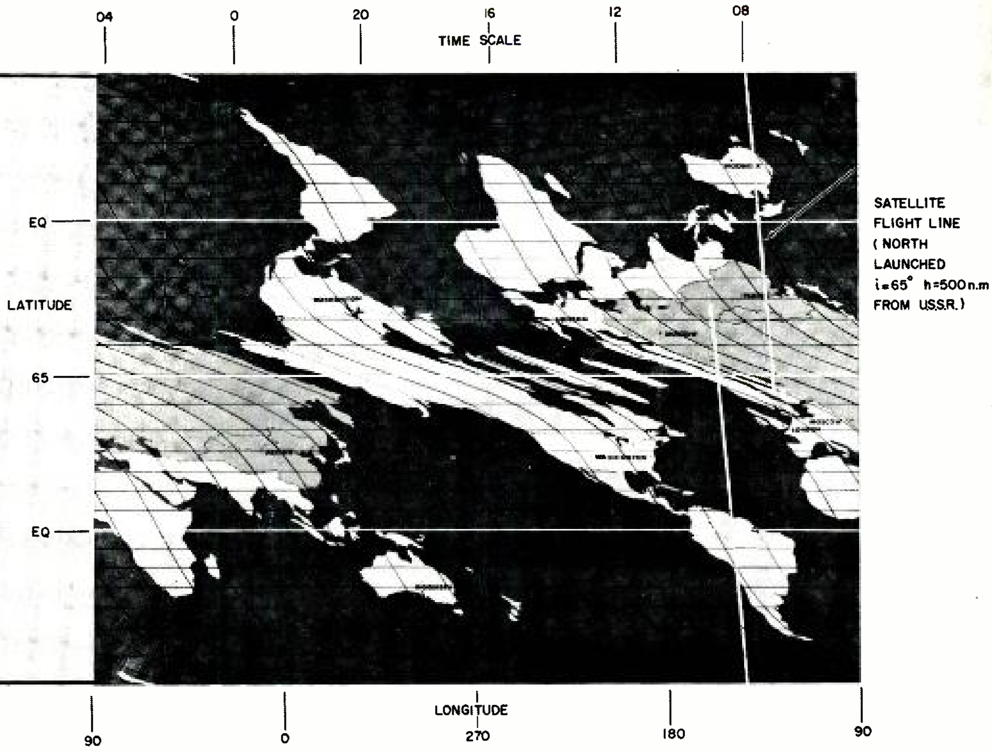

Fig. 1—B-chart.

In conducting studies of space surveillance, the SEER (Systems Engineering, Evaluation, and Research) activity in Moorestown has developed a number of design and operational aids, as well as procedures for applying these aids to space technology problems. These aids include B-charts, the PAGE computer program, and performance displays, each of which is discussed in this paper.

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Since 1957, RCA has participated in a wide variety of space-associated programs including TIROS, RELAY, SATELLITE INSPECTION SYSTEM, BMEWS, BMEWS-SPADATS integration, space surveillance operation of the Moorestown AN/FPS-49 radar, ARPA's antisatellite studies, and the Navy's EARLY SPRING antisatellite system.

Each of these programs generated problems in the analysis and synthesis of space networks, systems, and subsystems. In organizing a systematic approach to the solution of these problems, the Systems Engineering, Evaluation and Research (SEER) activity has developed a number of design and operational aids, facilities, and procedures for applying these aids to space technology problems. These tools are continually being refined to provide more efficient means for solving future space problems even as they are being applied to present problems.

One of the significant factors in the development of RCA's capability in this field was the company's participation in an experimental program using the Moorestown AN/FPS-49 tracking radar as an operational SPADATS sensor. The execution of this program as well as the continual liaison with the technical staff at the USAF 496L SPO, which sponsored the program, resulted in a clearer understanding of some of the space surveillance problems confronting military agencies now and in the future.

FACILITIES

Because of the need for extensive analysis and synthesis effort in the conduct of the space surveillance studies, SEER has available an IBM 7090 and an IBM 1620 computer at Moorestown for this purpose, on a scheduled basis. Extensive space-related programs, including programs which simulate ground-environment and satellite population, are in use for both computers. Workshop facilities for graphic and hand-calculator solution of space trajectory problems employ a group of unique aids which permit parametric solutions for various combinations of network elements. These aids include Breckman Charts (B-charts), PAGE (Performance Analysis of Ground Environment) computer program, and performance displays. Each of these aids is discussed later in this paper.

A Satellite Information Center has been established to house existing space surveillance information and to permit immediate updating of data and techniques as further studies produce refinements. The files of the Center contain:

1) Sets of B-charts, earth and space charts, globes, etc., for computations, analyses, and displays;
2) Trajectory descriptions of each orbiting object including flight lines, height characteristics, orbital elements, and the history of its variations;
3) Known physical characteristics for each orbiting object which may include mission, size, shape, material, equipment, emissions, mass, body dynamics, drag coefficients, etc.;
4) A compilation of geophysical constants and formulas;
5) A comprehensive bibliography (including abstracts of books, reports, journals, and articles) relating to the problems of space-object detection, identification, assess-

ment, cataloging, tracking, and control;

6) A description of the sensors, both radar and optical, in the space surveillance network, including their locations, scan patterns, operational parameters, and error characteristics.

In conjunction with the computers and the Satellite Information Center, the Moorestown AN/FPS-49 tracking radar is used to check space surveillance procedures developed by SEER. The performance of this radar as a space surveillance sensor was described in a report[1] published in 1961.

STUDY TOOLS

The unusual study tools previously mentioned were developed specifically to simplify the proper solution of space-surveillance problems. The most versatile of these tools is the B-chart.

B-charts

Maps and charts based upon the Breckman Projection, a copyrighted RCA technique, are variously referred to as B-maps, B-projections, or B-charts. The B-chart does for space and satellite problems what the Mercator projection did for earth charting and ship navigation centuries ago. Just as the Mercator charts render a ship's course as a straight line, a B-chart represents a zone of the earth in such a manner that the ground track of a circular-orbit satellite traversing that zone appears as a straight line. Thus, the B-chart gives an analyst in the office or field a tool which makes manageable all the complex relations of celestial mechanics and earth geography which are involved in present day space problems.

B-charts are now an operational tool in the Air Force Space Detection and Tracking System (SPADATS) and are an integral part of the space program participation of the Kwajelian Station (TRADEX).

The B-chart information displays the full geographic and time history of the object for a single day or a succession of days. As shown in Fig. 1, background grids against which the object's course is traced include latitude and longitude, local azimuth and ground range, political boundaries, and geographic features. The more significant properties of the B-charts are:

1) *Equal horizontal distances on the chart require equal time to traverse.* This fact holds whether the trajectory is circular, elliptical, or any planar shape, that is, the trajectory need not even be ballistic. Thus, the B-chart is applicable to objects that maneuver at constant inclination but arbitrarily vary all other parameters of motion. They also apply to problems with stepwise changes in inclination.

2) *The projection of the orbital plane on the earth cuts the B-chart in a vertical line.* The intersection of the plane of any orbit with the surface of a nominally spherical earth is a great circle. This great circle intersection is called the orbital cut. For an orbit whose inclination, *i*, is 90°, the orbital cut is a great circle through the poles.

3) *The ground track is a replica of the angle-versus-time characteristic of the object in its own plane.* For elliptical orbits this means that a single ground track pattern suffices for all inclinations as does the straight line for circular orbits, regardless of the motion of perigee. Drifts in perigee are accommodated by vertical shifts of the track with respect to the chart.

4) *Equal areas on the B-chart have equal probability of containing a given object.* This property holds for any trajectory, either circular or elliptical. It is, therefore, essentially useful in statistical analyses conducted on the charts, such as those involved in choosing optimum radar scan patterns to detect space targets, statistics of mutual visibility in communications networks; etc.

5) *The B-chart simultaneously displays both the time and place of the object.* This property automatically converts the ground track on the B-chart into a continuous ephemeris against a uniform time scale, whether the planar motion of the object is ballistic or not.

Perhaps the most important contribution of the B-charts is the compact, yet comprehensive, aid provided by the picture of the relationships between satellite motion, earth geography, and radar scans. This enables the analyst to discover problem areas (such as multiple intersections of flight path with coverage on a single pass), formulate them properly, state missions more precisely, and construct useful criteria for performance evaluation.

In general, the charts have two broad uses: design applications (comprising synthesis, analysis, and perfromance evaluation) and field uses (for example, at isolated radar sites or satellite communications ground terminals). The list below illustrates a few of the problems to which the charts have already been applied.

Design applications (that is, making use of the relationships between the statistics of space objects and associated ground environment) include:

1) Designing sensor scans to match a particular site to an assigned mission, such as monitoring space for new objects in a designated domain of height and inclination, updating objects which have been previously "catalogued" by Space Track personnel, rediscovering "lost" objects, and detecting remnant companions of newly launched objects.

2) Designing scans to match a group of sites to an assigned mission, so that each sensor works as part of a team. The radar, radio, or optical characteristics needed at each site for this mission are specified and the performance of the resulting network configuration is evaluated against given mission criteria. This network approach avoids the overdesign of individual radars which results from trying to make each site do the total job.

3) Optimizing site locations to meet given mission requirements. This problem is particularly important in programs involving space surveillance, satellite inspection, planning of translunar and deep space

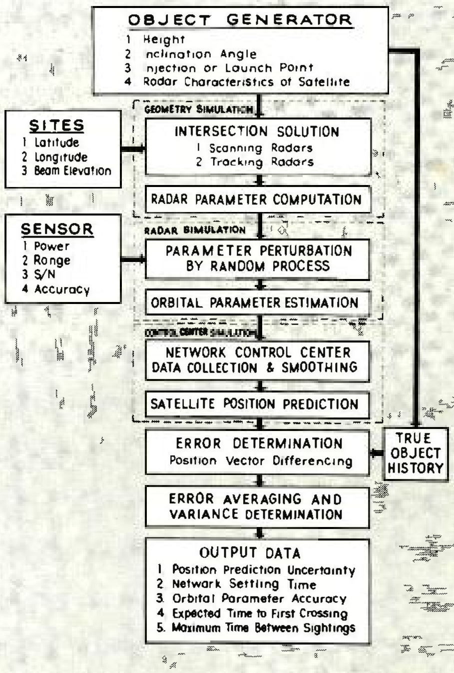

Fig. 2—Flow diagram for PAGE.

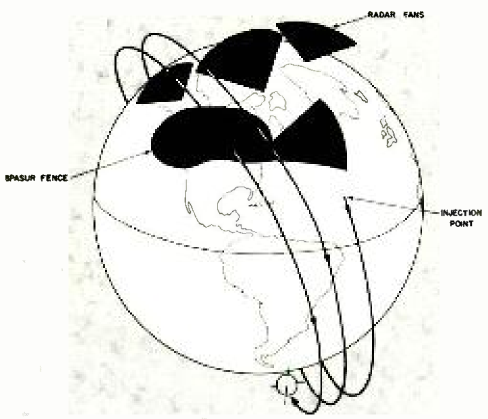

Fig. 3—History of intersection between satellite and radar network as a function of time elapsed since injection.

probe trajectories, orbital rendezvous or other "critical event" conditions, communications networks, etc.

4) Computing the average and peak data-processing burdens on ground stations in the network.
5) Specifying the cluster of satellites needed for global communication missions with respect to designing the orbits, placing a family of objects within an orbit, or arranging a group of such orbiting families. The change of the network performance is determined as the geometric relationships among the various objects change with time.
6) Evaluating the performance of existing and postulated ground networks for detecting ballistic missile attacks by considering all physically feasible energies, geometrically feasible launch angles, and politically feasible launch areas, including the oceans. On this basis, improvements may be recommended in the coverage.
7) Conducting feasibility studies on mid-course intercept of ballistic missiles or orbiting vehicles.
8) Determining optimum ground tracks and hence flight profiles (and then thrust timetables) for critical phases of special missions. Doing this on the B-chart makes use of the fact that the B-chart ground track is a replica of the angle-vs.-time characteristic.

Field applications (that is, the particulars of objects and ground environment) include:

1) Generating local look angles, range, range rate and time, under field conditions, conditions of urgency, or any other situation where a computer solution is not available or practical.
2) Providing a continuous ephemeris in topocentric or geocentric coordinates. Where several stations are involved, a chronology of events is prepared.
3) Developing on-board (space-vehicle) navigational procedures using B-charts based on the sphere of the earth, moon, sun, other planets, or celestial sphere. The charts also show the relative motion of one object with respect to another.
4) Determining the flight profile of a maneuvering or highly perturbed object from ground observations.
5) Developing the range, azimuth, elevation, and range rate programs (all versus time) for a particular sensor, to follow characteristic points on a given orbit, such as closest point on the orbit, point of closest approach, point of constant range, etc.
6) Determining and displaying the conditions for optical visibility of a given object from a given site.
7) Generating displays of the space situation for control centers and on-line flight analysis.
8) Providing quick-fix aids to command groups, planning groups, and auxiliary groups such as moonwatch teams, amateur radio operators, etc.

Ref. 2 provides a detailed explanation of the theory and use of B-charts.

Page Program

The determination of space ground environment network performance by the Page (Performance Analysis of Ground Environment) program is accomplished primarily by a digital computer using gaming techniques. The types of computations performed are presented in the following paragraphs. An overall Page flow diagram (Fig. 2) is furnished for orientation.

Geometric Intersection

After the descriptive parameters of a radar network have been specified and a satellite class (height and inclination) selected for investigation, the geometric encounters between the network and the satellites are investigated. This is done by selecting a satellite injection point on the basis of any prescribed random distribution or a specific launch point. As shown in Fig. 3, the satellite trajectory history for a given period of time is then defined and the successive encounters with each site are determined. Each geometric encounter is defined in terms of "perfect radar" range, range rate, azimuth, and elevation.

Radar Perturbations

The effect of sensor characteristics on network performance is introduced into the computations by the program as shown in Fig. 4. At each geometric encounter the instantaneous cross-section, range, and dwell time in the beam of the object are combined with the characteristics of the sensor to give a signal-to-noise ratio. This ratio is used to determine whether or not detection occurs and then to define the magnitude of error to be associated with each of the parameters found by the geometric encounter. As shown in Fig. 4, radar errors lead to a set of perturbed parameters and the consequent generation of a site-apparent object whose orbital characteristics are slightly (or greatly for a poor sensor) different than those of the true mathematical object. The magnitude of error associated with each radar parameter is indicative of data quality and is used to compute a credence factor. Credence provides a weighting factor used in smoothing data from different sites.

Orbit Smoothing

The radar data describing each site-apparent object are used by a simulated control center to calculate a center-apparent satellite orbit. The orbit of the

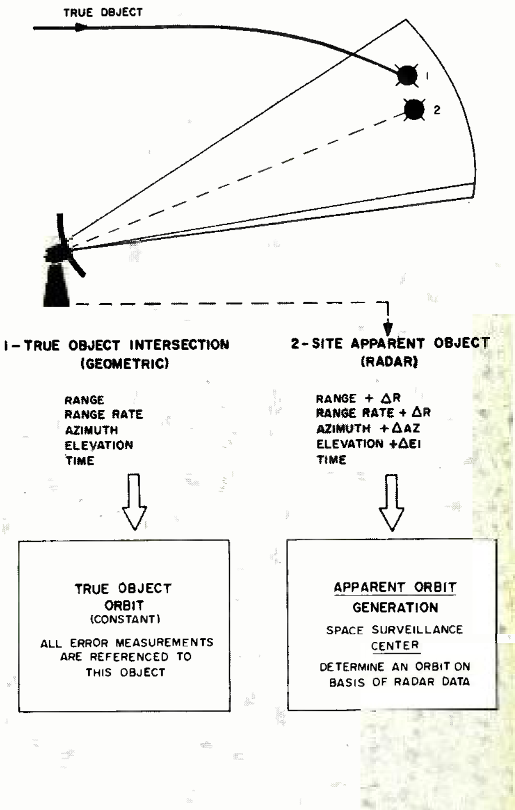

Fig. 4—Perturbation of geometric parameters by radar errors.

center-apparent satellite will, of course, differ from the true object orbit because of the data perturbations introduced by each sensor. Fig. 5 shows that, at each encounter of the true object with a sensor, the computer also determines the corresponding encounter of the center-apparent object with the same sensor. As before, the sensor characteristics result in a perturbed estimate of true object position, and it is this perturbed encounter which is smoothed with the center-apparent object encounter to provide an updated orbit.

Credences are employed as guides in combining the encounter parameters of the center-apparent object and the site-apparent object. The credences of all previous encounters are accumulated at the center and are changed in accordance with specified decay rates. The resulting credence provides a weighting factor when the data of a new encounter are smoothed with their associated credence. In this way, each new encounter is combined with all preceding encounter data to update the center's notion of the object's orbital elements.

Error Determination

At any prescribed time (or number of times) after injection, the program is instructed to determine the position of both the true object (which is the reference) and the center-apparent object as shown in Fig. 6. The position of the center-apparent object depends on the center's notion of the object's orbital elements at the time the position fix is requested. The center's estimate of the object's orbital elements at that time depends, of course, on the history of encounters preceding the prediction time. It is therefore possible to determine, as a function of time, how the center's notion of satellite position (network performance) behaves with respect to the reference object by finding the vector difference (error) between true and apparent objects at a sufficient number of prediction times. This error vector is converted to a more useful form by resolving it into three components: one along the satellite's velocity vector, the second in the plane of the orbit and perpendicular to the first component, and the third component perpendicular to the first two (that is, perpendicular to the orbital plane).

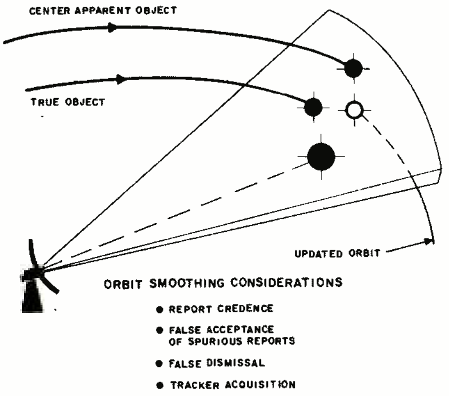

Fig. 5—Orbit updating by new encounters.

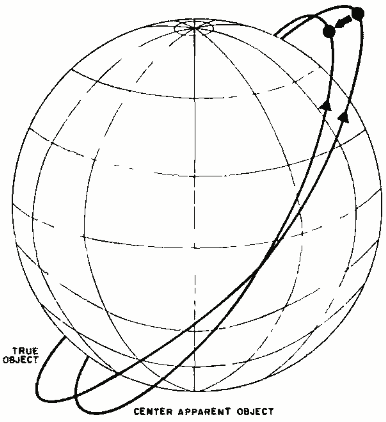

Fig. 6—Position prediction and error determination. 1) Position of center apparent object at a specific time is based on all data obtained prior to that time. 2) The vector distance between true and apparent objects is obtained.

Error Averaging and Variance Determination

The preceding paragraphs traced the events experienced by a single simulated satellite at a single height and inclination. To obtain an accurate estimate of the statistics which describe network performance for satellites at this height and inclination, it is necessary to simulate the passage of many satellites through the same order of events. For each new satellite, certain specified parameters are subjected to random variation and the process is repeated. At the end of each run, data pertaining to errors are collected, and averages, rms values, and variances are calculated. These quantities describe network performance for the height and inclination tested and constitute the bulk of the output data. Overall network performance is found by repeating this process for other combinations of satellite height and inclination. The process therefore is as summarized in the PAGE flow diagram shown in Fig. 2.

PERFORMANCE DISPLAYS

The height-inclination (*h*, *i*) plane is a representative performance display of the network reaction to various classes of objects. The parameters *h* and *i* are chosen to define the class of object because the height and inclination are threat-defining characteristics as well as orbital elements.

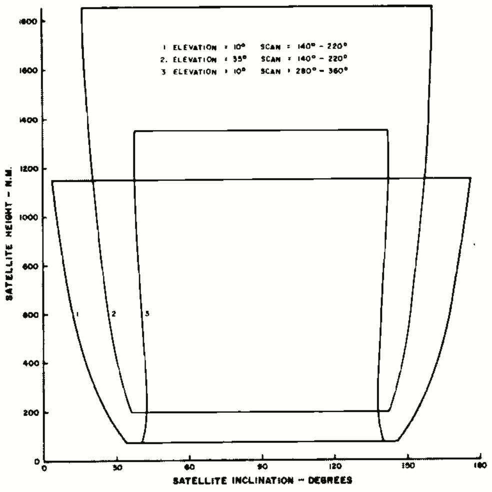

Fig. 7—Maximum visibility contours for sensor at 40° latitude.

The *h*, *i* plot is especially useful when the network performance can be stated in one of the following forms. (These statements are used as examples and do not represent actual requirements for a mission.)

1) *Contours of maximum visibility.* These contours (Fig. 7) show the limiting combinations of satellite height and inclination which are visible to a site or network.
2) *Contours of equal settling time.* In a sample plot, the 10-hour contour line on the *h*, *i* plane would contain all classes of objects for which the given network would know the orbital elements to prescribed accuracy, within 10 hours of launch. The 10-hour line will, of course, enclose the 5-hour line. Similarly, the 15-hour line will enclose all lines with smaller numbers. The plot will hold for the stated network under the stated assumption of radar cross-section and eccentricity.
3) *Contours of equal probability of detection.* In a typical case, the 80-percent probability contour line on the *h*, *i* plane would contain all classes of objects which would be detected by the given network within 24 hours of launch, with a probability of 80 percent.
4) *Contours of equal times to first detection.* Fig. 8 shows a sample plot of this contour of first geometric crossing.
5) *Contours of equal numbers of detections per day.*

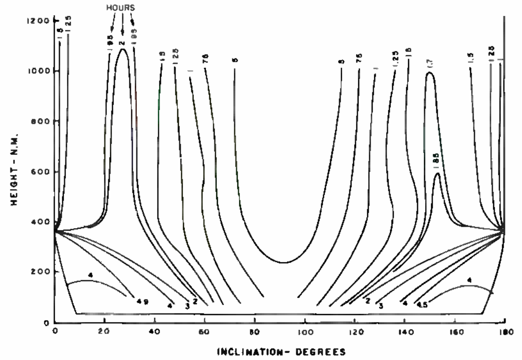

Fig. 8—Performance contours of expected time (hours) to first crossing.

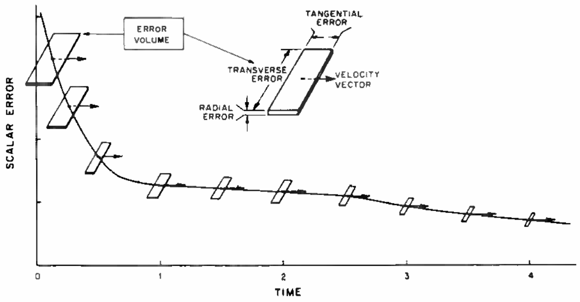

Fig. 9—Position estimate error-representative surveillance network.

6) *Contours of equal accuracy achieved after one day's operation.* Many other parameters are possible for the contour lines, the choice depending on the particular mission. In fact, number pairs may be used, rather than a single number, to characterize the performance against a given h, i class. For example, it may be desirable to display both the expected time to first detection and the standard deviation of the time to first detection. For a complete analysis the entire distribution may be presented for each of several discrete points in the h, i plane.

If the requirements for a mission can be stated in a form similar to the h, i display of network performance, a single figure of merit for network performance may be derived by superimposing the performance plot on the criteria plot and either matching these by eye or computing an approximate correlation. In any case, the h, i plane provides a format for both a quantitative statement of user requirements and a quantitative statement of network performance.

A sample of the fundamental output of an h, i pair analysis is presented in Fig. 9, showing the basic error convergence for a four-day run.

CONCLUSION

In summary, RCA has developed a set of analytical and design techniques which are suitable for a wide range of trajectory and surveillance applications. In conjunction with elaborate computer facilities, a local source of cyclopedic space data, the AN/FPS-49 tracking radar, and an experienced staff of engineers skilled in the coordinated use of these various tools, SEER has already produced solutions to a broad spectrum of pressing satellite/antisatellite problems.

The B-charts and the PAGE program constitute a team of synthesis-analysis procedures which can help define the proper role of various Department of Defense programs in military space, and indicate the optimum balance of ground environment installations and orbiting population to achieve these objectives.

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J. BRECKMAN received a BEE from Cooper Union in 1943 and an MSEE from the University of Pennsylvania in 1962. He is presently engaged in a doctorate program at the University of Pennsylvania. From 1943 to 1949 he designed test equipment and taught mathematics. While with the Signal Corps (1949-1954) he designed analog and digital computer systems. Since joining RCA in 1954, Mr. Breckman has designed digital control and data processing equipment for BIZMAC, served as chairman of the computer group for BMEWS, wrote the computer program for satellite observations in the BMEWS system, wrote the PAGE Program for the performance analysis of a total ground environment against a total satellite population, and invented the B-chart and developed its applications to radar scan design. Mr. Breckman was the 1963 candidate from the Defense Electronic Products for RCA's Outstanding Engineer of the Year award. He is presently Systems Manager, Space Operations, in the SEER organization.

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The authors (l. to r.) Art Franz, Jack Breckman, and Sid Miller.

THE POTENTIALS OF HIGH-POWER SATELLITES FOR COMMUNICATIONS

Major design considerations for a satellite communication system are the number of satellites and the orbital parameters. Most studies to date have been based upon the simplest possible satellite configurations so as to enhance the life of the system and reduce the total cost of launch vehicles and satellites. As space technology improves, more-complicated high-power satellites will be practical—and could be in operation in the early 1970's. In the near future, it will be necessary to evaluate the trade-off possibilities between low-powered satellites with large, costly ground terminals versus high-powered satellites with small, less-costly ground terminals. RCA is apparently the first to examine this problem in depth. For one-way broadcast service to small terminals, there is no question as to the value of high power in the satellite. But high power in the satellite for two-way point-to-point communications is not so clearly advantageous. The purpose of this paper is to acquaint the reader with the work to date and to stimulate interest in the problem.

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TO A COMMUNICATOR, a satellite is similar to a high tower, comparable to the microwave towers used for conventional transmission. The height of the tower may be from 6,000 to 22,300 miles, thus enabling satellite relays to span trans-oceanic distances. Coverage areas may vary from 50×10^6 to 80×10^6 square miles.

The first (low power) application to be tested (TELSTAR and RELAY) has been that of spanning transoceanic distances. Attention has been focused on linking the U.S. and Western Europe. Since each of these areas is already connected by vast internal distribution nets, large terminals costing \$3 million to \$5 million seem practical for interconnecting the U.S. and Western Europe. If the distribution nets existed on the other continents, global service could be established with 10 to 15 terminals of this size.

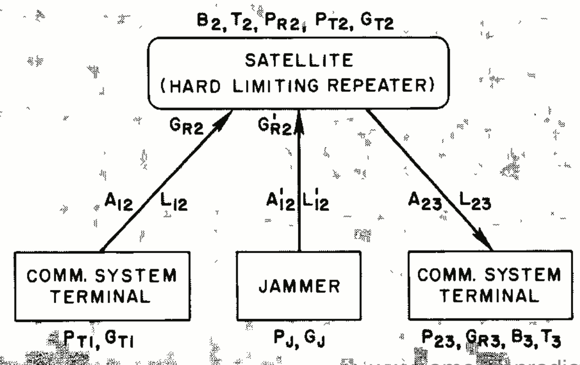
To provide commercial point-to-point traffic to and from the developing areas of the world, inexpensive, low- and medium-capacity terminals are needed. Several such terminals might be useful to reach the more important cities of each nation, the global requirements in this case being on the order of 500 terminals. Obviously, it is desired that the terminal costs be low—perhaps in the range of \$50,000 to \$200,000. *This may be realizable if satellite radiated power can be traded off with ground terminal antenna size.*

TABLE I—Ground Terminal Classification

	Antenna Dia, ft		*Power, kw*			
Service	*Range*	*Nominal*	*Prime*	*Radiated*	*Number*	*Receiver T (°K)*
Mobile	3-10	3	5	1	300	1000
Portable	20-30	20	20	4	100	300
Fixed	60 plus	60	100	20	15-25	100

Fig. 1—System model

P_T = transmitter power
P_J = jammer transmitter power
G_T = transmitter antenna gain (satellite antenna 17.8 db).
G_R = receiver antenna gain G_{R2} = 17.8 db, $G_{R?}$ = 20.8 db).
G_J = jammer antenna gain
A = path loss $4\pi R^2/\gamma$.
L = system losses (6-db limiter loss).
T = effective receiver temperature.
B = receiver bandwidth ($B = 10 \times 10^6$ cps).
D = antenna diameter.
n = number of channels (data rate/channel = 1000 bits/sec).
G_P = processing gain (40 db, constant).
$\frac{S}{N}_{out}$ = output signal to noise out ratio (12 db).



A study has been made of TV broadcasting via a satellite relay.[1] In this case, reception is possible with conventional equipment costing no more than a few hundred dollars if the radiated power from the satellite relay is 2 to 5 kw per TV channel. This system should be an extremely advantageous tool for educational TV in the developing areas of the world, and it should be useful for conference TV and other similar special applications in the U.S. and Western Europe. The study, made in RCA by the DEP Advanced Military Systems group, indicated that the satellite system operating costs would be competitive with conventional microwave techniques initially, with the promise of a five-fold decrease in costs as the satellite technology advanced. The objections are, of course, the high cost of development—on the order of \$300 million to \$500 million dollars.

The military has requirements for flexibility, security, and mobility on a global scale which cannot be met by any current technology. For the purpose of a specific example, Table I classifies typical ground terminals as to the mobility and the number of such terminals likely to be required globally. The data is nominal, based on the fact that the Defense Department has a population of about 3 million and for the purpose of control and administration, world wide communications must be available.[2] Mobility is determined primarily by the antenna size and power plant size. However, there is another point of concern. For 6,000 to 8,000-Mc carriers, pointing requirements in the three classes (Table I) are on the order of 1.0°, 0.5° and 0.1°. Thus for the larger antenna sizes, additional equipment is needed for pointing. In general, high power should reduce the complexity of the ground terminals. (Satellite radiated power effects only the required ground terminal receiver aperture. When high power satellites are employed, ground terminal receiver apertures may be relatively small. Since common transmit and receive apertures are likely, ground terminal transmitter power must be increased. This is not a problem when the number of channels to be transmitted is small, but may be extremely difficult and costly when large numbers of channels are to be transmitted from a single terminal.)

Earth synchronous orbits at 22.300 miles altitude eliminate many of the handover traffic control and pointing problems of the medium altitude systems. Because of the many operational and economic advantages of communicating via stationary satellites, the following discussion will be limited to systems consisting of synchronous satellites.

COMMUNICATIONS SYSTEMS CONSIDERATIONS[3,4]

The model used for this discussion is shown in Fig. 1 and the assumed values for the three type of ground terminals are listed in Table I. Other pertinent data is given in Fig. 1. It is assumed that spread-spectrum pseudo-random coding techniques are used, since this is useful in a severe jamming environment. It is assumed that the spectrum spreading is accomplished by modulating the data to be transmitted by a pseudo-random code sequence which has a bit rate considerably higher than the data rate. The ratio of the pseudo-random code bit rate to the data bit rate is termed the processing gain. The difference between the processing gain, or integration gain, and the required detection threshold plus system margins is the anti-jam margin. The anti-jam margin is the advantage (power. aperture) of the jammer over the communication terminal equipment.

Multiplexing of multiple code sequences is possible if the code sequences are orthogonal (or at least quasiorthogonal). When correlation detection is employed. only the desired signal is extracted from the multiplex group with the remaining signals, if the code sequences are relatively long, acting as noise. The use of the pseudo-random code and correlation detection therefore provide a general access capability to the system. The formulation below is accurate when operating in a jamming environment but also very nearly correct in a nonjamming environment. The data rate per channel is assumed to be 1.000 bits/sec. This is a convenient number since it is typical for vocoder traffic and high-speed digital traffic. For uncoded voice traffic, the number of channels will be reduced by a factor of three to four. The equations used are:

Signal power received (at satellite) $= P_{R2S}$

$$= \frac{P_{T1}\ G_{T1}\ G_{R2}}{A_{12}\ L_{12}}$$

Jammer power received (at satellite) $= P_{R2J}$

$$= \frac{P_J\ G_J\ G'_{R2}}{A'_{12}\ L_{12}}$$

Fig. 2—Communication from fixed terminals; number of channels vs. jammer threat.

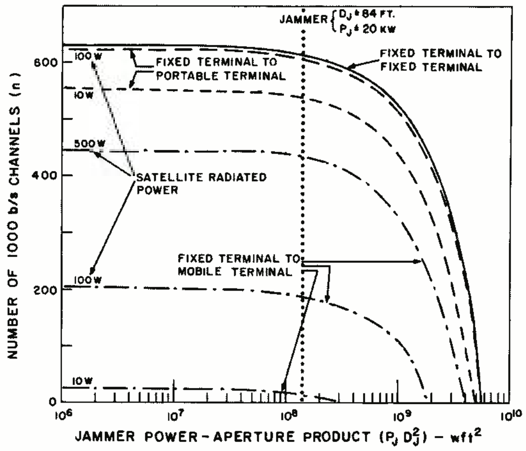


Fig. 3—Communication from portable terminals; number of channels vs. jammer threat.

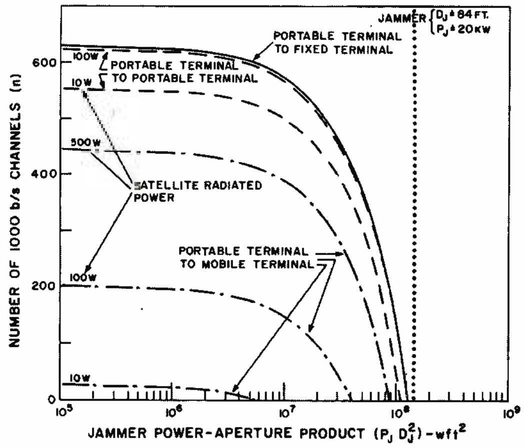
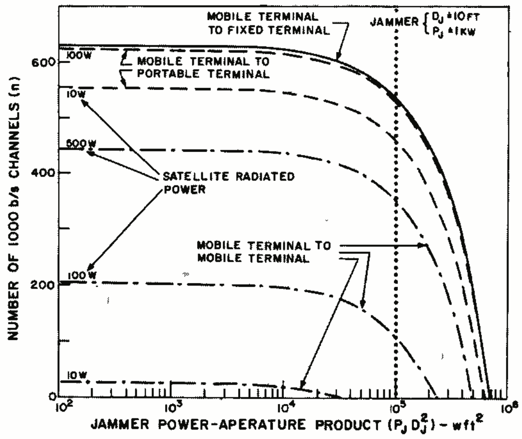


Fig. 4—Communication from mobile terminals; number of channels vs. jammer threat.



Noise power received (at satellite) $= P_{R2N}$

$$= K\ T_2\ B_2$$

$$S/N_{out} = \frac{\dfrac{P_{T2}\ P_{R2S}}{(1+n)\ P_{R2S} + P_{R2N} + P_{R2J}\ L} \cdot \dfrac{G_{T2}\ G_{R3}}{A_{23}\ L_{23}} \cdot G_P}{\dfrac{P_{T2}\ (P_{R2N} + n\ P_{R2S} + P_{R2J})\ L}{(1+n)\ P_{R2S} + P_{R2N} + P_{R2J}\ L} \cdot \dfrac{G_{T2}\ G_{R3}}{A_{23}\ L_{23}} + K\ T_3\ B_3}$$

Figs. 2. 3. and 4 illustrate the results of the calculations for the nine possible combinations of communications links (i.e. a fixed terminal to a mobile terminal, a mobile terminal to a fixed terminal, etc.). Figs. 2. 3. and 4 relate the number of channels available to the system and the jamming threat. It can be seen that the number of available channels is essentially independent of the jamming threat over a considerable range of jammer power-aperture products. Up to a point, jamming is hardly noticeable and the channel capability is limited by inter-modulation noise and receiver noise. Gradually, as the jammer threat (jammer power-aperture product) increases, the jammer noise predominates and the system channel capacity is adversely effected. For the cases illustrated in Figs. 2, 3, and 4, disruptive jamming might be considered to occur when jammer power-aperture products of 5×10^6, 10^7, and 10^5 watt-ft^2, respectively, are employed. These levels are determined principally by the relative power-aperture products of the jammer and the ground transmitting terminal. On each chart a typical jammer is shown for reference.

These charts illustrate clearly both the advantages and the limitations of high power in the satellite. Since all traffic must pass through the satellite, 300 mobile terminals, each with a single channel capability, will require a satellite capable of radiating about 200 watts or approximately 1 to 2 kw of prime power. This power requirement is independent of the type of ground transmitter terminal. One hundred portable terminals, each with a single channel capability, require a satellite capability of only about 50 watts of radiated or 250 to 500 watts of prime power. Although it is not shown specifically on Fig. 2, it is clear that 25 fixed terminals of the assumed size can be served by a satellite radiating less than 10 watts. (The curve *Fixed Terminal to Fixed Terminal* is independent of satellite power as long as the radiated power is greater than several watts, since the intermodulation noise due to multiplexing the many channels predominates.)

The minimal power levels just noted assume a single channel output for each terminal. In practice, each fixed terminal would have the capability to handle perhaps ten channels and a mobile terminal two or three channels. It must be assumed, however, that the ground net does not exist to interconnect several hundred terminals. Hence, the satellite power requirements in the three cases will differ by a factor of about five.

In addition to the spread spectrum techniques, advantage may be taken of the time delay between the transmission of a message and its reception due to the system geometry. For a synchronous satellite this delay is on the order of ¼ second. During this time interval, for a pseudo-random bit rate of 10×10^6 bits/sec and processing gains of 10^3 and 10^4, approximately 2,500 and 250 information bits, respectively, can be transmitted. If ground terminal frequencies are changed randomly (as seen by the jammer—but known a priori to all ground terminals) at ¼-second intervals, the jammer will not be aware, until too late, of the frequency employed by the communication system. Thus, if spread-spectrum and frequency hopping techniques are employed, an additional anti-jam capability of perhaps 20 db may be obtained. This does add to the complications of the satellite electronics, since a very-wideband repeater will be required. Also, to maximize the anti-jam capability, high satellite power is required. However, it is a step in the right direction, since it will assist the mobile terminal to compete more favorably with large jammers.

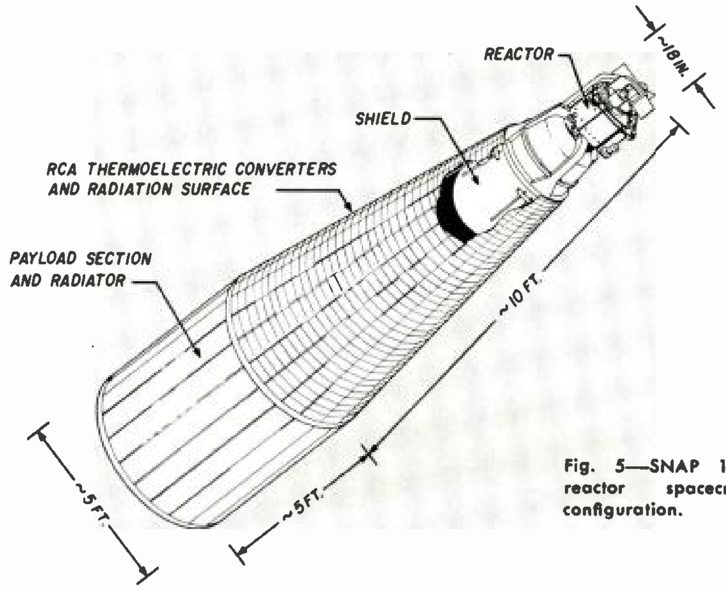


Fig. 5—SNAP 10A reactor spacecraft configuration.

Vulnerability to direct attack is also an area of concern for military communications. Both the satellite and the ground-terminal vulnerability must be considered. Few ground terminals are more vulnerable than many and few satellites are more vulnerable than many. There has been considerable criticism of the synchronous system because a few satellites are the nodal points for all traffic over about one third of the earth's surface. The assumption is that interception is relatively easy and that interceptors will be less costly than communications satellites. However, detailed evidence to support this conclusion has not been submitted. Based on calculations made by DEP Advanced Military Systems, the cost of the interceptor may be almost as much as that of the communications satellite. The destruction of a single communication satellite is not necessarilly of major concern. Of paramount importance is the destruction of the communication system, especially just prior to the initiation of large scale hostilities. To decrease the vulnerability spare (nonradiating) satellites may be placed in orbit as well as decoys. The total useful life, after an all-out attack, of the communication system is probably measured in hours. The spare satellites and decoys will either greatly increase the cost of the interception or delay the system destruction for many hours. Lastly, the military invariably provides a mixture of weapons and supporting equipment. If the satellite system is used for wideband communications and other more conventional links are available for the minimum essential narrow band traffic, the incentive to attack the satellite is substantially reduced—especially if interception is costly.

HIGH POWER SATELLITE VEHICLE

At the present time the technology for high power synchronous satellite spacecraft is not completely established and proven. The power supply weight, reliability and thermal control is under extensive investigation. Synchronous systems oriented to the earth's vertical are substantially more complicated than those satellites now being launched and long life capability must be proven in this area. These are state-of-the-art questions which can be answered in the near future. In fact, if development on a specific configuration were undertaken shortly high power systems could be available prior to 1970.

Regarding the power supply, the Air Force is developing the SNAP 10A, which should be flight qualified in the near future (Fig. 5). This is a reactor system using RCA silicon-germanium thermoelectric converters.[5] It is currently rated at 500 watts but by increasing the reactor temperature it can be upgraded to 2 or 3 kw. Its weight with shielding will be between 1,200 and 1,500 pounds.

Another possibility for power is the thin-film solar cell. Present systems including power conditioning, batteries, redundant cells for reliability, and protective covering against radiation damage weigh from one to three pounds per watt. At synchronous altitudes radiation damage is much less than that in the medium altitude range. Also, the vehicle is only obscured from the sun for a short period of time which greatly reduces the battery load. Thus one can estimate the weight, using current technology, at about one pound per watt. Thin film techniques, however, will reduce this weight by more than 50%. This work has been underway in RCA Laboratories for a number of years[6] and thin film cells do offer a possible alternative for the near future up to about 5 kw. Beyond this level the reactor-turbine will continue to have the advantage in weight.

Assuming 1,000 pounds for the vehicle and all other components, the space craft should not weigh more than 2,500 pounds. This is beyond the capability of any currently available booster, but published data on the TITAN III seem to indicate that some configuration of this booster series could be used to place 2,500 pounds in an earth synchronous equatorial orbit. This program is being substantially funded and from the test schedules, it is reasonable to assume the booster to be available for operational use in 1966 or 1967.

Components for attitude control and station keeping for this type of application have been under development for at least four years. In general, there is competition in every area and this is the best assurance of the successful completion of at least one approach to each problem area. Requirements for station keeping are on the order of 1° to 2° in geocentric angle and antenna pointing can be relaxed to the same standard. These are modest criteria which can be met by simple mechanisms offering the greatest probability of reliability for more than one to two years life.

Thermal design will provide a unique challenge. Conversion from a heat energy source to electric power is 10% efficient or less. The SNAP 10A design uses special radiators to reject over 50-kw (thermal). These cover the entire exterior surface of the space vehicle with the exception of the base. Since the conversion to radio energy probably will not exceed 20% efficiency and may be as low as 10%, an additional 1,600 to 3,200 watts must be dissipated. This must be disposed of by radiation and the radiator area will vary as the difference of the fourth power of the temperature of the electronics and the fourth power of the space background temperature. Thus the operating temperature of the electronics, principally the power amplifier tube, becomes an important parameter. At 70°C the emission is only 72 watts/ft^2 of radiator area; at 150°C, 170 watts/ft^2 may be dissipated. Depending on the assumptions made concerning meteroid density and the life criteria the radiator weight may vary from 1 to 5 pounds/ft^2. The amplifier tubes have been operated at the higher temperature and there is reason to believe that long life can be obtained at this level. Under the worst assumption above the radiator for the electronics would weigh about 220 pounds; under the most favorable conditions about 10 pounds. Since weight is always a critical factor, tubes suitable for high temperature operations will be useful although not necessarily essential at this power level. In any case special power tube designs will be necessary to transmit the heat from the tube to the radiator.

CONCLUSIONS

The conclusions of the DEP Advanced Military Systems studies are that high power in the satellite is a distinct advantage when small terminals are required. For TV systems from 30 to 100 kw of prime power could be used. For other types of traffic 2 to 3 kw appears to be a reasonable upper limit. The lower level of power should be available in the near future and higher powers should be seriously considered, for use in the early 1970's. There is a trade-off between high-power satellites and large numbers of low cost terminals. It is logical to take advantage of the broad coverage available to the satellite and to serve many subscribers, since this permits the satellite cost to be more broadly distributed. Hence, the high-power concept should be reviewed frequently as technology advances.

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JOEL S. GREENBERG received his BEE in 1952 from Polytechnic Institute of Brooklyn, and his MEE in 1960 from Syracuse University. He was employed at the Rome Air Development Center, Griffiss AFB, Rome, N. Y. from 1952 until mid-1961 where his experience was in the general areas of radar development and systems analysis. He worked for several years on the development of close support guidance and control systems and later supervised a systems analysis group in the areas of space surveillance, ballistic missile early warning, and ballistic missile intercept systems. In 1961 Mr. Greenberg joined the Advanced Military Systems group of RCA where he has been engaged in space system studies with major effort having been placed upon the analysis of future commercial and military satellite communication systems. Mr. Greenberg is the author of several technical papers pertaining to systems analysis and is a member of the AIAA.

OVERSEAS COMMERCIAL COMMUNICATIONS SATELLITE SYSTEMS: 1965—1975

This paper is based upon a study made in 1962 by DEP Advanced Military Systems of commercial communication systems using active repeaters in earth satellites. The study was requested for planning purposes within the Corporation in a field where RCA has the dual role of an international common carrier and a supplier of electronic hardware.

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THE Communications Satellite Corporation (COMSATCORP), authorized by law in 1962 by the U. S. Government, will be owned by private investors. It is intended to operate on a sound economic basis and show a profit. The experimental communication satellites, TELSTAR, RELAY, and early SYNCOM, the forerunners of future operational satellites,[1] are launched by the THOR-DELTA booster vehicle. The designs, weights, and orbits of these experimental satellites, based on the limited payload capability of this rocket, generally preclude their use in full-scale commercial operations. For such operations new satellites must be designed, for which more powerful launch vehicles such as the ATLAS or TITAN family are required.

Two configurations for the satellite system are emerging.[2-7] The first, a synchronous system, employs satellites orbiting in the equatorial plane at 36,000 km (19,360 nautical mile) altitude. The orbital period of such satellites is 24 hours, and they appear stationary viewed from the earth. These satellites, suitably spaced along the equator, furnish complete global coverage except for small polar caps. In the second, a medium altitude system, the satellites are in random orbits at altitudes of about 11,000 km (6,000 nm); the orbital periods are not synchronous, and individual satellites rise and set over the horizon. It is therefore necessary to have a sufficient number of satellites in orbit for a specified probability that at least one satellite is mutually in view to pairs of ground terminals wishing to communicate.

TABLE I—Systems Configurations

	Medium Altitude	*Synchronous*
GROUND TERMINALS		
Transmitter Power	1 to 2 kw	1½ kw (50-kw peak)
Modulation	FM	SSB
Number of antennas/terminal	3	1
Antenna dish diameter	60 ft	65 ft
Automatic tracking	Yes	No
System noise temperature	80°K	80°K
Number of channels	600	600
Frequency	6 Gc	6 Gc
SATELLITES		
Altitude	6,000 nm	19,360 nm
Orbit (circular) plane	Random	Equatorial
Number of satellites	43	6 (3 are spares)
Number of 2-way voice channels/sat.	1,200	1,200
Number of satellites/launch vehicle	5	2
Stabilization	Spin	Spin
Station keeping	No	Yes
Receiver temperature	1000°K	1000°K
Modulation (satellite-to-ground)	FM	FM
Transmitter power	12 watts	12 watts
Antenna gain (max.)	13.1 db	20.3 db
Frequency (satellite-to-ground)	4 or 6 Gc	
Power supply	Solar Cells plus Batteries	
Weight	220 lb	280 lb

The evaluation criteria used to compare these two systems include considerations of technical feasibility, access to the system by users, service to small users, and economics. The common requirements placed upon both systems are: 1) each system must handle the projected communications traffic through 1975, 2) the quality of service must be high, and 3) the systems should be technically achievable in the same time era.

TRAFFIC PREDICTIONS

The projected growth of U. S. traffic (volume of overseas telecommunications in and out of the continental U. S. expressed in two-way voice channels) is shown in Fig. 1. The lower curve is an extrapolation of historical growth dating back to 1946. The historical data are derived from records of U. S. common carriers filed yearly with the Federal Communications Commission (FCC).[8] The middle curve reflects the estimates of the American Telephone & Telegraph Company (AT&T).[7] The solid curve for the years 1960 to 1965 includes existing and known (1962) planned submarine cable construction and follows closely the 20%-increase curve. The solid segment of the uppermost curve spanning the decade of the 1970's is based upon estimates submitted to the FCC in 1961 by an Ad Hoc Committee of U. S. Common Carriers.[9]

Whereas the U. S. projections in Fig. 1 are supported by statistics, corresponding data are not available for traffic not involving the U. S. However, considerations of total world traffic are obviously important for a satellite system with possible international users. A method due to Brinkley[10] was invoked to estimate the remainder of the expected world traffic. This method relates communication volume with trade (exports and imports) and is based upon the fact that approximately 80% of international traffic is assoicated with business.[11,12] Following this method, the world traffic requirement is estimated by the following rule:

$$\begin{array}{c}\textit{World traffic}\\ \textit{requirement}\\ \textit{(in year } y\textit{)}\end{array} = \left[\frac{\textit{total world trade (1959)}}{\textit{U. S. trade (1959)}}\right] \times \left[\begin{array}{c}\textit{U. S. traffic}\\ \textit{requirement}\\ \textit{(in year } y\textit{)}\end{array}\right]$$

Total world trade is now about four times U. S. trade.[13] Historically, the rate of increase of U. S. trade has been equal to that of the world. Therefore, the projected world traffic requirement is estimated to be about four times that of the U. S. To specify the overseas fraction, the traffic flowing within the continents which is more economically handled by ground microwave links,[11] must be subtracted from this total. The remainder, approximately 50%, is overseas traffic. The final result is that overseas traffic not involving the U. S. is estimated to be approximately equal to the traffic in and out of the U. S. shown in Fig. 1.

TABLE II—Launch Vehicle Technology*

Launch Vehicle	*Orbit*	*Payload (lb)*	*Cost ($ million)*	*Launch Reliability***
ATLAS-CENTAUR	Synchronous (equatorial)	600–1000	9.0[15,16] in 1965–66, decreasing to 6.0 by 1975	0.6 in 1965–66 increasing to 0.8 by 1970
	6000 nm (polar)	2500		
Modified TITAN II	Synchronous (equatorial)	>650	5.0	0.7 increasing to 0.9 in 1975

* For details, see Reference 14, Appendix I.

** Launch reliability refers to both launch and orbit attainment. This is the reliability of placing on the order of five satellites per launch vehicle in random orbits for the medium altitude system and two maneuverable satellites per launch vehicle at a desired stationary location for the sychronous system. The problems confronting these two tasks are not the same although the same basic launch vehicle configuration may be employed. To date neither of these tasks has been accomplished, but by 1965–66 it is anticipated that hardware will have been developed for both with comparable reliability of performance. Therefore, the same launch reliability has been assumed for both medium altitude and synchronous systems.

SYSTEMS CONFIGURATIONS

After consideration of the state of the art, the hardware performance parameters shown in Table I were chosen for the two systems. These numbers are in general agreement with proponents of the two systems. Detailed analysis supporting these results is given elsewhere.[14]

LAUNCH VEHICLES

Many launch vehicle configurations varying in cost, payload capability, and reliability are possibilities for the Communications Satellite System. Since none were built or qualified as ready at the time of the study (1962), the resulting uncertainty in performance was bounded by selection of two likely vehicles as representative upper and lower bounds (Table II). The Atlas-Agena with modifications falls within these bounds.

SATELLITE POPULATION

The number of satellites required to handle growing world traffic for a medium altitude and for a synchronous system, the latter with three groups of satellites, is shown in Fig. 2. Reliability of service dictates two satellites per group (station) for the synchronous system although a single satellite satisfies traffic requirements during the early years. The medium altitude satellites are assumed to be in orbits with random inclination angles and with random spacing within these planes. The number of satellites is determined by a specified probability that at least one satellite will be in the mutual view of two ground terminals. The number of medium altitude system satellites was chosen to meet the traffic needs of the North Atlantic area; it is optimistically (from the viewpoint of this system) assumed that these same satellites will also provide for all other global traffic as they proceed on their orbits.

GENERAL SYSTEMS CHARACTERISTIC

The differences in parameters between the two systems lead to correspondingly

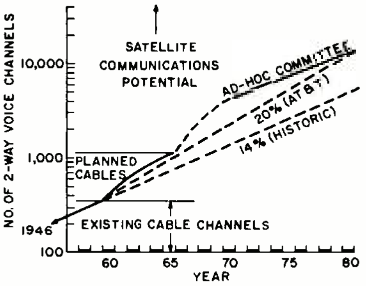

Fig. 1—Projected U.S. transoceanic communications traffic.

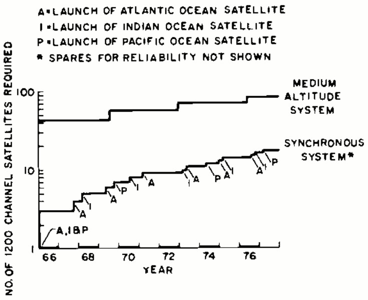

Fig. 2—Required communication satellite population for world traffic.

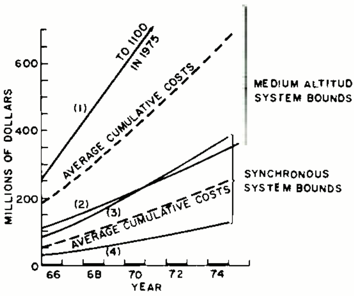

Fig. 3—Expected space costs, world traffic, where curve 1 is for the Atlas-Centaur (MTBF = 2, N = 5); curve 2 represents modified Titan II (MTBF = 5, N = 5); curve 3 refers to Atlas-Centaur (MTBF = 2, N = 2); and curve 4 covers the modified Titan II (MTBF = 5, N = 2).

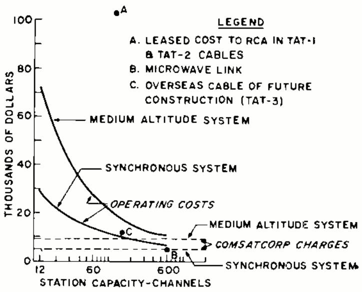

Fig. 4—Ground terminal operating costs per-channel year.

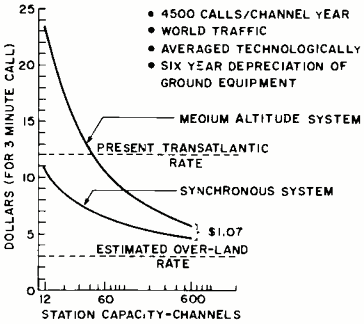

Fig. 5—Comparative user rates.

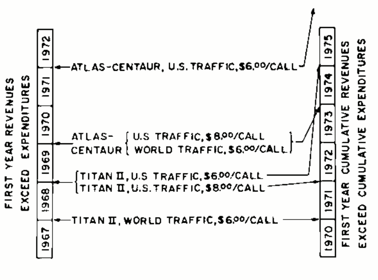

Fig. 6—Comparison of various possibilities; synchronous system revenues versus expenditures.

different operational characteristics. Such characteristics as *access* and *connectivity* can be evaluated in economic terms while characteristics such as *delay* and *echo* require more subjective evaluation. These are discussed below.

Access and Connectivity

In an ideal global system it should be possible for all ground terminals to simultaneously communicate in pairs as desired. New ground terminals should be easily and economically integrable into this system. Two requirements must be fulfilled: 1) the system must provide a number of radio frequency channels equal to the number of simultaneous users, and 2) the satellite must be in simultaneous view of ground terminals in widely diverse geographical locations or facilities provided for routing through several satellites on a multiple "hop" basis. The first requirement, termed the *multiple-access capability*, depends upon the modulation method, and more specifically to the number of independent carriers or bands in the radio frequency spectrum which the satellite repeater will accommodate. The second requirement may be termed the connectivity of the system and depends upon the satellite orbital parameters.

Access

A high degree of access is of great value, especially to the small user, since he can communicate directly via the satellites without using the facilities of immediate neighbors. Many potential small users can thereby communicate directly overseas or over continents independently of the development of ground system networks. However, the small users, although many in number, do not constitute a large part of the traffic load; hence the importance of general access must be measured in terms other than economic.

Single-sideband (SSB) with frequency-division-multiplex offers the ultimate in multiple access and has been recommended for the synchronous system.[2,3] Since this technique presents certain problems to the ground transmitters[17] and in the satellite repeaters, its relative costs are increased. Frequency modulation (FM) with frequency-division-multiplex on the other hand has been proposed for the medium altitude system.[4] This modulation method is more limited in providing multiple-access and its proponents have described systems with only 1 carrier per repeater.[4] However, the ground terminal equipment and repeaters are comparatively simpler, less costly, and can use the highly developed techniques of the microwave land systems. Should FM or other modulation techniques be used in the synchronous system, its costs will be reduced; therefore the choice of SSB for this system constitutes an upper cost bound (i.e., pessimistic from the viewpoint of this system) in the economic analysis which follows.

Connectivity

In the synchronous system direct connectivity is provided to all stations within view of a satellite over nearly a hemisphere. Global coverage is provided by use of three relay stations and at most two hops. In the medium altitude system, multiple hops via intermediate ground terminals become necessary between increasingly distant ground terminals; thus the need for as many as three hops for a global trunk plus additional hops to get into the trunk increases costs due to multiple tracking antennas and routing needed at the relaying ground stations. In addition, the delay (see next section) is increased. In the cost analysis, a one-hop medium altitude system (i.e., U. S. to Europe) is compared with a global synchronous system, a model most favorable to the former system.

Delay and Echo

The propagation time between earth terminals via a synchronous satellite is approximately 0.3 second, and between telephones and satellite ground terminals possibly another 0.1 second, making a total one-way delay of 0.4 second. Thus for the synchronous system a speaker cannot receive a reply to his remarks for at least 0.8 second for hemispheric coverage; approximately twice this for world-wide coverage. Some contend that this reduces the usefulness of the circuit so that it cannot serve as a first-class telephone circuit.[6,7] Stanford Research Institue[18] has constructed a simulator to investigate the psychological effects of such time delays on people using two-way telephone circuits. The simulator which included an echo suppressor built by General Telephone and Electronics[19,20] "has been used to conduct a number of subjective operational tests both with people aware and with people not aware of the time delay that was being introduced into the circuit."

These available experimental results indicate that neither delay nor echo will constitute a serious impediment to telephone traffic in a synchronous system. However, experiments elsewhere are continuing[21]; a final verdict has yet to be reached. Note that a medium altitude system can have delays comparable to those of a synchronous system when communicating over near hemispheric distances using multi-hop routing. Delay and echo should present no problem for telegraphy, telex, and television type services.

SPACE COSTS

The cost of instituting and maintaining a satellite system depends upon many parameters. The probability of successful injection into orbit and the life of a satellite in orbit being statistical parameters, the costs of the space portion of a satellite communications system are best specified by a mean value and a standard deviation. The equations (developed by Dr. Harlan D. Mills, DEP Advanced Military Systems) are:

$$u_i(A) = \left[\frac{a_i - a_{i-1}}{n_i p_i} + \frac{1}{m_i p_i} \frac{1}{\sum_{j=1}^{n_i} \frac{1}{a_i - 1 + j}} \right] \left[R_i + n_i S_i \right] \qquad (a_o = 0)$$

$$\sigma^2{}_i(A) = \frac{1}{n^2{}_i p^2{}_i} \left[n_i(1 - p_i)(a_i - a_{i-1}) + (1 + n_i - n_i p_i)\left(\frac{n_i}{m_i}\right) \frac{1}{\sum_{j=1}^{n_i} \frac{1}{a_i - 1 + j}} \right] \left[R_i + n_i S_i \right]^2$$

Where: $u_i(A)$ = mean costs in *i*th year for station A (station A is one of the stations of the synchronous system. Station A may also be taken as the total space portion of the medium altitude system); $\sigma_i(A)$ = standard deviation of space costs in *i*th year for station A; n_i = number of satellites per launch vehicle in *i*th year; R_i = cost of launch vehicle in *i*th year; S_i = cost of satellite in *i*th year; p_i = probability of launch success in *i*th year; m_i = mean time to failure of satellites in *i*th year; a_i = required number of satellites at station A in *i*th year.

The total costs are given by:

$$u_i(s) = u_i(A) + u_i(B) + u_i(C)$$

$$\sigma_i^2(s) = \sigma_i^2(A) + \sigma_i^2(B) + \sigma_i^2(C)$$

Since the above parameters will vary in time with advancing techniques, and because of present uncertainties in space vehicle performance and expected satellite life. costs for each system were computed using an optimistic lower bound. with a modified Titan II vehicle and a satellite with *MTBF* (mean-time-between failures) of 5 years, and a pessimistic upper bound with the Atlas-Centaur and a satellite with *MTBF* of 2 years. These costs are shown in Fig. 3 together with an averaged curve for each system. This averaging process implies similar technological advances for the two systems. Note that the space costs are much greater for the medium altitude system; the upper bound of the synchronous system costs being comparable with the lower bound of the medium altitude system.

GROUND TERMINAL OPERATING COSTS

The economic model used in this study presupposed independent business entities for the space portion of the system and for the ground terminals. The space business, corresponding to ComSatCorp later legislated, assumes the cost of developing prototype satellites including reliability testing, the over-all system testing prior to full-scale commercial operations, launch pad costs, vehicle costs (plus satellites) including three sigma (3σ) back-up vehicles, control or tracking station costs, and debt and amortization. Adding general and administrative expenses for officers' salaries, engineering, legal and other items including a profit based upon investment, an annual revenue requirement is determined. This revenue is prorated to the ground terminal users on a per-channel-year basis shown by the dashed lines (ComSatCorp charges) in Fig 4.

The ground terminal business has its own costs in addition to the ComSatCorp charges. These include electronic hardware, real-estate, central station and auxiliary power, and operating salaries. The total costs (excluding general and administrative items and profit) are shown on a per-channel-year basis as a function of the station capacity in Fig. 4. The medium altitude system is seen to be more costly. Note that the ComSatCorp's charges constitute a large fraction of the operating costs of large terminals but only a small fraction for small terminals. It is also evident that small terminals cannot compete with large terminals for the same business.

Of particular interest are benchmark points *B* and *C* in Fig. 4. Point *B* is the annual cost of a two-way voice circuit in a 3,000-mile overland microwave system. Point *C* is the cost per-channel-year of a cable (TAT-3) which will provide 128 two-way voice circuits. A new cable-laying vessel will lay 3.000 miles of this cable starting from New Jersey in July 1963 to meet 600 miles of cable already laid by the British General Post Office.[22] Only the synchronous system appears to compete economically with this cable.

USER RATES

The operating costs of ground terminals plus margins for G&A and profit are paid by the end-user. Fig. 5 compares the user rates in the two systems. The synchronous system provides the lowest cost service, particularly for users of small stations. The $1.07 difference per call between the two systems for a large station accumulates to nearly a billion dollars in 10 years for the projected traffic. The rapid growth of traffic projected in Fig. 1 was based upon a general reduction of present rates. Fig. 5 indicates that such reductions are indeed possible.

COMSATCORP INVESTOR

From the viewpoint of the investor in the ComSatCorp various possibilities of the synchronous system are shown in Fig. 6. The left column shows the first year when annual revenues exceed annual expenditures. The right hand column shows the first year cumulative revenues exceed cumulative expenditures. This figure assumed an operational system producing revenue by 1966. For this to occur, the investor would have to put his money into the enterprise during 1962-1963. It is seen that, excepting for the most optimistic possibility, at least 10 years must elapse before a cumulative profit is possible. Present (1963) indications are that investment will not occur until 1964, incurring a corresponding slippage of the time table of Fig. 6.

Note that Fig. 6 projects revenues based upon either world traffic or U. S. traffic loadings. The Europeans have recently (1963) manifested heightened interest in their own satellite system.[25] Should the proposals of the European manufacturers (Eurospace) be implemented the ComSatCorp could not count on the world's total traffic as a basis of revenue. There are many other implications of a European system; a separate study of this is required.

RECENT DEVELOPMENTS (1963)

While the TAT-3 cable (see Fig. 4) uses vacuum tube repeaters spaced at 20-mile intervals. AT&T has recently disclosed the development of a new cable which uses transistorized repeaters spaced much more closely.[22] This is reported to produce a sufficient increase in bandwidth to handle 720 two-way channels or a TV signal. The use of such a cable (possibly[22] by 1968) was not projected in the AMS Study.[14] The resulting channel-year cost is reported to be ⅓ that of the TAT-3 cable,[22,23] which may be cheaper than even the synchronous system and microwave land systems of comparable capacity.

This cable development, according to General Sarnoff, has altered the economic attractiveness of the satellite system,[22] and he has urged a reexamination of the *Communications Satellites Act of 1962*. He has further suggested in June 1963 in letters made public that all transoceanic services be included in the charter of ComSatCorp. This has created considerable discussion in the industry.[24]

CONCLUSIONS

A number of the conclusions below are based upon analyses which cannot be included in a paper of this length. For details, consult Reference 14.

1) *Economics.* The synchronous system will be more economical than the medium altitude system for the large and especially for the small user. The referenced 720-channel cable poses a competitive threat to both systems for the world's heavy route traffic, the medium altitude system in particular. However, the synchronous system can provide a global service with general access and good connectivity to compensate for a possible modest cost advantage of future submarine cables.

2) *Technical Feasibility.* An analysis of satellite vehicle configurations, orbit injection, stabilization, station-keeping, capability and availability of launch vehicles. and ground terminal equipment shows that initial operation by 1966 is possible for both systems, provided immediate attention and serious efforts were directed to solution of certain problems detailed in Reference 14.

3) *Access and Connectivity.* The SSB modulation, proposed for the synchronous system, provides direct access to all users and the stationary orbit provides simple, lowest cost connectivity.

4) *Service to the Small User.* This is best afforded by the synchronous system, due to its lower costs and superior connectivity.

5) *Delay and Echo.* Available test data indicate that the synchronous system should pose no major problem to voice communications. However, tests are continuing; this point is not settled as yet.

6) *Spectrum Utilization.* Coexistence with microwave land systems is possible.[14]

7) *Nuclear-Powered Satellites.* Such high-power satellites may afford further economic benefits in the mid-1970's to the synchronous system.[14]

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Dr. MORRIS HANDELSMAN received his BEE from the College of the City of New York in 1938, his MEE from the Ohio State University in 1946, and his PhD (EE) from Syracuse University in 1955. From 1942 through 1946 Dr. Handelsman served in the U.S. Army Signal Corps as a commissioned officer and attended both the Harvard University and the Massachusetts Institute of Technology Radar Schools. In the following years, he headed microwave research groups at Wright-Patterson Air Force Base, Watson Laboratories at Red Bank, N.J., and was chief of the Radar Laboratory, Rome Air Development Center (RADC) at Rome, New York 1953-1956. In 1956, he became Director of Advanced Systems, RADC, and was responsibile for a number of developments in anti-ICBM systems, BMEWS, space surveillance, and countermeasures. In 1959, Dr. Handelsman became a Member of the Technical Staff of RCA-DEP Advanced Military Systems, at Princeton, N.J., and until 1961 did research on radar and undersea warfare systems. In 1961, he was named Associate Director, AMS, and became responsible for advanced work on communication satellites, space systems, and interplanetary missions. Dr. Handelsman has taught at Syracuse University as an Adjunct Associate Professor in the EE Department and also at New York University. He is the author of numerous technical and scientific papers and is a member of the IEEE, Acoustical Society of America, American Rocket Society, (now AIAA), Sigma Xi, and American Physical Society.

SAMUEL GUBIN received his BS from Yale University in 1929. After a year with Westinghouse, he returned to Yale for his MS degree which he received in 1931. Thereafter he joined RCA in Camden, N.J., serving as a design engineer until 1939. He then become staff assistant to the chief engineer. From 1946 to 1957 Mr. Gubin was in private business serving as a manufacturing consultant in industrial applications of electronics. Later, during the Korean War, he manufactured electronic test equipment. In 1958, Mr. Gubin joined United Aircraft Corporation at East Hartford, Connecticut, where he prepared systems analyses and proposals on airborne weapons systems and target drones. In 1959, he returned to RCA, Moorestown, N.J., in the capacity of manager of lightweight tactical radar systems. His activity was extended in 1960 to the management of the instrumentation radar group. In 1961, Mr. Gubin joined Advanced Military Systems where he has participated in studies of satellite communications systems. In recent months he has become involved in the applications of direct energy devices. Mr. Gubin has a number of patents in the field of transmitters and receivers. He was chairman of the Philadelphia Section of the IRE in 1946 and is currently a member of IEEE and of AIAA.

A HIGH-RESOLUTION RANGE COUNTER

A feasibility model of a range counter that can operate at ± 1-meter resolution (150 Mc) has been developed at the DEP Aerospace Systems Division, Burlington, Mass. This paper describes some of the advanced circuit, logic, and mechanical design of the device, which utilizes RCA digital microcircuits.

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Aerospace Systems Division
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With the advent of various techniques and devices that make high-resolution ranging systems possible, the circuit designer must develop compatible circuitry to take advantage of these new devices. The Aerospace Systems Division, Burlington, has developed a feasibility model of a counting system that operates at a 150-Mc clock rate, or ± 1-meter resolution. Fig. 1 shows the mechanical layout of portions of the counter including the 150-Mc decade packaged in RCA's *d*igital *m*icro*c*ircuits (DMC).

SYSTEM DISCUSSION

Fig. 2 shows a straight-forward counting scheme—a gated clock controlled by the start-stop pulses. The counter's time reference is a crystal-controlled oscillator whose period corresponds to the desired range resolution. If the desired range interval is ± 1 meter, then the oscillator must operate at 150 Mc. The oscillator's output is gated to the counting circuits by the *start-stop* flip-flop. This flip-flop is turned on by an incoming pulse on the *start* line and is turned off by a pulse on the *stop* line.

The counting flip-flops are arranged into decades. Each decade has reached some count when the *stop* pulse occurs. When the *start-stop* flip-flop goes off, a 0.8-second one-shot multivibrator is started. This initiates the readout period which results in the count of each decade being presented on a magniline readout. The count of each decade is converted by relays to an appropriate signal to drive the display unit. Once a decade has reached the final position for readout, no further power is required to maintain this position, thus providing an infinite-storage device. As a result, all power can be removed from the readout circuitry when the one-shot period is over.

The *overflow* flip-flop indicates the lack of a return pulse to stop the counter. When the counter has reached its maximum capacity, the *overflow*

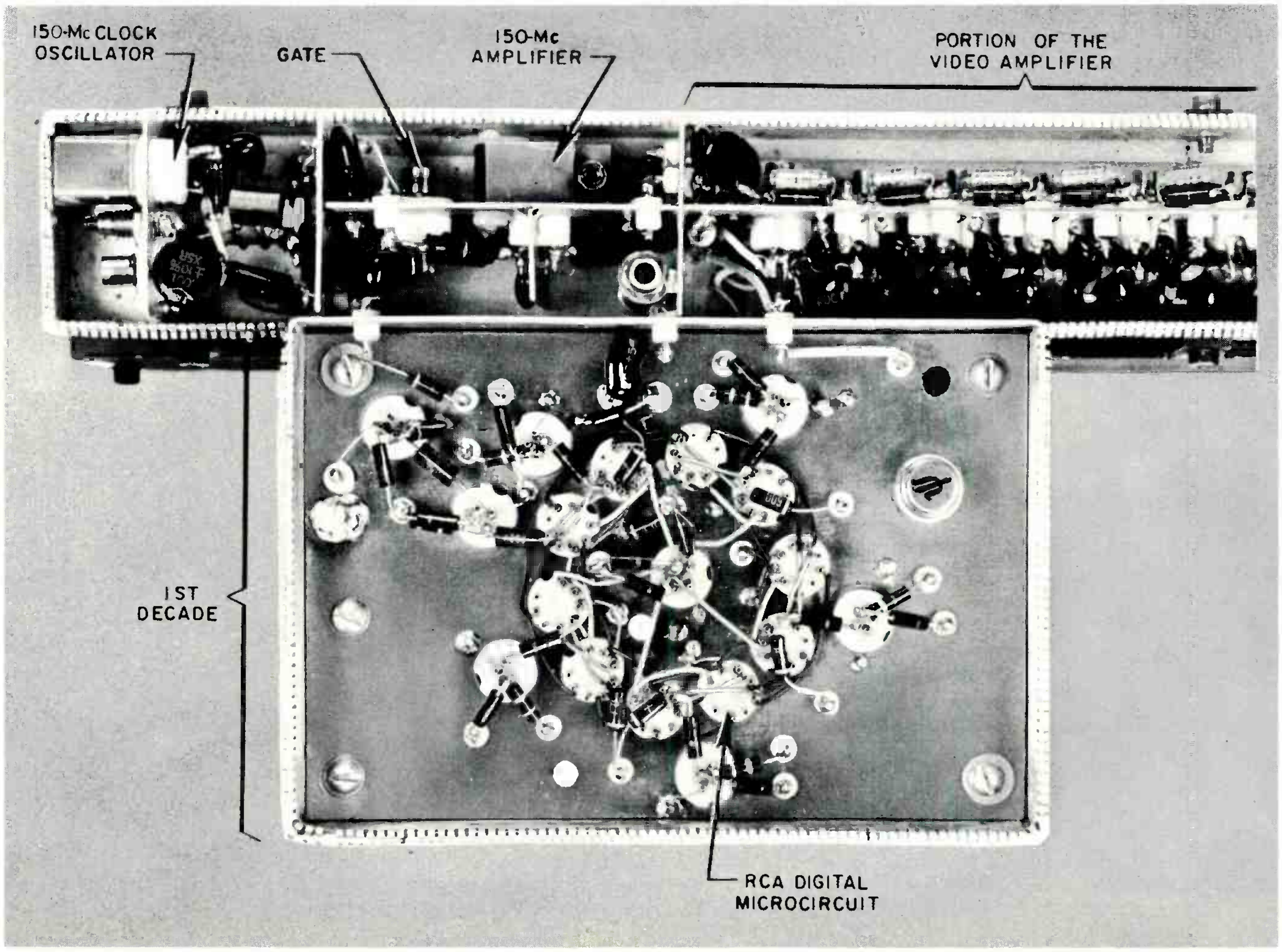


Fig. 1—Mechanical layout of the clock, amplifier, gate, 1st decade and a portion of the video amplifier.

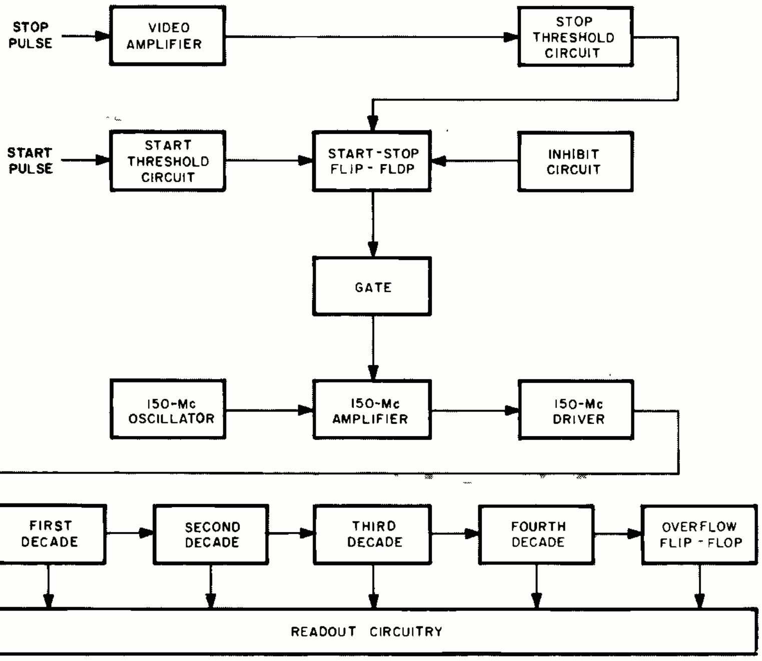


Fig. 2—High-resolution range counter.

flip-flop indicates that the reading obtained is not valid.

In addition, the *inhibit* flip-flop prevents the counter from being turned *off* before an adjustable length of time. After this time, the *inhibit* flip-flop changes state, allowing the next pulse from the *stop* line to turn off the *start-stop* flip-flop. This *inhibit* flip-flop prevents external noise which can be sufficiently high to turn off the counter—from negating the function of the system. Complete resetting of the counter is automatic, but it can be reset manually.

DESIGN CONSIDERATIONS

Because of the high frequencies and fast rise times involved in this system, the selection of components and the construction of hardware must be done carefully. The circuit configurations must be designed to optimize the performance of all devices. Careful mechanical layout and miniaturization (Fig. 1) are necessary to minimize parasitic inductance and capacitance. For example, shunt feedback is used around each stage of the video amplifier, causing low input and output impedances which, in turn, require extremely short leads to minimize stray inductance.

Since the maximum possible range of the counter is 9,999 meters (four decades) and the resolution is ± 1-meter, the oscillator should have a stability of 1 part in 10^5. This stability insures the maximium error to be the counter error of ± 1 cycle. Therefore, the 150-Mc oscillator must be crystal controlled to conserve space and power; a seventh-over-tone crystal oscillator is used rather than a lower-frequency oscillator and multiplier.

The 150-Mc amplifier is necessary for two reasons—to act as a buffer and to provide at least 3 volts peak at the driver input. A grounded-base stage is used with a matching network on both input and output for good isolation. Although several methods were explored in gating this amplifier, only one was successful. The main cause for failure was that the impedance of a saturated transistor or diode was not low enough at 150 Mc to act as a shunt or series switch, therefore causing *on* and *off* levels to be nearly equal.

Fig. 3 shows the successful circuit which utilizes a current robbing technique. When the gate transistor Q1 is turned *on*, the emitter of Q2 is held positive; hence, Q2 is *off* and provides more than adequate isolation. This circuit is capable of switching from one state to another within one cycle of the clock, thereby preserving the resolution of the counter.

Included in the *stop* line is a 60-db, 200-Mc bandwidth current amplifier which the expected low-level *stop* pulse (as low as 2 to 8 μamps) necessitates. The bandwidth is needed to preserve the rise time of the *stop* pulse and thus the resolution of the counter.

One of the features of this amplifier is that the gain is time programmed from the *start-stop* flip-flop to reduce false triggering. This tpg circuit, similar to agc, allows the amplifier gain to range from approximately unity at time = 0 to full gain at maximum range. This is possible since the *stop*-line signal strength varies inversely with time, as might be expected. This time-programmed function is achieved by controlling the conductance through a set of diodes in shunt with the input by several RC networks.

The basic amplifier (Fig. 4) has six stages, using individual parallel-voltage feedback and emitter degeneration and peaking. This approach produces the desired bandwidth and approximately 54-db gain. In addition, a common-base, common-emitter input stage providing an added 6 db is included to reduce the input impedance to its lowest possible value. The amplifier achieves the desired characteristics by using 2N918 transistors biased at their optimum operating point.

This video amplifier drives a threshold device which provides a logic level to trigger the *start-stop* flip-flop. Since the start line has a similar threshold device, the differences in delay in the start and stop line—approximately 15 nsec—are caused primarily by the video amplifier.

The first decade accepts the clock rate of 150 Mc; however, each flip-flop within the decade operates at one-fifth the bit rate. The one suitable circuit, which consists of five flip-flops and ten *and* gates, is shown in Fig. 5A[1]. Fig. 5B illustrates the idealized output wave forms of each flip-flop.

As shown in Fig. 5A, the output of the flip-flops are cross-coupled to the opposite input gates in a ring formation. The counter is in the *reset* position with all right sides *on* and the clock line held to ground. The various gates are enabled by the *off* side of the previous flip-flop in the ring and the input positive clock pulse. Therefore,

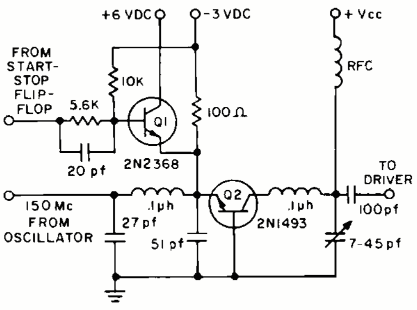


Fig. 3—150-Mc clock and amplifier.

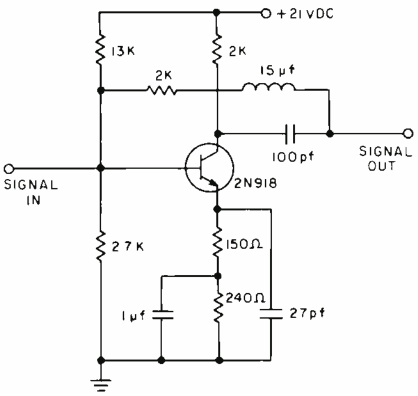


Fig. 4—A sample video amplifier stage.

the left side of the first stage is turned *on* by the first pulse, which enables the left-side gate of the next flip-flop, so that the second pulse turns the second stage *off*, etc. If the input signal gets through a gate, it can only turn a flip-flop from a one to a zero. If the flip-flop is already *on*, no switching can occur. Thus, there are four enabled gates which do not switch because their flip-flops are already *on*. Each succeeding input pulse switches a succeeding stage *off* until the fifth pulse, at which time the sixth pulse starts again with the first stage turning it *on*. Succeeding pulses turn *on* succeeding stages until the counter is back in the reset position after the tenth pulse. According to Zoltan Tarczy-Hornoch and ASD experimental tests, this scheme depends primarily on the gate sensitivity and rise time and not on the speed of the flip-flop.

L. C. DREW received his BS in EE in 1960 from Tufts University. Previously, Mr. Drew was an Army electronic technician for three years, and taught electronics to Army personnel who later operated and maintained Nike systems. While attending college, he was a research assistant engaged in designing and testing instrumentation for physiological studies of the brain. Since his graduation, he has participated in the design and field test of a large ECCM system as well as nuclear instrumentation for underground tests. Mr. Drew joined RCA in April, 1962, and since then has worked in the field of high-speed pulse circuitry and wideband video amplifiers. Mr. Drew has two patent disclosures in the field of high-speed pulse circuitry.

The counter's most critical feature is the driver, which must turn *off* and recover within one cycle of the clock rate; therefore, the propagation rise-fall time as well as the pulse width must be less than a half cycle or approximately 3½ nsec. Since the driver transistor is biased in the saturated condition, these conditions are difficult to achieve. With the help of snap-off diodes utilized in the development of such pulse generators, drivers have been designed that can produce a pulse width at the base of approximately 2 nsec at a clock rate as high as 250 Mc. The normal minimum sensitivity of the driver is 2 to 3 volts peak. However, it operates more reliably with a 4-to-6-volt input. Such a driver was developed, and a 250-Mc counter utilizing this driver with the above counting scheme tested successfully, thus insuring the use of this counting circuitry as a reliable 150-Mc counter.

Various circuit designs of the gates and flip-flop were tried—namely, RCTL, DCTL, RCTL in a current mode, and T^2L. All appeared to operate successfully; however, the T^2L was deemed the most feasible to be packaged in the RCA digital microcircuit format, because it conserves power and space. The packaging technique increased the speed of previous breadboard counters by almost a factor of 2. The other three decades of the counter utilize a conventional universal RCTL flip-flop. Since this type of flip-flop has been widely discussed in other literature, nothing further is said here.

The readout of all four decades is performed by the output of each flip-flop driving a relay driver. The relay contacts form the decoding logic to switch the readout magniline to the proper number for each decade.

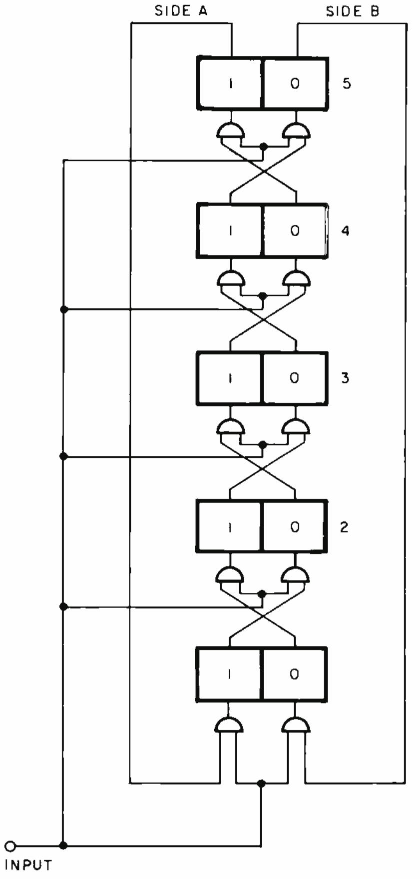
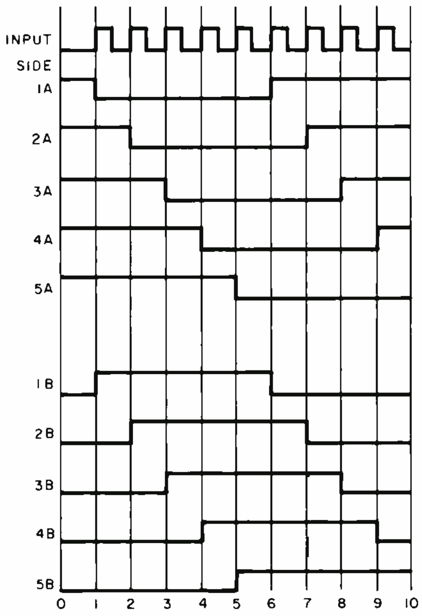


Fig. 5a—The 5-Stage decade counter shown in a reset condition of side "B" conducting.

Fig. 5b—Idealized outputs of 5-stage decade.



CONCLUSION

This range counter system which has been successfully operated under environmental conditions similar to military specifications, has the potential of being used in many various systems—long distance surveying, satellite docking, range determination, etc. Its capabilities could be expanded for extremely long ranges. The techniques described here make real time ranging systems with good resolution not only feasible but practical.

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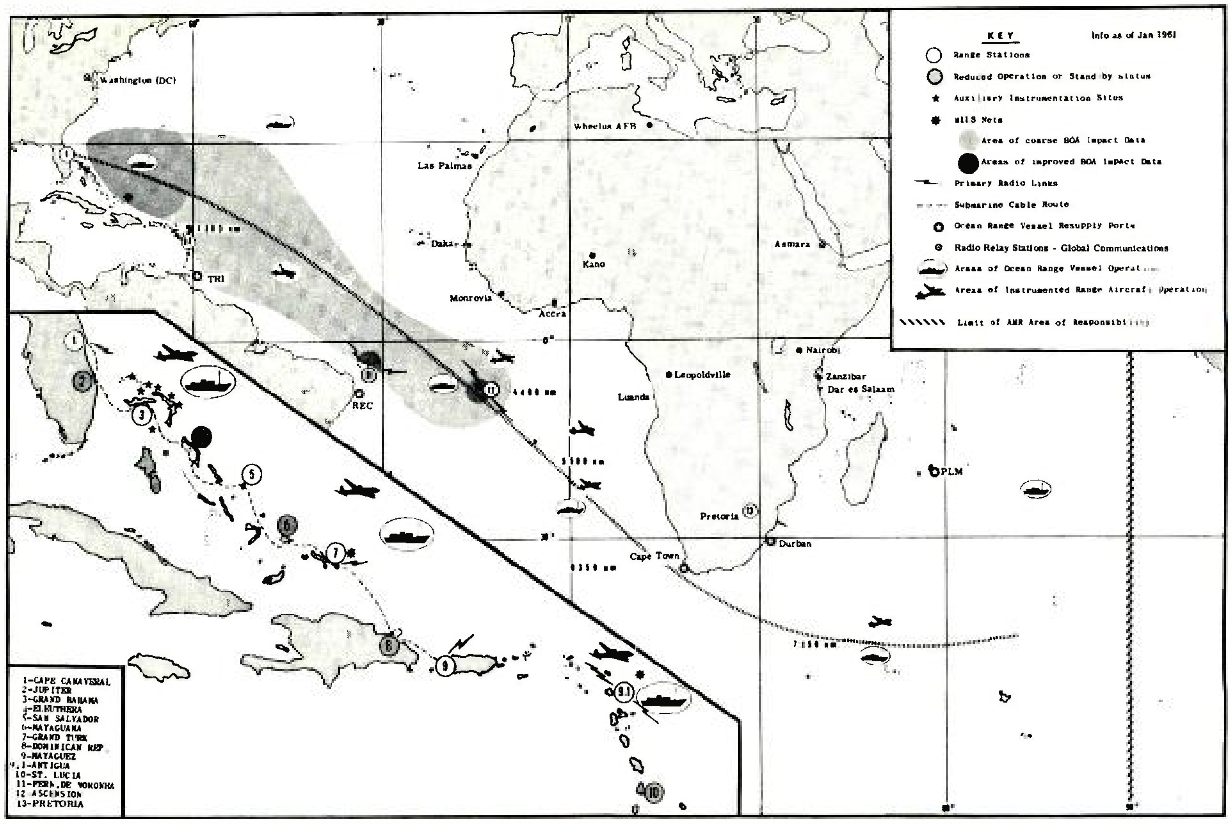


Fig. 1—The Atlantic Missile Range. (Cape Canaveral has been renamed "Cape Kennedy.")

THE RCA MISSILE TEST PROJECT

G. D. CLARK, Mgr.
Missile Test Project
RCA Service Company
Patrick Air Force Base, Fla.

On May 11, 1949, President Truman signed the bill establishing the Air Force Missile Test Center (AFMTC) to provide a range for testing developmental rockets and missiles. Available for use by all elements of the Defense Department—Army, Navy, and Air Force—AFMTC was located at Cape Canaveral in Florida because of the geographical advantages afforded by the string of island tracking sites.

On July 24, 1950, the first missile, a captured German V-2, was launched from the then-little-known Cape Canaveral. During these first few years of operation of the Missile Test Center, all services relative to the planning and operation of the range were performed by military and civil service people.

In 1952, the Air Force contracted with the RCA Service Company to provide technical assistance in specialized areas of range operations. S. D. Heller—assisted by a group of 26 specialists—served as technical advisor in the fields of radar, telemetry, optics, and communications. It soon became evident that the development, maintenance, and operation of the range were enormous in scope and that it would be practical to contract with industry for the management of the entire AFMTC.

TECHNICAL SUBCONTRACTOR

In 1953, the contract for this task was awarded to Pan American World Airways (PAA) and RCA Service Company. Pan American was named prime contractor responsible for range management and logistic support. As technical subcontractor, the RCA Service Company provided the technical planning, engineering, maintenance and operation of the technical facilities. This work was performed by a new RCA organization, the RCA Missile Test Project, with A. L. Conrad as the Project Manager. (Mr. Conrad is now President, RCA Service Co., and Mr. Heller is Division Vice President, Government Services.)

Today, as an operational component of the Air Force Systems Command, AFMTC develops, maintains, and operates the Atlantic Missile Range (AMR). Under this mission, AFMTC has the responsibility to obtain and coordinate all government and contractor services needed to provide effective support of the Department of Defense, NASA, and other agency programs.

Beginning at Cape Canaveral, AMR today extends over 9,000 miles down into the Indian Ocean (Fig. 1). To provide instruments for recording and measuring a missile in flight, AMR has developed into a complex of sites and equipment—communications, telemetry, missile tracking, and data reduction systems—valued at more than $1 billion and placed at strategic locations on the Florida mainland and down-range islands. Instrumentation has been placed at 11 island bases. However, to fill in open ocean areas, AMR utilizes a fleet of six telemetry ships, four fully instrumented radar tracking ships and seven telemetry aircraft.

The RCA Missile Test Project has grown with the Atlantic Missile Range. At the end of the first year of operation (fiscal 1954), the RCA work force had reached 692. Today, the Missile Test Project (MTP) has a work force of 3,500 scientists, engineers, and technicians who operate and maintain all the data gathering, data processing, and communications equipment at all AMR land and ship locations. The present RCA Missile Test Project organization is shown in Fig. 2. Fig. 3 shows the past growth of AMR and MTP. The AMR curve can be related to costs of instrumenting and operating the range and reflects the growing complexity of the range instrumentation. The MTP curve is related directly to the number of people required for the technical operation of the range.

RCA'S OPERATION

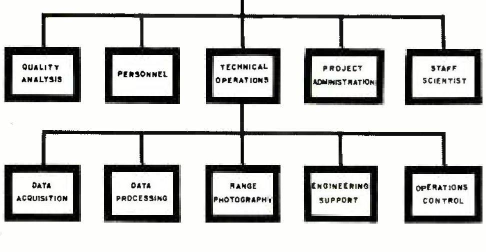
In supporting the activity at AMR, the RCA Missile Test Project's main task today is acquiring and processing data for the range users. These activities constitute the core of the range's being, in the sense that its primary purpose is to provide test facilities for missiles, and its primary product is corrected and reduced missile data.

Before a test launch is conducted at Cape Canaveral, the range user (the missile contractor) presents AMR with his requirements for that test. Operations Control, a joint group composed of RCA and PAA people, work directly with the range user in determining what is required and how the AMR will be used to afford the best opportunity of satisfying all requirements. This group then converts the requirements into an operational directive that specifically tells the data acquisition teams what must be operated, concurrently and in sequence. Following these operational directives, the range-photography and data-acquisition teams operate the range equipment to acquire and record all necessary data. This data is then reduced by data-processing, combined into final flight-test reports and delivered to the range user.

At the Cape Canaveral and associated mainland sites, RCA technicians support the launch agency by operating optical and electronic equipment consisting of the MISTRAM and ASUSA electronic interferometer tracking systems, the FPS-16 tracking radars, fixed 70-mm recording cameras, tracking cinetheodolites and similar instrumentation as well as the elaborate timing and communication networks that tie all systems together. The camera crews record on film—for documentation and for later study and evaluation—every event associated with a launching.

The electronic technicians and operators record metric data that is later reduced to time, position, velocity, and acceleration. Computer operations people process portions of this data in real time and present to the Range Safety Officer a prediction plot (latitude and longitude) as to where impact will occur if the vehicle's thrust is cut off at any time. Shifts of employees provide these services 17 hours a day.

Fig. 2—The RCA Missile Test Project organization.



G. DENTON CLARK received his BSEE and his MS at McGill University in Montreal, Canada. Prior to joining RCA, he was a Research Officer with the Communications Branch of the National Research Council in Ottawa. Mr. Clark joined the RCA Victor Company, Ltd. in Montreal, Canada, in October 1956. He was later appointed Manager, Field Operations, and supervised the installation of communications and radar systems throughout Canada. His next post was in Camden as Manager, Montreal Engineering. Mr. Clark came to the BMEWS project at the RCA Service Co. in Riverton, N.J. in October 1958 as Manager of Communications Engineering, guiding the communications design, installation, and check-out for Site I at Thule, Greenland. He then served as Manager of Site I operations at Thule and similarly later at Site II in Clear, Alaska. He has been Manager of the RCA Service Company's Missile Test Project at Patrick Air Force Base, Florida, since May 1960.

Data on the internal performance of a test missile is collected by telemetry people at Cape Canaveral and at the down-range stations. Events such as engine performance, acceleration, guidance parameters, temperature, etc., are monitored continually in real time. Hundreds of other events are measured and recorded on magnetic tape for study after the test has been completed. Last year more than 16,000 miles of magnetic tape were used for this purpose. The main telemetry building at Cape Canaveral house some 307 racks of electronic equipment and is the largest such installation in this country.

Down through Station 9.1 (Antigua) all range stations are tied together by a submarine cable. Beyond that point, single sideband radio is used. Operation and maintenance of this communication complex linking all range stations, ships, and aircraft are part of the RCA Missile Test Project's responsibilities. Also, part of RCA's responsibility is operating and maintaining an outside cable plant at Canaveral large enough for a city of 50,000 people. Twenty miles south of Cape Canaveral at Patrick Air Force Base — headquarters for AMR — range management officers and the supporting elements, such as engineering, shops, data processing, and photographic laboratory, are located.

RCA photographic technicians at Patrick AFB operate the photographic laboratory and process all motion picture and still film exposed on AMR. A large part of their workload concerns processing color documentary film for the Air Force and the range users. These films record a complete history of a missile from the time it arrives at AMR. This laboratory delivers approximately 700,000 feet of motion picture film and 50,000 still photos each month.

The Engineering Support activity consists of electronic engineers and "hardware specialists" who support their operating counterparts in the field. This work involves engineering design, fabrication, installation, modification, shop maintenance, repair and calibration of test equipment, and depot overhaul.

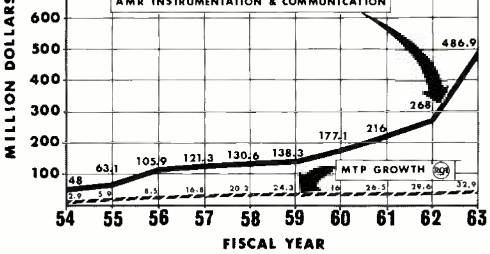
When all of the flight test data has been acquired, it is compiled and subjected to a comprehensive analysis by RCA data-reduction specialists. The flight-test report published by this activity contains all of the reduced data required for a given test in a form suitable for further evaluation by the missile contractor or the sponsoring government agency. The RCA Missile Test Project's data-processing is the largest scientific computer center anywhere in RCA.

To provide continuous evaluation of how well the RCA job is done, a Quality Analysis group of data specialists and engineers operate as a staff function. In addition to monitoring the accuracy of AMR's final product (data) and quality-controlling equipment and performance, this group conducts scientific investigations on how to do the job better.

CONCLUSION

The Atlantic Missile Range is faced with many complex problems as a result of the continual advancing missile technology and the evolution from ballistic missiles to space vehicles. The RCA Missile Test Project is playing an important role in the development of plans and procedures to meet these problems.

Fig. 3—Growth of Atlantic Missile Range and RCA Missile Test Project.



THE NEW 601-301 COMPUTERS AT RCA LABORATORIES

RCA Laboratories has recently put into operation the first RCA 601 computer equipped with a 604 high-speed arithmetic unit. An RCA 301 computer is used for off-line processing of input and output data. The computers will be available for use by engineers and scientists from all RCA locations and provide a unique capability for handling problems requiring high arithmetic speed, large high-speed memory, and flexible logic for efficient programming. An extensive library of scientific subroutines is being developed to take advantage of the 604 floating-point hardware. The 601 computer will be operated in conjunction with other Applied Mathematics activities, which provide a well-rounded capability covering numerical analysis, programming, and mathematical research. The computer will also be utilized by the Administration and Operations Research activities at Princeton, and by RCA Electronic Data Processing in the servicing of its other 601 installations.

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Research Services Laboratory
RCA Laboratories, Princeton, N.J.

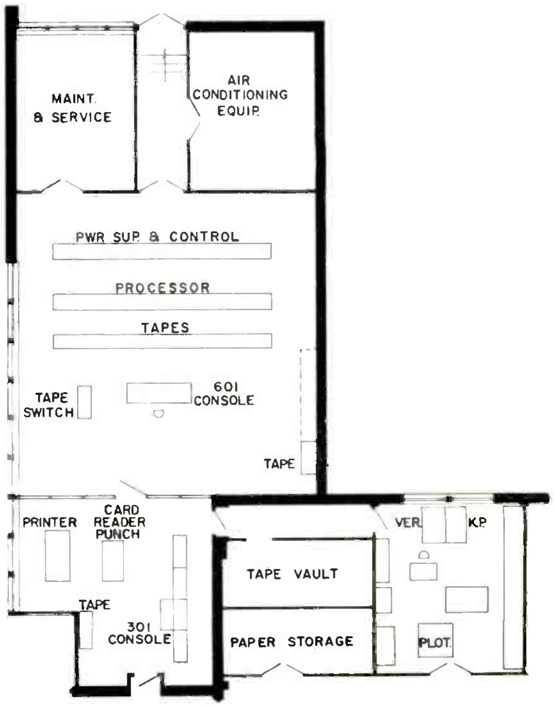

Fig. 2—Floor plan of new computer wing which is outlined by heavy line. Two rooms at lower right are part of original building.

Fig. 1—The new computer wing housing RCA 601 and RCA 301 at David Sarnoff Research Center.

On October 1, 1963 the RCA 601 computer system at RCA Laboratories went into operation. This occasion was the logical outgrowth of a number of onrushing events. There was an urgent need to install a new computer at RCA Laboratories—an *RCA* computer, of course, and one that could handle complex scientific problems that require the largest computers generally available. RCA had recently manufactured and installed several 601 computer systems and one had just been assembled equipped with the 604 high-speed arithmetic unit. This enhancement provides the hardware for efficient floating-point arithmetic calculations and results in a total computer system that is outstanding for scientific computation as well as for other data processing applications.

The Princeton installation gives RCA a new scientific computation center with capabilities previously obtained only through the use of competitors' equipment. It will enable RCA Laboratories to bring back in-house all of its computation problems, many of which were being processed on outside computers. Moreover it will also provide engineers and scientists at other RCA locations with the opportunity of using the powerful RCA 601-604 system in their design, development, and applied research activities. The computation facilities at RCA Laboratories have traditionally been available to all RCA engineering groups. Now once again these facilities provide hardware capabilities that are unavailable elsewhere in RCA and match the analysis and programming strength available at Princeton.

APPLICATIONS AT THE DAVID SARNOFF RESEARCH CENTER

The need for a computer of the magnitude of the 601 did not arise overnight and typical applications were already in existence, although handled less satisfactorily on a variety of other computers. Local usage divides into two major problem-solving fields—scientific and management. Consequently, a computer is needed which is adequate for both activities. The scientific work, however, predominates in the Laboratories, and has had a considerable head-start over our other computer uses.

Scientific

Underlying most of our scientific computer applications is the concept of numerical computation. Many problems can be formulated mathematically, but the solution of the resulting equations is not readily obtained as a simple expression using known mathematical techniques. In the end, however, performance of the system under study will be evaluated in terms of the numerical values of certain variables. The computer is used to find these numerical values for any desired input conditions. The analysis of the original problem, the selection and development of special numerical methods, and the programming of the specific problem for running on the computer all take considerable human intervention on the part of highly skilled mathematicians, programmers, and the scientists and engineers themselves. We therefore have a group of applied mathematicians associated with the computer and provide special training in computer programming to other Members of the Technical Staff. In terms of their formulation, the problems we handle can be classed into several broad mathematical categories such as the solution of ordinary differential equations, matrix algebra, finding the roots of polynomials, and the fitting of curves to experimental data. A few examples taken from the Laboratories' current research program will serve to highlight the goals of some of our large scale computer applications.

The first of these is in the design of electron guns. The electron trajectories in a vacuum tube are determined by the electrode structure and the voltages applied to these electrodes. We have developed mathematical techniques, and programs based on them, which enable a computer to plot the actual path of the electrons, given the geometry of the tube and the applied voltages. Alternatively, critical parameters relating to the crossover point and the aberrations can be accurately computed. RCA engineers responsible for the design of kinescopes are currently using these computer programs in their work. Effort is now continuing to take into account space charge effects, that is, the electric fields introduced by the charge on the electrons themselves. Our approach is all the more useful because of its general applicability and is possible

ELEMENTARY FUNCTIONS

BESSEL FUNCTIONS

ORDINARY DIFFERENTIAL EQUATIONS

LINEAR EQUATIONS

EIGENVALUE ANALYSIS

FOURIER ANALYSIS

CURVE FITTING

POLYNOMINAL ROOT FINDER

. . . ETC.

Fig. 3—The RCA 601 installation at Princeton, and a partial list of mathematical subroutines to be programmed for the RCA 601.

only by using a high-speed digital computer.

A second example comes from the field of solid state materials. The variety of solid state materials in both chemical composition and structure is essentially infinite. Consequently, it is important to be able to correlate the electronic behavior of these materials with their compositions and structures, so as to synthesize those worth the effort of synthesis and measurement. In the past we have developed computer methods for determining the electronic band-structure of solids. These methods had particular bearing on explaining the electrical behavior of semiconducting materials. Today we are also using computers to understand and predict the details of the light emission process in laser materials. The field of lasers has been one of phenomenal research activity and rapid progress. RCA's important contributions in this field have been greatly aided by theoretical studies of the behavior of crystals which contain activator atoms that can be stimulated to emit light at useful wavelengths. The complex differential equations that arise in these studies again require numerical computation to yield useful information.

It is especially fitting that computers today can be used in investigating the ideas that will shape the computers of the future as illustrated in a third example. The low-temperature, or cryogenic, computer memories being developed today consist of complex arrays of thin-film elements. These are addressed by a network called a *cryotron tree*. This circuit network has distributed inductance and resistance and its speed of response is important in the operation of the device. This time constant, as well as other important switching parameters, can be calculated with the aid of the computer. The size array that can readily be evaluated is directly related to the high-speed storage capacity of the computer and a machine in the 601 class is needed to handle the problems of current interest.

Management

A computer of the 601 capability advances us from routine data processing and information retrieval to the use of the computer as a major element in an overall information system used for management decision. Certainly we obtain greater efficiency in the processing of administration data such as the financial operations of cost accounting, payroll, and accounts payable; and personnel matters such as salary administration, and personnel records. However, another one of the significant user groups of the new RCA 601 is the Operations Research activity located at Princeton and serving as a staff function to RCA's Corporate and Division Management. To this group, the computer is a powerful tool for simulating a business situation with its many variables and for evaluating the performance of the prediction schemes that they develop. In some cases, the programs developed by this group are utilized directly by them on the RCA 601 to provide answers to specific problems. In other cases, where an operating system has been developed to be used by operating management at another location, the programs will be translated into the language of other machines available locally, such as the RCA 501.

CHOICE OF THE RCA 601

There are a number of reasons for choosing the RCA 601 in preference to one of the other RCA computers for the applications described. First, we required a computer with adequate capability to handle scientific problems that we otherwise had to put on outside, large-scale computers. These problems are characterized by a need for large-capacity high-speed memory and high arithmetic speeds with relatively modest requirements for handling quantities of input and output data. RCA's 501 and 301 computers were less well matched to these needs. The 3301 will provide these capabilities, but the 601 was already available—and time was an important element. The location at Princeton not only provides a facility needed there, but also serves as a reasonably central location for engineers from other RCA divisions, for programming work related to RCA Electronic Data Processing's marketing functions, and as a backup machine for other RCA 601 installations.

The 604 high-speed arithmetic unit is the first one to be installed in a 601 system and will therefore require considerable programming ingenuity and enterprise on the part of the Applied Mathematics Group at RCA Laboratories. We see the 601 as handling all the Laboratories' computing needs. With its capabilities, our programming contribution is not limited merely to what we have to do to exploit it for our own applications, but we have the opportunity to do programming research in such areas as algebraic manipulation and compiler writing techniques that will be of value to RCA's total computer effort.

There is still another very real way in which the RCA Laboratories machine benefits RCA's computer marketing activities. There are already several other operating 601 installations in the field and this machine is used to back up these installations in case of overload or other contingencies. It also provides an RCA site for the development and maintenance of 601 programs by RCA Electronic Data Processing (EDP). Also, in the development of computer sales, no one can doubt the advantage of having a successful 601 installation in our own house. Many EDP customers show considerable interest in the computer-research activities at RCA Laboratories. Such visitors are now able to see how the Laboratories uses a powerful RCA computer and what we are doing in terms of programming developments.

THE COMPUTER INSTALLATION

A photograph of the computer wing housing the 601-301 system is shown in Fig. 1. The entrance on the right serves as an alternate entrance to the David Sarnoff Research Center and is adjacent to a new parking area that was put into use about a year ago. A glass partition separates the 601 in the background from the 301 in the foreground.

Fig. 3 is a photograph of the 601 computer with console in the foreground, seven of the nine tape stations in front of it, and the main processor behind the tape stations. The third row of equipment contains the power supplies control units and the 604 high speed arithmetic unit. The 301 system is behind the camera in this view.

In order to keep site costs to a minimum, the new wing was designed to house only the computers, the air conditioning, and the maintenance engineering staff, as shown in Fig. 2. Data preparation and tape and paper storage is accommodated in the original laboratory building adjacent to the new wing in the equivalent of the space required by our previous computer. The original building is also used for entry and for offices for the Applied Mathematics Staff. There is minimal viewing space, but an elevated view of the computer is obtained from the vestibule at the building entrance.

Equipment Complement

Since the RCA 601 is a magnetic-tape oriented computer, we have an RCA 301 computer to serve as off-line equipment for input-output functions. The 301 is used to go from card to magnetic tape and tape to printer. It will not be used as an independent computer, since it will be fully occupied as the input-output device for the 601.

RCA 601 has the hardware for doing floating-point arithmetic provided by the 604 arithmetic unit. The cycle time for this computer is 1.5 μsec and it will perform a floating point add in 7.8 μsec and a floating point multiply in 11.6 μsec. The magnetic core, high-speed memory has been installed with 12,000 words of storage and is expandable to 32,000 words. We have nine magnetic tape stations available to the 601. A paper-tape reader and monitor printer are located at the 601 console to provide communication between the operator and the computer.

The RCA 301 has a high speed memory of 10,000 characters. It is coupled to the RCA 333 printer, which has a 120-character line and prints at the maximum rate of 1,000 lines per minute. The card reader-punch is in a single unit that reads at the rate of 800 cards per minute and punches at the rate of 250 per minute. One of the magnetic tapes is directly connected to the 301. We also have the switching capability for electronically transferring several tapes between the 601 and the 301. This minimizes the handling of tape reels and greatly increases the efficiency of operation. The total configuration is intended to meet both the scientific and management computing needs at RCA Laboratories and the back-up requirements for other 601 installations.

OPERATION

The computer itself will be operated by our Applied Mathematics Group headed by N. L. Gordon. This is one of the groups in the Research Services Laboratory, which in turn has the primary responsibility of supporting the rest of the research function with special skills or equipment that cut across the individual areas of research investigation. As already mentioned, the 601 carries all the computing load, and even such data-handling functions as sort and merge. The 301 is used solely as off-line input-output equipment and no separate usage charge is made for it. A 601 hourly rate has been developed in conformity with the procedures used for established rates on the other RCA computers located within RCA. In addition to in-house scientific applications, the Applied Math Group operates the computer for RCA Laboratories Administration, for RCA Operations Research, and for open-shop usage by engineers and scientists from other RCA divisions. EDP, however, has the opportunity to use the computer outside of the first shift as backup for its other 601 installations and for the advanced programming activities that are part of its marketing responsibility. Still another application that looms on the horizon is the direct hook-up of the 601 to experimental research programs. This on-line use could take various forms including the testing of new computer components, such as experimental memory units, or the real-time analysis and control of a process or experiment with the aid of a cathode ray tube display.

Operation of the computer is only a small part of the total activity of the Applied Mathematics Group. Our Mathematics Staff is engaged in a variety of activities needed to implement the effective use of the computer. On the software side, one of the first jobs we tackled was the programming of frequently-used mathematical functions. This involved an analysis of appropriate methods to be used and the programming of subroutines. A *partial* list of these subroutines is given in Fig. 3. Certain needed routines are also furnished by EDP. Our more experienced open-shop users have been trained in the use of the 601, and of the assembly system in particular, under EDP auspices. Other users have learned to write 601 programs by employing a simplified programming system taught by our own staff in a brief course. The availability of a FORTRAN compiler for the 601, provided by EDP, opens the door to much more extensive use of the computer by both RCA Laboratories personnel and engineers from other divisions.

In addition to the specific function of implementing the use of the computer, our Applied Mathematics Group has the continuing overall responsibility for solving problems submitted by the research staff by seeing them through the various stages of mathematical analysis, numerical analysis, programming and production runs. The availability of the 601 has also given impetus to an increased effort in programming research. This work will be problem-oriented in the engineering and scientific field and we expect ultimately will lead to improved computers for solving such problems.

CONCLUSION

We are fortunate that the first RCA 601 computer equipped with the 604 enhancement has been made available to RCA Laboratories. This will give scientists and engineers throughout RCA access to a computer that is unique in programming flexibility and performance. At the same time the 601 presents a challenge to exploit its capabilities. It is fitting that this large users' group within RCA will have an opportunity to contribute to the development of applications and programs that will increase the computer's value. We can expect the utilization of the computer to grow rapidly, with much of the user programming being done in FORTRAN, a common problem-oriented programming language. As the usage is building up, our operation in turn is being put to the test of providing efficient systems and procedures for maximizing the productive accomplishments by means of the computer.

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DR. JEROME KURSHAN received his AB (with honors in Mathematics and Physics) from Columbia University in 1939 and his PhD in Physics from Cornell University in 1943. He was an Assistant in Physics at Columbia University in 1939 and held the same position at Cornell University from 1939 to 1943. He received a government citation for wartime contributions to the Office of Scientific Research and Development. Dr. Kurshan joined the RCA Laboratories as a Member of the Technical Staff in 1943. During World War II, he also taught evening courses for Rutgers University under sponsorship of the Emergency Science and Management War Training Program. At RCA Laboratories, he conducted research in the fields of electron tubes and semiconductor devices and helped to administer the latter research program. Dr. Kurshan was named Mgr., Graduate Recruiting in January 1956; Mgr., Technical Recruiting and Training in June 1956; and Mgr., Employment and Training in January 1958. He was appointed to his present position, Mgr., Research Services Laboratory, in March 1959. This activity provides RCA Laboratories with technological skills in nuclear radiation, physical and chemical analysis, applied mathematics and computation, materials synthesis, electronic devices, and information services. Dr. Kurshan is a Senior Member of the IEEE, of which he is a Member of the Professional Group on Engineering Management, a past member of the Education Committee, and of the Subcommittee on Solid State Devices, and a past Chairman of the Princeton Section. He is also a member of the American Physical Society, Phi Beta Kappa, Sigma Xi, Phi Kappa Phi, and Pi Mu Epsilon.

PLASMA-MICROWAVE INTERACTIONS

This paper is concerned with plasma interactions with electron beams, electromagnetic waves, and magnetic fields. These interactions produce generation and amplification of power at super-high and extremely high frequencies. This radiation can be coherent or incoherent. Such interactions in combination with the high field capability of hard superconductors may lead to useful power at 1,000 Gc or higher. Potential uses of plasma devices are as transmitters, couplers, and maser pumps. The problems which must be solved first, however, include improved methods of plasma production and sensitivity of resonances to local environment.

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The generator and amplification of power at super-high (3 to 30 Gc) and extremely high (30 to 300 Gc) frequencies represent a major challenge to our technology. Limitations imposed by the size of the required structures and by their ability to dissipate heat are the two principal obstacles. In general, both of these problems become more acute as the frequency increases because the amplifying structures must be made smaller. This reduction in size imposes unrealizable mechanical tolerances while it simultaneously increases the power density in the dissipative elements of the device, even in the centimeter range when super-power sources are considered.

To date, engineering ingenuity and imagination coupled with improved materials have kept performance one step ahead of the absolute requirements, but the separation remains uncomfortably small. Accordingly, attention is being directed toward physical systems, interactions, and effects which may provide amplification or oscillation but which do not exhibit the same frailties as solid structures. Gaseous plasmas represent one of these classes.

A gaseous plasma is a gas either partially or totally ionized. The positively and negatively charged particles are present in approximately equal numbers, and the density is such that the Debye length is small compared to the size of the container. This simply means that the system must not deviate from electrical neutrality except over very small distances. In general, plasmas are a cantankerous state of matter. They tend to be difficult to produce, resistant to measurements, and hostile to other materials. However, they possess some most attractive properties. First, they exhibit a remarkable number of electromagnetic resonances. These resonances are *microscopic* in nature; most importantly, these resonances can be adjusted by varying *macroscopic* quantities like magnetic fields, currents, and voltages. This is precisely what is required for advances in microwave power generation —a system whose resonance is electrically adjustable and does not require complicated mechanical structures. A second important property of plasmas is their basic gaseous character. Clearly something already vaporized cannot be melted. Furthermore, plasmas lend themselves to convection cycles for cooling by transfer or replacement of the reactive element itself.

BEAM-PLASMA INTERACTIONS

Presuming that these advantages offset the identifiable disadvantages, attention can be turned to the nature of the possible interactions. The interaction between an electron beam and a plasma is receiving the most widespread attention at this time. In principle, at least, the plasma replaces the slow wave structure of conventional traveling wave tubes. A small signal is placed on the electron beam (Fig. 1). The beam, with the input signal propagating along it, enters the plasma. If the electron densities in the beam and plasma are properly adjusted, the signal is amplified at the expense of DC energy of the beam. This interaction had been predicted in 1948 and in 1950 by Haeff[1] and by Bohm and Gross[2]. Experimental confirmation, however, was delayed until 1958 when Boyd, Field, and Gould[3] first observed gain using a plasma of mercury vapor. In their experiment, the plasma was formed by an arc discharge through mercury vapor. As the arc current was increased, the detector output power also increased. Thus, macroscopic adjustment of a microscopic resonance was utilized in obtaining the first positive experimental result. Subsequently, others[4,5] did similar experiments, but with the addition of a longitudinal magnetic field. They observed that bandwidths comparable to those of traveling wave tubes were realizable, and that gains of 9 db/cm could be achieved at 3 Gc. The important consideration of higher frequency interaction is currently being studied in RCA Laboratories at Princeton. In February, 1963, Swartz and Napoli[6,7] reported a

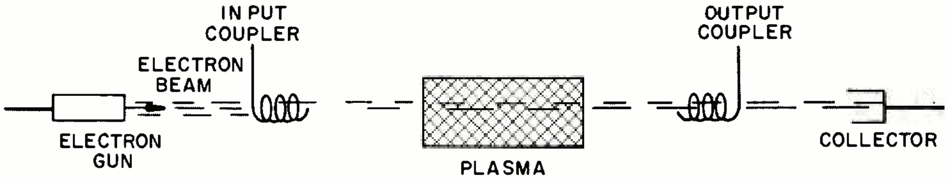


Fig. 1—A beam plasma amplifier.

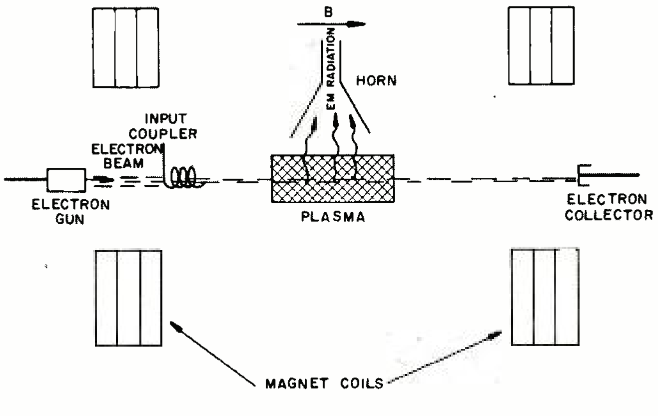


Fig. 2—A beam plasma radiator.

plasma amplifier which gave a net gain of 8 db at 23 Gc.

Still, output coupler tolerances and power densities remain as major problems, limiting the attainable frequencies and power levels. One possible solution is to utilize the plasma as its own coupler. By orienting a DC magnetic field parallel to the beam it may be possible to stimulate the plasma into directly radiating the amplified power. This possibility comes out of analysis on a finite beam by Kino[5], who suggested it might explain how radiation is emitted from stellar atmospheres. An experimental study in DEP Applied Research[8] has as its goal the identification of such an effect for use with plasma amplifiers. A schematic representation of the apparatus is shown in Fig. 2. Fig. 3 is a photograph of the actual apparatus.

Preliminary results from the first experiments (4 to 6 Gc) showed enhancement of the radiation by the presence of the plasma up to 23 db at the center of 100-Mc bands. A careful study—in which the plasma density, electron density in the beam, and the strength of the magnetic field are systematically varied—is required to better understand these results.

A second possible solution to the output coupler problem is to utilize the Cerenkov interaction. The Cerenkov interaction occurs when charged particles travel through or near a dielectric material, at a velocity greater than the speed of an electromagnetic wave in the same medium. Under this condition, a wave is launched into the dielectric as shown in Fig. 4. The use of this mechanism for the generation of microwaves has been under consideration for some time[9,10,11], the earliest suggestion[12] coming in 1947. In general, emphasis has been on millimeter waves and under pulsed conditions. However, DEP Applied Research[13] has been carrying on CW studies at 5 cm.

The goal of these studies has been to measure the strength of the interaction and to investigate the influence of bunch shape. The dielectric experimentally employed has been limited to simple scalar ceramics, but tensor plasma dielectrics are part of the plan. The dielectric in this case fulfills a double purpose. First, its presence leads to the conversion of DC energy of the beam into microwave power. In addition, it serves as its own coupler. The amplified energy does not propagate on the beam, but is already decoupled from the beam and propagating in the dielectric. The total power may be up, while the dissipated power density is down because of the distributed character of the dielectric coupler.

Still another important advantage of the Cerenkov technique is that ribbon or sheet beams can be used. This geometry minimizes self-shielding which, in cylindrical beams, has led to the need for hollow beams. These are difficult to form and maintain. In the Applied Research experiments, the beam was 1 cm wide, 0.1 cm thick. Using an emission current of 45 μamp. at 60 kv, 0.004 μw were collected compared to a predicted 3 μw of *total* radiation. Since in this early experiment not more than 1% of the total radiated power was collected, this agreement was considered encouraging. Fig. 5 is a photograph of the apparatus being used in these experiments. It is important to note that the Cerenkov interaction may be considered as the most general case of a traveling wave tube; all other TWT's can be regarded as special cases in which radial propagation modes have been eliminated by choice of structure.

Fig. 3—Beam plasma facility.

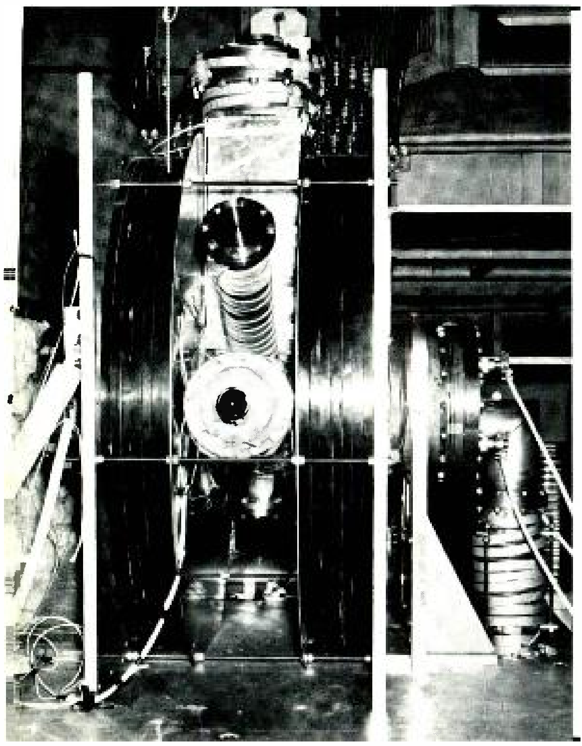
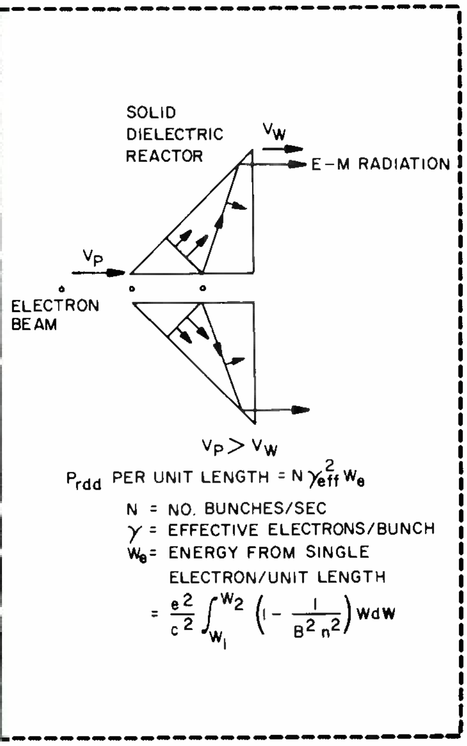


Fig. 4—Simple Cerenkov amplifier.



P_{rdd} PER UNIT LENGTH $= N \gamma_{eff}^2 W_e$

N = NO. BUNCHES/SEC

γ = EFFECTIVE ELECTRONS/BUNCH

W_e = ENERGY FROM SINGLE ELECTRON/UNIT LENGTH

$$= \frac{e^2}{c^2} \int_{W_1}^{W_2} \left(1 - \frac{1}{B^2 n^2}\right) W dW$$

The approaches up to this point are all the subject of current experimental studies. Next to be considered are those in which calculation, extrapolation, and speculation play the dominant role.

An interesting and perhaps important extension of the simple Cerenkov amplifier is the regenerative Cerenkov amplifier (Fig. 6). A bunched electron beam passes through a selected dielectric, as before, but energy from an early bunch is totally reflected by the boundary of the dielectric and interacted with a later bunch. This concept suggests that a nonresonant regenerative action is possible using only a gross structure. Furthermore, since reflection is a sub-surface phenomenon, multiple beam geometries like that shown in Fig. 7 may also be imagined. Analysis of the single beam regenerative case is presented in Reference 13, and experiments are being planned to explore its achievability.

The interactions considered thus far have involved beams and plasma. The beam provides both DC energy and a propagating medium for the signal. One might consider interacting the signal wave directly with a plasma, thereby eliminating the task of beam formation[14,15]. The laws of thermodynamics, however, require that the organized energy be present if amplification is to be realized. In brief, the plasma must be made to flow to provide the equivalent of DC energy. Furthermore, the flow velocity must be carefully adjusted, relative to the wave velocity in the plasma. At present these requirements are much more difficult to meet experimentally than those of electron beams. Nevertheless, serious analytical work is proceeding on this kind of wave-plasma amplifier.

CYCLOTRON RADIATION

Beam-plasma and Cerenkov amplifiers give promise of eliminating complex structures. Wave-plasma amplifiers might eliminate the electron beam. The next obvious step is to eliminate the wave, i.e., consider an oscillator. One extremely simple possibility that fits this case calls for the exploitation of cyclotron radiation. When charged particles move in a magnetic field, those with a component of velocity perpendicular to the field gyrate. Circular motion occurs only when centripetal acceleration is present, and acceleration of free electrons is always accompanied by radiation. In this case, the gyrating particle radiates energy at the angular frequency at which it revolves.

A magnetic field applied to a plasma, then, leads to radiation at the expense of the thermal motion of its constituent electrons and ions. The massive ion frequency is orders of magnitude lower than the electron frequency and is generally neglected. Simple calculations demonstrate that at low values of applied magnetic field, the radiated power density from a laboratory plasma is absurdly low[16]. (A field of 100 gauss on plasma with 10^{13} electrons/cm^3 at 2000°K could provide only 10^{-11} watts/cm^3 at 280 Mc.) As the applied field is increased, however, both the frequency and the power density increase, the frequency linearly and the power quadratically (Fig. 8). This is a most unusual case. Nevertheless, were it not for the advent of the hard superconductor, little likelihood of utility would exist for cyclotron radiation. To be useful, fields of at least 100,000 gauss are required. Conventional magnets of this size require a complex of buildings and a river to cool them. However, hard superconductors, like RCA's vapor-deposited niobium stannide remain superconductors in such fields and so might be much smaller.

While superconductive magnets providing fields of hundreds of kilogauss are not yet available, one is free to speculate about their use. Such extrapolation leads to cyclotron frequencies of thousands of gigacycles per second and power densities of milliwatts per cubic centimeter. Of course, identifying an effect and using it are two different things. Analyses of coherence, spectral purity, energy input schemes, and thermal compatibility remain to be carried out. One use, however, may be as a pump source for a 500-Gc maser (Fig. 9). The liquid helium used to cool the maser could also be used to cool the superconductive magnet wire.

The pump power required may be as little as 2 mw/cm^3, which is of the same order of magnitude that the plasma could emit. Furthermore, pump power need not be coherent. Maser crystals for this frequency are not yet available but there is reason to believe that they could be produced. Thus, conjecture about a 500-Gc maser pumped by cyclotron radiation from a plasma, emitted in response to the field of a superconductive magnet, seems permissible. A great deal of analysis and experiment, however, is required to demonstrate feasibility.

CONCLUSION

The list of possible interactions and effects which might be useful in the generation of microwave power is certainly not limited to those cited here. Many

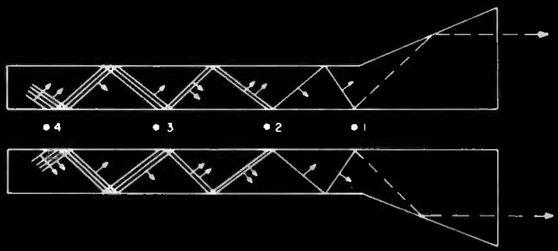


Fig. 6—Regenerative Cerenkov amplifier.

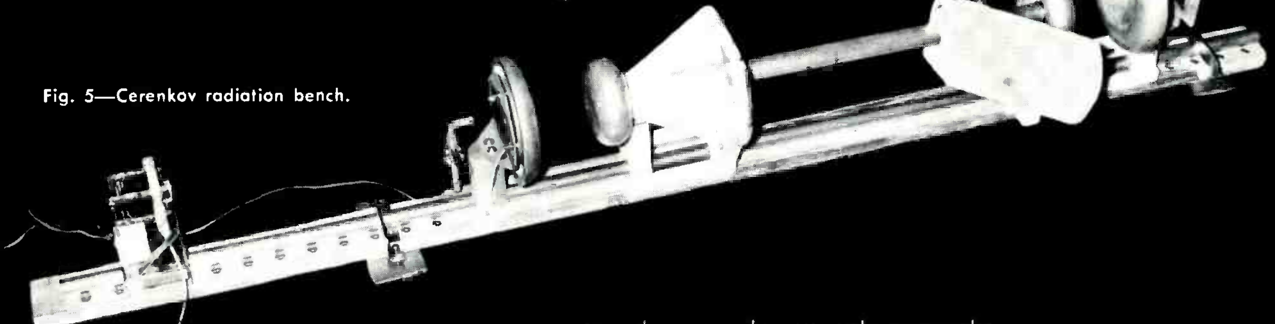


Fig. 5—Cerenkov radiation bench.

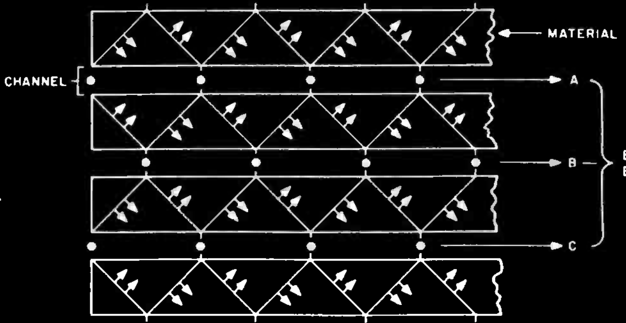


Fig. 7—A multiple beam Cerenkov amplifier.

more can be found, although in general they fall into the same classes as those described. They represent beam, wave, or DC field interactions with gaseous plasma. A logical question is, "*What remains to be done before large scale exploitation can begin?*" The answer is, "*A very great deal, even though progress has been impressive.*" First the effects themselves must be studied under research conditions. Of particular concern is the possibility that the gain mechanisms may saturate at moderate power levels. Until the effects are better understood, one cannot say with certainty that this will not occur.

Sensitivity to a host of ambient conditions is another aspect which must be systematically investigated. Temperature gradients, stray electric and magnetic fields, as well as their gradients, can drastically affect the behavior of a plasma.

A third very critical area is in the production of the plasma itself. Techniques need to be established for producing clean, quiet plasmas; these must exhibit any required degree of ionization at any level of neutral particle density. This may be a most difficult task. Effects of impurities will most certainly require extensive study, much as they did, and still do, in semiconductors.

Finally, emphasis must be placed on methods of producing plasmas of high electron density on a continuous basis, if work on submillimeter waves is to be successful. Only after this basic and applied research has been done, can attention be directed to taking the final step, i.e.; the designing and optimizing of parameters in favor of gain, output power, efficiency, or lifetime. At the moment, the prospects for this last step are bright, and there is every reason to look forward to taking it.

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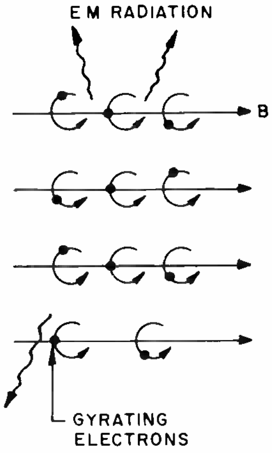
Fig. 8—Cyclotron radiation.



$P_C = (5.3)(10^{-32})\,NB^2T$

P_C = WATTS/CM^3

N = ELECTRONS/CM^3

B = MAGNETIC FIELD IN GAUSS

T = TEMPERATURE IN °K

$F_C = (2.8)(10^6)\,B$

F_C = FREQUENCY OF RADIATION

B = AS ABOVE

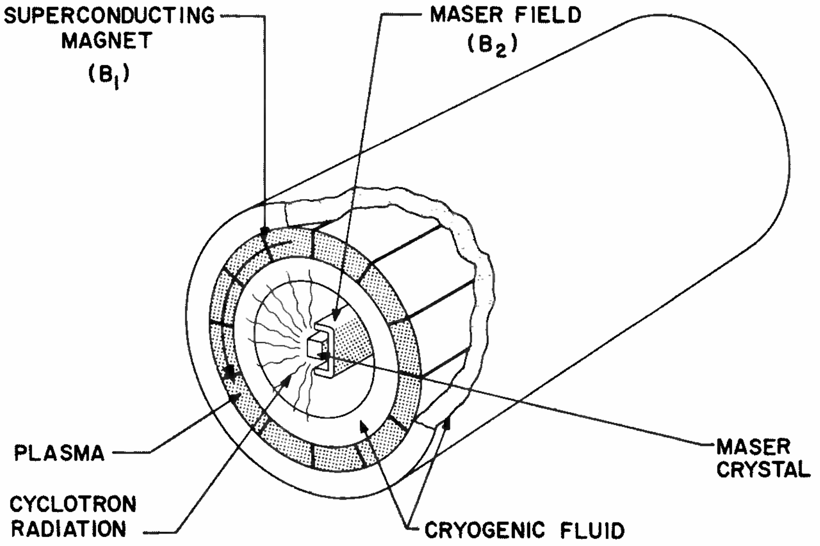


Fig. 9—A cyclotronically pumped maser.

DR. JAMES VOLLMER received a BS in General Science at Union College in 1945, an MA and Ph.D in Physics at Temple University in 1951 and 1956 respectively. His research activity has included studies in X-ray diffraction, nuclear radiation damage to semiconductors, infrared properties of materials, and plasma physics. After teaching for five years at Temple University, and supervising a research group for eight years at Minneapolis-Honeywell, Dr. Vollmer joined RCA in 1959. He became Leader of the Plasma Physics Group at that time. In 1963, Dr. Vollmer was promoted to Manager of Applied Physics. In this position he is responsible for research programs embracing plasmas, masers, lasers, optics, superconductivity and electro-optics. He is a member of the American Physical Society, past President of the Philadelphia Physics Club, a Senior Member of the IEEE, a Director of the Philadelphia Science Council, and a member of the Franklin Institute. His honors include membership in Phi Beta Kappa, Sigma Xi, and Sigma Pi Sigma. He has published five papers in professional journals, has four U.S. patents issued, and five U.S. patents pending.

PRELIMINARY EXPERIENCE WITH THE GaAs LASER

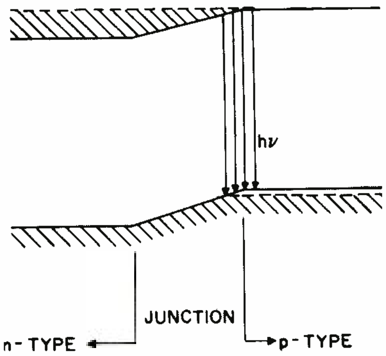


Fig. 2—Energy diagram for a forward biased p-n junction.

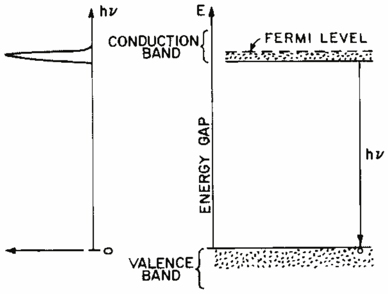


Fig. 1—Energy diagram for a semiconductor.

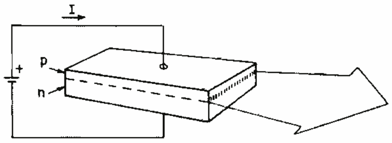


Fig. 3—Structure of the injection laser.

In the conventional solid-state laser, ordinary (incoherent) light provides the input power, i.e., the "pump." But the GaAs laser is pumped directly by an electrical current, a much more efficient process. By direct modulation of the input current, the output coherent light can be modulated at very high frequencies. This adaptability to VHF modulation is not equalled by any other kind of laser. The device is very small and does not require bulky driving equipment. Improvements in structure and processing promise high power operation. This paper reviews the principles involved in the GaAs laser, and describes the performance of GaAs lasers realized at RCA Laboratories up to March 1963.

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The GaAs laser is a newcomer to the laser family which now comprises a tremendous variety of members. Unlike other lasers which are pumped optically, the GaAs laser is pumped *electrically*. In optically pumping a laser, a source of electrical energy is used to make very intense incoherent light that is supplied to the laser material—which converts the incoherent light into coherent light of another wavelength. This is a two-step process and, as such, is somewhat inefficient. (The highest efficiency obtained in optically pumped lasers is of the order of 1%.) In the GaAs laser, on the other hand, the electrical energy is converted *directly* into coherent light. Since it is a one-step process, the transformation can be done very efficiently. (Efficiencies of the order of 50% have been obtained.) Furthermore, one does not need relatively bulky equipment between the source of electrical energy and the laser material itself.

But, most important, since the power supplied to the laser is in the form of an electrical current, it lends itself to modulation at high frequencies. In contrast, with optically pumped lasers the modulation of a light beam requires optically active materials, which are relatively inefficient and are difficult to modulate at high frequencies. Since we know how to modulate an electrical current, it appears a simple matter to modulate a GaAs laser.

SOME HISTORY

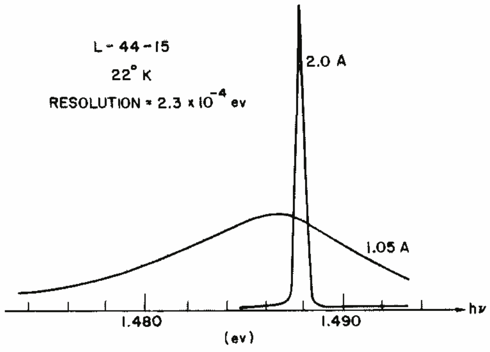
Electroluminescence in GaAs was first reported by R. Braunstein[1] in 1955. In 1961, aware of the laser possibilities of GaAs, and taking advantage of the advances in the technology of GaAs, we took another look at its electroluminescent properties. The spectral characteristics, as well as other properties of p-n junctions which shed light on the recombination processes within this material have been examined.[2,3] It is then that we found that the internal conversion efficiency of GaAs is near unity. This high conversion efficiency opened the possibility of realizing an injection laser. On the other hand, our experiments with modulation of incoherent sources of infrared[4] showed that it is possible to modulate the GaAs light source with frequencies of at least 200 Mc.

The laser possibilities of GaAs were verified and described[5] in October 1962.

PRINCIPLE

Let us examine the light emission process in a semiconductor. Fig. 1 shows an energy diagram for a semiconductor. The electrons are distributed in states occupying various energy levels. These levels are grouped into two bands, the valence band and the conduction band, separated by an energy gap. Fig. 1 represents an n-type degenerate semiconductor which means that there are electrons in the conduction band and that all the states below the Fermi level are completely occupied. The injection of the hole into the valence band is equivalent to the creation of an empty

Fig. 4—Emission spectra below and above threshold current.



state in the valence band. Now an electron from the conduction band may make a transition to this empty state, since this is a low-energy state for the electron. In this transition, the excess energy is emitted as a photon having an energy $h\nu$, which is equal to the difference between the energies in the initial and final states. A whole range of energies can be emitted because there are electrons at initial states at various energies. The number of photons emitted at a given $h\nu$ is then related to the number of electrons in the corresponding initial state, and so we can plot the number of photons of a given energy that can be emitted in the left-hand side of Fig. 1. The shape of this distribution is related to the occupancy of the conduction band. This diagram is an emission spectrum. To produce an overlap of occupied states in the conduction band with empty states in the valence band one resorts to a p-n junction as shown in Fig. 2. This overlap can be obtained by applying a sufficiently large forward bias across the p-n junction. In the recombination process, the electron stays in the conduction band for a time determined by the transition probability. The transition probability in turn depends on the number of modes of that frequency available in this system. In any volume of matter, there are many photons and other vibrational modes present; these are quantum mechanical entities called *zero-point vibrations*. These zero-point vibrations are incoherent, and there may be many of them at any given frequency. When one transition has been stimulated by a photon, we have now two identical photons traveling in the material. These two photons have the same frequency and are in phase. These two coherent photons can in turn stimulate the recombination of other hole electron pairs in their path and, in the process, create more photons of the same frequency and phase—and the photon wave grows in intensity. Since many photons are available to stimulate the recombinations, many *modes* (that is, photons of many frequencies and many different phases) are amplified simultaneously. As a consequence, the output is an incoherent light.

If now we design a structure which favors a given mode, photons in this mode will be amplified more than other modes, and as a result, we will end up with a *coherent* beam of electromagnetic energy. The exact nature of the transition process is still controversial. It may be a transition from the conduction to the valence band or it may be a transition between impurity levels which merge with a band. In either case, the general principle is the same. Since the laser action depends on the stimulation of transitions by photons of a given frequency, it is important that the field of stimulating photons be allowed to increase in density. Therefore, one must beware of losses. In addition to losses which consist in hole electron pairs making nonradiative transitions, one has to cope with a variety of photon losses, as follows:

1) *absorption* (across-the-gap transition, free-carrier absorption, and transitions from impurity states)
2) *scattering*
3) *transmission*
4) *diffraction*

The absorption losses due to *across-gap transition* consist of the emitted photon exciting an electron from the valence band to an empty state in the conduction band. This is the creation of a hole-electron pair. If this hole-electron pair subsequently recombines by re-emitting the same photon, there is no loss; but since energy is usually degraded, chances are that the photon emitted in this recombination will be of an energy lower than that of the stimulated mode.

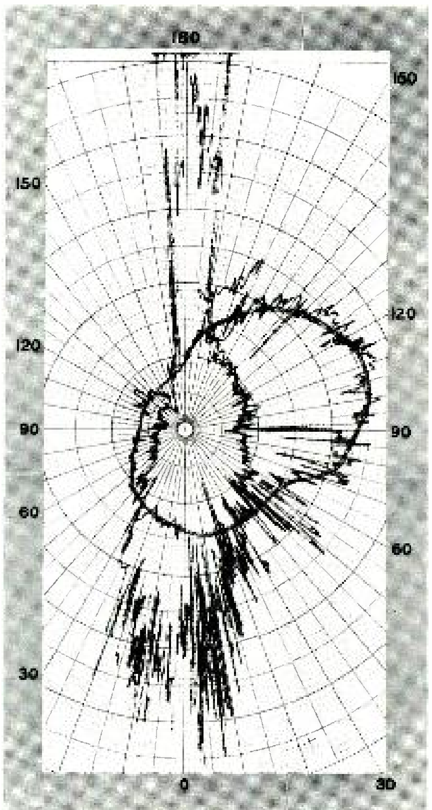
Free-carrier absorption consists of the excitation of an electron in one of the bands from an occupied state to some empty state of higher energy in the same band. When the electron returns to its lower energy state, it releases the excess energy in the form of heat. This makes free-carrier absorption a very serious photon loss, because not only does a photon disappear from the field of photons, but also the crystal heats up. The recombination process happens to be strongly temperature-dependent, the probability for radiative recombination being an inverse function of temperature.

Losses in the form of *impurity absorption* consist of the excitation of electrons from occupied impurity states into empty states of the conduction band or from occupied states in the valence band to empty impurity states.

For optimum stimulation, we are interested in keeping the coherent photons traveling in the same direction without divergence; however, photons can interact with impurities and other inhomogeneties in the material and be diverted in other directions. This process is called *scattering*.

Let us consider transmission losses. A resonant structure consisting of reflecting surfaces such as a Fabry-Perot cavity causes photons to travel back and forth in the material thus increasing at every pass the density of coherent photons. However, to make the device useful, we must allow some of the photons

Fig. 5—Radiation pattern from a GaAs diode in the plane of the p-n junction. The smooth line represents the radiation pattern below threshold. The trace going off scale is the directional pattern above threshold.



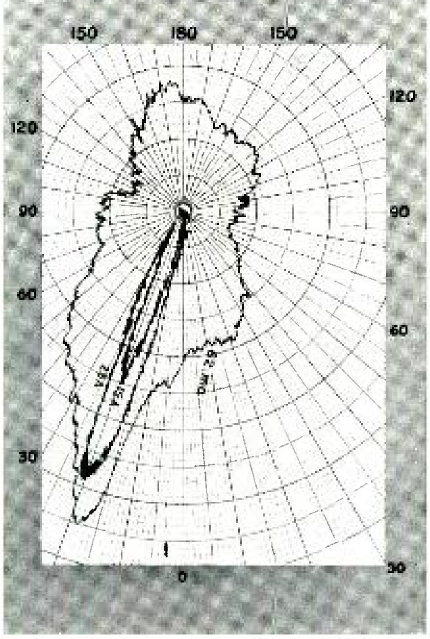


Fig. 6—Radiation pattern from a GaAs diode in a plane transverse to the p-n junction. The broad distribution is that of an incoherent source (below threshold); its shape is determined mostly by the supporting structure (a pressure clip). The beamed distribution is that obtained above threshold.

Fig. 7—Cross section of laser beam viewed by a focussed image converter.

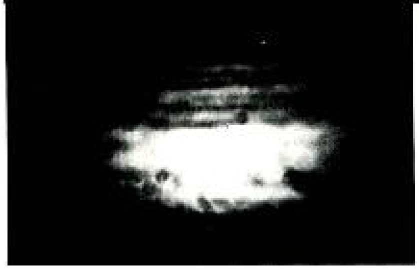


Fig. 8—Cross section of laser beam at higher current than in Fig. 7.

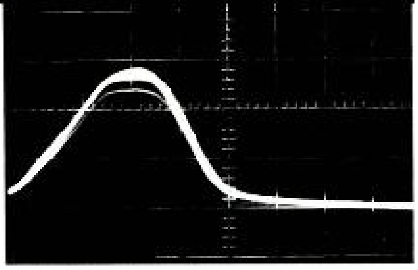


Fig. 10—Laser ouput vs time (1 μsec/cm). Two traces: upper trace taken without a polarizing filter; lower trace taken through polarizer with E vector perpendicular to plane of p-n junction.

to emerge from the crystal. This is accomplished by making one of the surfaces partly reflecting. Then, the radiation which is allowed to come out is lost as far as the stimulation process is concerned.

The recombination process occurs in a narrow region at the p-n junction. We are interested in photons traveling along the plane of the junction. When light traverses a region which is small compared to its wavelength, the light beam is caused to diverge. This diffraction phenomenon occurs at every step of the way in the plane of the junction and constitutes a loss of photons.

A rough calculation for the minimum carrier pair concentration p required for laser action in the band-to-band recombination follows.[6] We simply write that the light emitted is equal to the difference between the light generated in the material and the light lost in the material:

$$\frac{c}{n}\nabla\rho(\nu) = [\rho(\nu)+\rho_0(\nu)]\; p^2\gamma(\nu) - [\rho(\nu)P(\nu)+\cdots] > 0 \qquad (1)$$

Where $\rho(\nu)$ is the density of photons of frequency ν that are created in the material; c/n is the velocity of light in the semiconductor; $\gamma(\nu)$ is the probability per second per electron per unit volume and per hole per unit volume for the triggering of a radiative recombination emitting a photon of frequency ν. The emission rate follows Bose statistics and is proportional to the density of possible photons having a frequency ν. The minimum density of such possible photons consists of the zero point photons $\rho_0(\nu)$, which are given by:

$$\rho_0(\nu) = \frac{8\pi\, n^3\, \nu^2}{c^3}$$

The last bracketed term in Equation 1 comprises all the photon losses. The greater the number of loss mechanisms, the higher will be the threshold for laser action. What we can find from Equation 1 is at least a minimum value for the injection concentration that will give laser action. The only term shown in the losses of Equation 1 is the absorption of photons leading to pair creation. The term $P(\nu)$ is the transition probability for exciting an electron from the valence to the conduction band; $P(\nu)$ is known from the absorption coefficient. We shall neglect losses other than pair creation.

The optimum condition for minimum injection threshold is obtained when all the surfaces are perfectly reflecting. Then no light can come out, and the laser modes keep building up. In this case, Equation 1 can be rewritten:

$$\rho(\nu) = \frac{\rho_0(\nu)}{\dfrac{P(\nu)}{p^2\gamma(\nu)} - 1} \qquad (2)$$

Examining Equation 2, it is obvious that the denominator can vanish. Then $\rho(\nu)$ tends to infinity while the emission spectrum becomes a narrow emission line. Such a spectrum describes the output of the laser, although this equation says nothing about coherence. The process can be explained phenomenologically as follows. A photon stimulates a pair recombination which produces a second photon of the same frequency and phase as the stimulating photon. Now we have two photons propagating in the same direction in the material and they can interact with another hole-electron pair to produce another photon also of the same frequency and phase. This process continues building up the field of photons into a growing wave. This is an amplification process sometimes referred to as *superradiance*. However, the zero-point modes consist of many incoherent photons; so, photons of many frequencies and various phases are amplified simultaneously. A suitable design of the structure will favor the propagation and the amplification of one particular mode. This is the mode which will give the laser emission.

We want to find the pair concentration which makes the denominator of Equation 2 vanish:

$$p^2 = \frac{P(\nu)}{\gamma(\nu)}$$

It can be shown that:

$$p = 4.8 \times 10^{15}\, T^{3/2}\, (m_h m_e)^{3/4}$$

Where: m_h and m_e are the density of states effective masses for the holes and electrons respectively. This is an absolute minimum criterion for laser action assuming that the loss of photons is only due to band-to-band transitions and that we have a perfect Fabry-Perot cavity. This minimum value for critical pair concentration has been calculated for a number of materials (at 4.2°K for laser action; values in pairs/cm^3):

Germanium	1.4×10^{17}
Silicon	3.1×10^{17}
Gallium Arsenide	4×10^{15}
Gallium Phosphide	4.2×10^{15}
Gallium Antimonide	5.7×10^{15}
Indium Antimonide	10^{14}

The significance of this calculation is that the material must be degenerate

Fig. 9—Variation of light intensity as a function of the current through the diode.

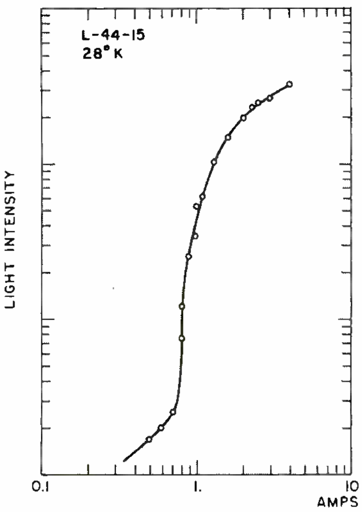


Fig. 11—Photographs of a diode through a focussed image converter. Top: below threshold; bottom: above threshold.

enough to place the Fermi level several kT's inside the corresponding band. A phenomenological justification for this criterion follows. The light emitted in the recombination process is necessarily of energy lower than that which separates the Fermi level from the opposite band edge. These photons will not be reabsorbed by creating pairs because their energy is not sufficient to excite a carrier from one band edge to beyond the Fermi level in the opposite band. On the other hand, the lower energies emitted cannot be reabsorbed because the would-be final states in the conduction band below the Fermi level are all occupied.

LASER STRUCTURE

The laser consists of a wafer of n-type GaAs doped with 10^{17} to several times 10^{18} donors per cubic centimeter. The dopant used has been either tin, silicon, or tellurium. A planar p-n junction is produced in the wafer by diffusing zinc at about 800°C for about 1 hour. The wafer is cut in either the *(100)* or *(111)* plane. Ohmic electrodes are deposited on opposite facets of the wafer: sintered nickel on the p-type side and gold-tin on the n-type side. Then the wafer is broken into small pieces along cleavage planes. In this way one obtains small parallelepipeds with perfectly flat and parallel surfaces. The dimensions of the laser pellets are approximately 0.2 mm by 0.5 mm. The thickness is about 0.1 mm. Connections are made to a source of electrical energy which biases the junction in the forward direction while the diode is immersed in a refrigerant such as liquid nitrogen or liquid neon. Light is emitted in the direction of the arrow (Fig. 3).

MEASUREMENTS

The onset of laser action can be observed in the spectrum of the emitted light. Fig. 4 shows the emission spectrum at two different currents, one below the threshold and the other above the threshold. Below threshold, the emission spectrum is very broad (about 100 angstroms wide) while above threshold the emission spectrum is of the order of 2 angstroms wide and very intense.

Because the stimulation process produces waves propagating in the same direction, the laser output is in the form of a directional beam. This can be verified by measuring the radiation pattern of the laser (Fig. 5). A broad distribution is obtained below threshold but above threshold the emission is directed in a narrow beam. The radiation pattern for Fig. 5 was taken in the plane of the junction. In a plane transverse to the junction, the distribution is as shown on Fig. 6. The nonuniformity of the emission pattern below threshold is due to shadowing effects of the laser holder. The shape of the beam is best seen by placing an image converter in the path of the beam and photographing the pattern obtained (Fig. 7). Below threshold, no definite pattern is observed; but at threshold, the bright patch of Fig. 7 appears. It shows that the emission beam consists of a broad fan-shaped beam. The emitted beam is about 5° wide and less than 1° thick. In this photograph, the laser beam is a horizontal fan. It comes from a vertical junction. When the current intensity through the laser is increased, one obtains the pattern of Fig. 8. It shows a brightening of the main fan plus the occurrence of other lobes, which may be single-slit interferences.

Since the laser output is in the form of a directional beam, one can measure the threshold by placing a detector in the path of the beam and measuring the light intensity as a function of current (Fig. 9). We see that the light intensity increases linearly with current while the emission is incoherent. When coherence sets in, the beam becomes directional, and therefore the emission condenses into a small solid angle, which results in a very high density of light at the detector. Correspondingly, the detector output rises abruptly. After the beam is formed, the coherent light tends to grow linearly with current until sample heating turns off the lasing action.

Another feature of the injection laser is that the light emitted comes out polarized preferentially with the *E* vector transverse to the plane of the junction (Fig. 10). This figure consists of two traces of detector output as a function of time. One trace is taken without using an analyzer beween the laser and the detector, whereas the other trace, in near coincidence with the first one, is taken through an infrared polaroid aligned with the *E* vector transverse to the junction. A 90° rotation of the analyzer causes extinction of the light output.

Fig. 11 shows the distribution of the emitting area before and after threshold as viewed through an image converter focussed onto the laser surface. We see that below threshold the emission comes from the plane of the junction. Above threshold a very bright spot appears where the laser action takes place.

We are also interested in knowing the duration of the coherent mode. Fig. 12 shows the output of the detector as a function of time. The laser is driven by a 90-μsec pulse. The coherent output lasts for about 70 μsec. The coherent output decays due to heating of the crystal and for the remaining 20 μsec. the intensity of the emitted light (now incoherent) is small because the emission is no longer concentrated in a small angle.

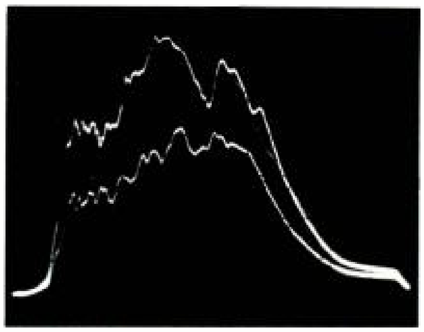
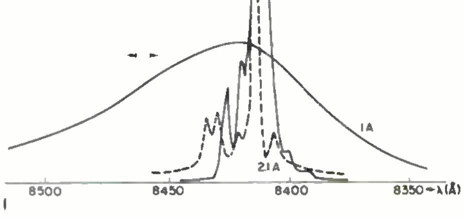


Fig. 12—Time dependence of the light output during a 90 μsec pulse of current. Laser action lasts about 70 μsec.

At high injection currents, coherent emission occurs in several modes each having different wave lengths. This is shown in Fig. 13, which represents the emission spectrum at two currents above threshold as well as the spectrum below threshold for comparison. Note that the emission consists of many lines. Fig. 14 shows the emission spectrum at 2.1 amps through the diode when viewed through a polarizer. One will note that when the polarizer has the *E* vector perpendicular to the junction the shape of the spectrum is nearly the same as that of the spectrum without analyzer. When the analyzer is rotated by 90° so that the *E* vector is parallel to the junction, most of the peaks have disappeared. This demonstrates the dominance of the mode propagating with the *E* vector transverse to the junction. The emission spectrum was obtained by integrating the output at various wavelengths over a period of time. But, the various emission peaks do not occur simultaneously. This is inferred by Fig. 15, which shows the emission as a function of time for four different values of current through the laser, all these cur-

Fig. 13—Emission spectrum from GaAs diode below and well above threshold.



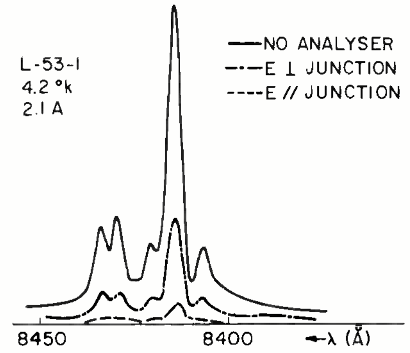


Fig. 14—Emission spectrum at 2.1 Amp; a. no polarizer, b. polarizer with E vector perpendicular to plane of junction, c. polarizer with E vector parallel to plane of junction.

rents being above threshold. The different lengths of the four pulses are due to the fact that the duration of the current pulse through the diode increases with increasing current. The remarkable feature is that different bumps appear as a function of time as the current is increased. Each bump corresponds to the onset of a different mode of laser action. A recent measurement of the power emitted from a laser indicates that it is of the order of two microjoule per pulse. In spite of its small size, the GaAs laser is still of great interest from power point of view. Average coherent power of 1 watt has been reported.[7]

CONCLUSION

The GaAs laser promises the efficient conversion of electrical energy into coherent light which can be modulated at very high frequencies. The device is very small and does not require bulky driving equipment. Its adaptability to modulation at high requency is not equalled by any other kind of laser. With improvement in structure and processing, we can look forward to high-power operation.

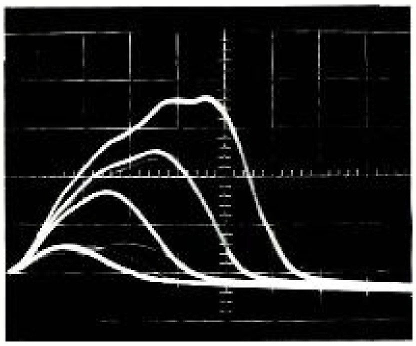


Fig. 15—Time dependence of laser output at four currents above threshold, abscissa = 1 µsec/cm the lower curve corresponds to a 9 Amp pulse, the highest current corresponds to a 10 Amp pulse.

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DR. JACQUES I. PANKOVE obtained his BS in 1944, and after two years of military service, his MS in 1948 from the University of California, both in EE. In 1948 he joined the RCA Laboratories, where he has made many contributions to the understanding of semiconductor devices. In 1956, he was the recipient of a "David Sarnoff Fellowship" to study abroad for one year, at the University of Paris, France. His research topic there (towards a doctoral thesis awarded in 1960) was the study of infrared radiation from surface processes in germanium. Since his return to RCA Laboratories, he has worked on superconductivity, where he has evolved several new device concepts and has done research on silicon carbide. He has investigated the optical properties of degenerate germanium and the electrical properties of tunnel diodes in germanium, as well as in superconductors and in thin oxide layers. Currently, he is concerned with interjection luminescence and the laser action in gallium arsenide and other compounds. Dr. Pankove has published over 20 papers and has over 30 issued patents. He has received two "RCA Laboratories Achievement Awards." He is a member of the APS, IEEE, the Electrochemical Society, and Sigma Xi.

JAMES E. BERKEYHEISER served from 1942 to 1948 in the U. S. Navy as an Aviation Radioman and as an Electronics Technician. He joined the RCA Laboratories in 1948 as a wireman. In 1950, he was called back into the Navy, and assisted with the re-establishment of the Aviation Ordnance School at Jacksonville, Florida. He was Supervisor of the electrical phase of instruction. He rejoined RCA Laboratories in 1952 and received his BSEE in June 1960 from Drexel Evening College. Mr. Berkeyheiser has designed flying spot scanners and worked on projection color television, panel light amplifier and panel light amplifier type of x-ray fluorescent screen. He assisted with work in thin SiC films. He has assisted in the study of silicon carbide and has set up facilities for the deposition of SiC films; he has also made spectroscopic measurements and has built and designed a variety of specialized equipment. He has designed equipment for the evaporation and study of thin films. More recently, he has assisted in the study of GaAs lasers.

FRANK HAWRYLO attended Trenton Junior College (1956 to 1958) and graduated with an AS degree. From 1958 to 1960 he was employed by various departments of the State of New Jersey. In April, 1960 he joined RCA Laboratories as a research technician. Some of the projects he has been associated with are the tunnel diode, wide band gap transistor, hetero junctions, light transistors, and at the present time, gallium arsenide injection lasers. The work involves preparing and fabricating materials, making electrical measurements, and the evaluation of materials.

HERBERT NELSON received his BS from Hamline University in 1927 and his MS in physics from the University of Minnesota in 1929. From 1929 to 1930 he was an engineer with the Westinghouse Lamp Company in Bloomfield, New Jersey. He transferred to RCA in 1930 and was engaged in R&D at the Tube Plant in Harrison, New Jersey, until 1953, when he joined the Semiconductor Research Group at the RCA Laboratories, Princeton. Mr. Nelson's work has covered almost every important phase of vacuum tube and semiconductor device technology and research. His many original contributions include novel space-charge amplifiers, vacuum gauges, and new types of transistor structures. His diffusion-lapping technique has led to silicon transistors with greatly improved characteristics and is also especially useful for the fabrication of miniature integrated-type devices. Mr. Nelson has been one of the pioneers responsible for the development of epitaxial technology. His recent investigations has contributed greatly to the successful fabrication of GaAs injection lasers. He has received two "RCA Laboratories Achievement Awards," and shared in the "1962 David Sarnoff Outstanding Achievement Team Award in Science." He has published many technical papers and has been issued numerous patents. He is a member of Sigma Xi and of the APS.

The authors (l. to r.) Herbert Nelson, Dr. Jacques I. Pankove, Frank Hawrylo, and James E. Berkeyheiser.

Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST

Computer Analysis of a High-Resolution Electron Gun

by JOAN LURIE, *Astro-Electronics Division, DEP, Princeton, N. J.*

The analysis described herein was part of an effort to develop a high-resolution electron gun for use in image orthicon camera tubes.[1] The objectives of the computer analysis were to predict the resolution obtainable from several gun configurations, and then to employ these results in the design of improved electron guns.

In order to calculate resolution, the potentials and electron trajectories inside the gun must be known. Since exact solution of Laplace's equation is not feasible for most electron guns, the potentials have been calculated on a computer. The computer input was the potential distribution along a closed boundary as shown in Fig. 1 for a standard image orthicon gun. The boundary potentials between the electrodes were measured on a resistor board analog of the gun; the axial potentials were calculated by the computer.

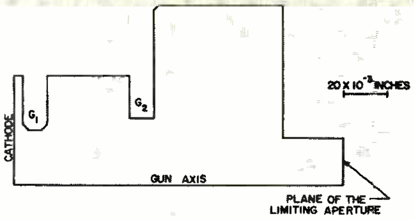
The electron trajectories were computed by numerical integration of the equations of motion. The initial velocities were chosen to correspond to the thermal velocity distribution characteristic of the cathode temperature. Thus thermal effects are accounted for although space charge effects are not included in the calculation.

The beam resolution is found by measuring the minimum diameter, in the gun interior, of that bundle of electrons whose trajectories pass through the limiting aperture. According to Dr. Otto Schade[2] the equivalent rectangular passband of an electron beam N_e, in cycles per unit length, cannot exceed the ratio of 0.8 to this diameter. The crossover diameter measured from the trajectories computed for the standard gun is about 15 microns, which corresponds to $N_e = 50$ line-pairs/mm. Since the input velocities were thermal only, this resolution can be achieved only with a *smoothed-cathode* gun.

The computed position of the crossover is in a plane where the on axis potential exceeds 200 volts. For small current densities the omission of space charge effects from the program should not lead to serious errors. This has been verified by comparison with experimental data: the resolution obtained from smoothed-cathode guns operated at low beam currents (20×10^{-9} amperes) agrees well with the predicted value. The experimental resolution decreased at higher beam currents, suggesting the effect of space charge.

The computed potentials in the interior of the standard image orthicon gun indicate a diverging field near the gun axis on the cathode side of the G_2 electrode. The effect of this field is to shift the crossover toward the limiting aperture. This produces higher beam current, but increases the angle subtended by the crossover at the aperture. If the distance between G_1 and G_2 is increased, while other dimensions and potentials are unchanged, this diverging field should not be present and the crossover should move back toward the cathode. Then, since the electron paths after crossover are rectilinear, the beam current will decrease. Conversely, if the distance between G_1 and G_2 is decreased, the crossover should move toward the aperture and the beam current should increase.

Fig. 1—Computer input — potential distribution along a closed boundary.



Two guns incorporating the above changes were analyzed on the computer. The results confirm the predicted changes in the beam properties. The gun with the wider G_1-to-G_2 spacing showed a narrow crossover relatively close to the cathode, giving improved resolution but lower beam current. The "short gun" (i.e., that with the narrower electrode spacing) did not display a sharp crossover, indicating poor resolution. However, the beam was derived from a relatively large area of the cathode indicating high beam current.

The results of these three analyses indicate that a gun of the type shown in Fig. 1 can produce high resolution but is not suitable for applications requiring both high beam current and high resolution.

Acknowledgement: The author is grateful to I. M. Krittman for his careful proofreading.

1) Contract AF 33(657)7939: Applied Research on High Resolution Camera Tubes.

2) See, for example, Otto H. Schade, "Image Gradation, Graininess and Sharpness in Television and Motion Picture Systems. Part II," *Journal of the SMPTE*, March, 1952. *58*, #3.

CORRECTION:

In the previous issue of the RCA ENGINEER (Oct.-Nov. 1963, Vol. 9, No. 3), an error occurred in identification of the photographs appearing with the *Note* by W. H. Liederbach ("Development of a New Package for Tunnel Diodes") on page 73.

The identifying numerals beside each photo now read (incorrectly) 1, 2, 3, 4, and 5, 6, 7, 8. They should be corrected to read **1**, **3**, **5**, **7**, and **2**, **4**, **6**, **8**, from top to bottom of the lefthand and righthand vertical row of photos, respectively, in order to properly match the descriptive captions that appear below the photos.—*The Editors.*

30-Gc Multiplier as an Ultrastable Parametric Amplifier Pump

R. J. KAMPF, R. S. FORMAN, O. J. HANAS, AND D. H. KNAPSCHAEFER,
Communications Systems Division, DEP, Camden, New Jersey

A nondegenerate, x-band parametric amplifier has been pumped at 30 Gc by a multiple chain whose input is a 78-Mc crystal oscillator (Fig. 1). (The multiplication stages up to 10 Gc were developed under a separate program.) A varactor tripler is added as the final stage of the pump source.

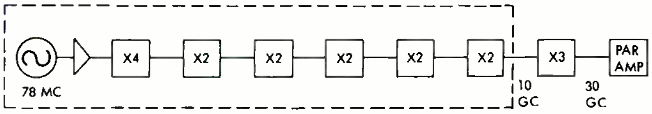
The FM noise input has been measured at the 10-Gc port of the packaged multiplier and found to be 70 db below the carrier in a 100-cps bandwidth at 500-cps separation from the carrier. The AM noise in a 100-cps bandwidth was measured to be more than 110 db below the carrier. The output tripler is a breadboard device built without bias shielding, but should exhibit comparable characteristics in a product design. The significant data obtained from the amplifier-pump combination is:

Signal Frequency:	8.75 Gc	*Noise Figure:*	4 db
Gain:	17 db	*Pump Frequency:*	30 Gc
Bandwidth:	35 Mc	*Pump Power:*	12 mw

The diode used in the amplifier is an RCA type VD216A gallium arsenide varactor.

The conversion loss of the input tripler of the multiplier chain was 9.5 db at the time of this experiment. The same tripler circuit has exhibited a conversion loss of 6.5 db with better diodes. Thus,

Fig. 1—Ultrastable paramp pump.



24 mw pump power is available from this configuration. The parametric amplifier gain and bandwidth were measured using 24 mw from a pump klystron. Under these conditions, 15-db gain and 90-Mc bandwidth were obtained.

Acknowledgement: The authors wish to thank I. Joffe, for the use of the 10-Gc multiplier chain for this experiment. Portions of this work were carried out under Navy Contracts N62269-1814 and NOw 63-0814d.

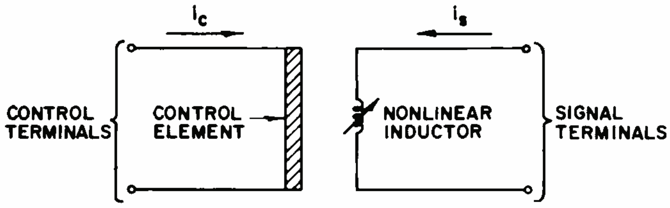
The Ryotron—A New Cryogenic Device

by R. A. Gange, *RCA Laboratories, Princeton, N. J.*

The *ryotron,* an RCA-pioneered inductance switch, differs physically from a cryotron in that the control strip consists of a soft superconductor while the gate strip consists of a hard superconductor. The control strip acts as a ground plane to the gate strip. In the absence of control current, the control strip (ground plane) is superconducting, thereby causing the magnitude of inductance of the gate strip to be very small (about 10^{-11} henry). However, when control current flows through the control strip (ground plane), it causes this ground plane to assume an "intermediate state," i.e., a state of essentially zero resistance existing simultaneously with the absence of diamagnetism. As a result, the control strip (ground plane) no longer acts as a shield to a magnetic field, and the magnitude of inductance of the gate strip abruptly increases by 2 to 3 orders of magnitude. A network of ryotrons has the capacity to perform logic by having all unwanted paths admit to very large inductive elements (as opposed to resistive elements in the unwanted paths of a cryotron network). The desired paths of such a ryotron network, however, would admit to essentially zero inductance. Consequently, the delay of a gate current(s) from the input of a ryotron network to its output would be only a function of the risetime of the input gate current; the "ripple through delay" of gate current though a ryotron network in principle can be made to be virtually zero. Although not essential to the operation, two ground planes may be used to eliminate inductive pickup which might be present in the gate strip upon the introduction of control current. A normal resistive material is used in shunt with the control strip ground planes to self bias the control strip ground planes into the intermediate state. As an example of an array of ryotron elements, six elements may be arranged to form a 1-input, 4-output selection tree function. By changing the appropriate control currents, the gate current may be steered to any one of the four outputs.

This ryotron selection tree differs essentially from the conventional cryotron tree of similar level in the following manner: Control current applied to the cryotron tree instead gives rise to a magnetic field which causes a section of drive path to assume the resistive state. In sharp contrast, control current applied to a ryotron tree causes two ground planes associated with the corresponding section to assume an "intermediate" state. As a result, the inductance of a segment of that drive path section (which is sandwiched by the ground planes) assumes a very large magnitude of inductance. Thus, each unwanted drive path admits to a very large inductive element. The magnitude of the equivalent inductance of all the unwanted drive paths is much larger than the inductance of the desired drive path. Consequently, when initial drive current is introduced, the inductive division of this current establishes sufficient drive current in the desired row or column "instantaneously," i.e., as fast as the input current can rise. This absence of delay is independent of the number of levels of the tree.

Fig. 1—Symbolic representation of a ryotron.



Ryotrons may also be used as basic *and, nand, or,* and *nor* gates; the interconnection of the latter is somewhat novel in that the fanout is of a "serial" nature. A "universal building block" is depicted which may in principle be instructed into any base function. By the proper interconnection of points of this latter block, combines of inputs for *or* and *and* or *nor* and *nand* operations may be realized.

The discussion thus far has represented the ryotron as a variable inductance with two states—those of minimum and maximum impedance. However, in essence the ryotron is an amplifier and if used as such, amplification of gate currents is possible. The ryotron may function as a parametric amplifier by pumping the control current at a frequency which supports amplification of the gate current. Because the magnetic field of the control current acts as a source of energy to the gate current associated with the ryotron, power amplification of this current may be realized.

If the gate path of a ryotron is placed in shunt with a hard superconductor, the inductance of which is much larger than the inductance of the gate path, pulse amplification may be realized via a DC transmitter action.

A Large-Capacity Cryoelectric Memory With Cavity Sensing

by L. L. Burns, D. A. Christiansen, and R. A. Gange, *RCA Laboratories, Princeton, N. J.*

A superconductive memory that lends itself to an extremely large storage capacity, billions of bits, has been developed at RCA Laboratories. The memory consists of a continuous sheet for storage, *X-Y* current coincident access lines driven by cryotron trees, and sensing through a cavity of very simple geometry. A single process fabrication technique makes all storing elements, all adding lines and switches and all connections.

The storage plane, together with cryotron address matrices, is contained on a 2-by-2 inch glass substrate (Fig. 1). Memory packing density is 10,000 bits per square inch.

The memory is fabricated via vacuum deposition techniques and consists of a superconducting memory film, a sense tongue, and *X* and *Y* superconducting lead (Pb) drive lines. The latter are orthogonal to, and insulated from one another, and are insulated from the storage plane over which they pass. The sense tongue is beneath the storage plane; both films are electrically connected along the back edge. The interrogation of a given cell is achieved by the introduction of drive currents at the inputs of the *X* and *Y* selection trees subsequent to the existence of control currents in the cryotrons of these trees. The selected cryotrons in both trees maintain a resistance in all but the desired path, thereby causing coincidence of the *X* and *Y* drive currents over the storage plane at the intersection of the two selected paths. If the drive currents are such as to have their magnetic fields add to that of the stored currents, the net magnetic field present at the region of storage plane beneath the intersection at which the drive currents are coincident will be sufficient to destroy a superconducting state of this region; as a consequence of this disturbance the cavity resonator is excited. The sense output voltage is taken from an impedance matching transformer which is connected to the front edge of the

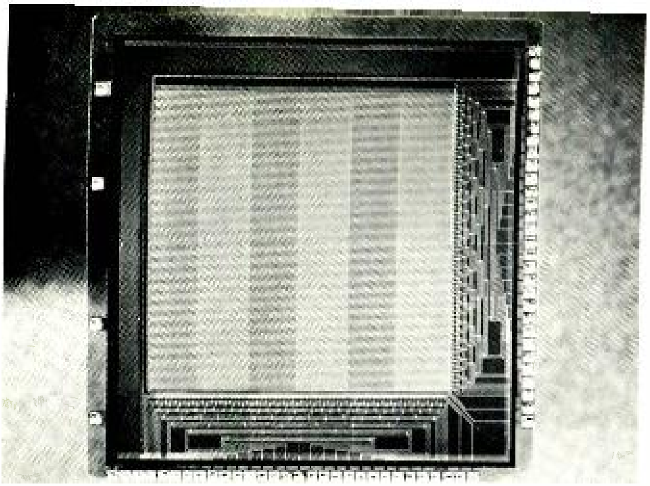


Fig. 1—A 16,384-bit continuous film memory with cryotron address matrices.

storage plane and sense tongue. The removal of the drive currents establishes persistent currents which are opposite to those stored previously; the readout is therefore destructive. If the drive currents are such as to have their magnetic fields subtract from that of the stored current, the net field is insufficient to destroy the stored current and no sense voltage is observed.

The bit density of 10,000 cells per square inch does not represent a limit for a continuous sheet memory. Anticipated bit densities may be larger by three or four times. By stacking these larger memory planes, a very large random access memory is feasible with a capacity of possibly a billion bits.

The importance of large, fast random-access memories does not need to be stressed. Superconductivity appears to offer the highest promise for high speed, large capacity memories for several reasons: 1) The diamagnetic property of superconductors can be used to shield the sensing circuits from the driving lines, thereby obtaining noise-free signals and thus removing any limit to the size of the plane due to disturbs. 2) Cavity sensing not only permits an extremely simple construction by removing otherwise intricate registration problems but also removes delays heretofore inherent in the transmission of the sense signal. 3) Address matrices are being made at the same time as the memory plane; demonstrating for the first time a fully integrated fabrication technology capable of physically realizing a capacity of billions of bits. 4) In addition, high-speed operation is inherent in superconductive phenomena, although not fully exploited in the first step reported here.

Acknowledgement: The research reported in this *Note* was sponsored by the Air Force Systems Command, Rome Air Development Center, Griffiss Air Force Base, New York, under Contract Number AF30(602)-2722.

A New Silicon VHF Planar Power Transistor

by F. L. KATNACK
AND W. D. WILLIAMS,
*Electronic
Components
and Devices
Somerville, N. J.*

In a high-power, high-frequency transistor, the long emitter periphery required in power transistors must be made compatible with the requirement for small-area electrodes in high-frequency transistors. These conflicting requirements have prevented the complete transistorization of many transmitters. Significant progress has been made toward solving this problem, and a new silicon planar power transistor, the RCA 2N2876, developed as a result of this work, is concrete evidence of the success that has been attained.

Electrical Characteristics: The RCA 2N2876 transistor provides a minimum RF power output of 10 watts at 50 Mc and of 3 watts at 150 Mc when operated from a 28-volt-DC supply. (For typical performance curves, see Fig. 1).

The emitter in the 2N2876 has a 0.4-inch periphery compressed into an area of only 0.0015 square inch, achieved by folding the long emitter periphery into a comb shape (Fig. 2). This configuration provides a peak collector current of 2.5 amperes and a typical gain-bandwidth product of 200 Mc.

Packaging Techniques: An entirely new type of enclosure had to be developed to exploit fully the power-frequency capabilities of the 2N2876. This new enclosure, a 7/16-inch double-ended stud type of package, includes provisions for electrically isolating the silicon pellet from the case and still retains the low thermal resistance between these elements that is necessary in a high-power transistor. In the 2N2876, the junction-to-case thermal resistance is low enough so that the increase in transistor junction temperature is less than 10 °C/watt of collector dissipation. This value allows the transistor to be rated for a power dissipation of 17.5 watts.

Because of the very low input impedances of transistors, lead inductances, especially in the emitter lead, cause inefficient operation and decrease power gain in high-power RF amplifiers. A low-silhouette shell having short rigid pins and a ceramic-to-metal seal was designed to reduce lead-inductance effects to a minimum (Fig. 3).

Reliability Features and Applications: For most applications of high-power, high-frequency transistors, high reliability is a major requirement; and in the development of the 2N2876 VHF power transistor, considerable emphasis was placed on the achievement of a reliable product. The silicon dioxide-passivated planar structure, the large-area connection to the metallizing on the pellet, and the all ceramic-metal construction of the 2N2876 each contribute to the reliability of the transistor. The 2N2876 is also prestressed by temperature cycling from −65 to 200°C and by operating the transistor with the junction at 200°C before final testing.

All 2N2876 transistors are tested to assure that no secondary breakdown—a type of failure in high-frequency, high-power transistors operated as class A amplifiers—occurs within the specific range of voltage and current over which the transistors are rated to operate. Secondary breakdown is generally believed to be caused by a localized thermal runaway that is dependent on both voltage and power. A new method of rating the 2N2876 VHF power transistor was used to assure that they will not be operated in a secondary-breakdown region.

The 2N2876 finds wide use in high-frequency amplifiers, both as an output stage and as a driver for varactor chains.

Fig. 1—Typical operating characteristics of the RCA 2N2876 silicon vhf planar power transistor.

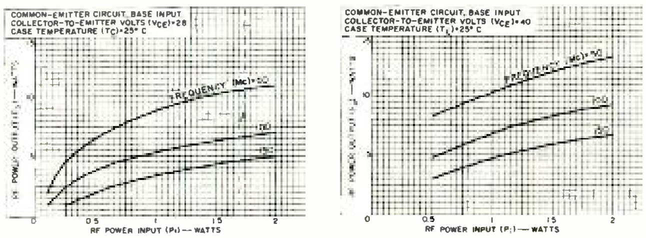


Fig. 2—Comb-shaped configuration of the emitter periphery in the 2N2876 transistor.

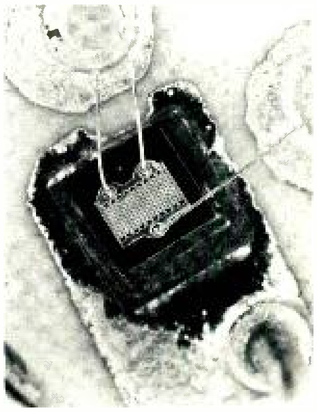
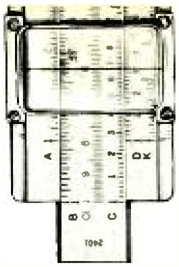


Fig. 3—Over-all package for the 2N2876 transistor.

Engineering NEWS *and* HIGHLIGHTS



HIGHLIGHTS OF RCA CHIEF ENGINEERS' MEETING

Integrated circuits, computer applications in engineering, and the education, motivation, and recognition of the engineer were among the topics discussed at the recent annual RCA Chief Engineers' Meeting in Princeton, N. J. Approximately 100 chief engineers and other key engineering managers attended the two-day meeting that enabled them to exchange information on subjects of mutual interest.

Plans for RCA's prospective retraining program, "Current Concepts in Science and Engineering," were presented by **John Wentworth,** Manager of the program. He explained that initially this program will be given to engineering supervisors.

"Engineering Education—Hindsight and Foresight" was discussed by a guest speaker, **Dr. J. D. Ryder,** Dean of Engineering, Michigan State University. (He is also Chairman of the IEEE Editorial Board.) In his talk, Dean Ryder said that many colleges are "developing curricula which emphasize the scientific bases for future decisions rather than the empirical foundations for past guesses." He suggested that because of this approach "the engineer of tomorrow does exist . . . he has a thorough knowledge of science as his background, rigorous mathematics as his language, and his methods of analysis and synthesis in engineering application as his tools. Where scientific fundamental may be the fundamental or an engineer's aptitude to design around the lack."

The program was conducted in the form of formal papers, question periods, panel discussions, and workshop discussion groups.

DR. J. G. WOODWARD HONORED BY AUDIO ENGINEERING SOCIETY

Dr. J. G. Woodward, a member of the Acoustical and Electromechanical Research Laboratory of RCA Laboratories at the David Sarnoff Research Center in Princeton, recently received the *Emile Berliner Award* of the Audio Engineering Society at its Fifteenth Annual Convention held at the Barbizon-Plaza Hotel in New York City on October 17. Dr. Woodward was awarded the bronze plaque for outstanding developments in the field of audio engineering. He was cited for "his research and development in underwater sound, electromechanical feedback systems, musical acoustics, stereophonic sound reproduction and magnetic tape and disk recording."

RCA LABS PAPER ON LAMINATED FERRITES WINS "BEST" AWARD AT FJCC

Co-authors **Dr. Ralph A. Shahbender, Dr. Kam Li, Stuart E. Hotchkiss, Chandler Wentworth,** and **Dr. Jan Rajchman,** RCA Laboratories, Princeton, N. J., received an award for presenting the "best paper" at the Fall Joint Computer Conference last month in Las Vegas, Nevada. The paper was concerned with laminated ferrite memories. Plaques to each of the co-authors and a cash award was presented by the American Federation of Information Processing Societies. —*C. W. Sall*

"INDUSTRIAL PRODUCTS" ACTIVITY FORMED

Dr Elmer W. Engstrom, President, RCA, has announced that effective December 1, 1963, **F. H. Erdman** is appointed Division Vice President, Industrial Products. The Industrial and Automation Products Department, formerly a part of the Broadcast and Communications Products Division, will become a part of the Industrial Products activity. **N. R. Amberg,** Manager, Industrial and Automation Products Department, will report to Mr. Erdman. Mr. Erdman will report to Dr. Engstrom.

L. A. THOMAS AND W. H. BOHLKE

It is with regret that we report the passing of **L. A. Thomas** (Astro-Electronics Division) and **W. H. Bohlke** (RCA Service Company). In paying our respects, the Editors wish to acknowledge the pioneering efforts and many professional contributions of these men. As RCA ENGINEER Editorial Representatives, they participated in professional technical publication activities of the company—and in particular, contributed very significantly to the early planning, formation, and subsequent conduct of the RCA ENGINEER. Mr. Bohlke with 35 years of continuous service with RCA and Mr. Thomas with 22 years of continuous RCA service, are remembered by their concerted efforts in the documentation, publication, and communication of information of value to the RCA engineering community.

RCA 601 COMPUTER PROGRAMMING COURSES AT PRINCETON

A special training course is providing instruction to members of the Technical Staff at the RCA Laboratories on the use of their new RCA 601 computer, recently installed (*See article by Kurshan, this issue*).

Some 22 Members of the Technical Staff registered for an intensive programming course on the use of the RCA 601 computer and related software. EDP provided this training at RCA Laboratories during the four-week period beginning September 16, 1963. The course was presented to Technical Staff Members who have had considerable programming experience and the need to program in machine language.

In addition, limited programming courses will be provided by Applied Mathematics personnel. These courses, which will require a maximum of three days, were scheduled to start in November 1963. The course content will allow for instruction on the use of a subset of the RCA 601 basic language.

NEW SOUTHWEST WING FOR RCA LABS.

Construction has begun on a laboratory wing to be added to RCA's David Sarnoff Research Center. Scheduled for occupancy in 1964, this new three-story wing will provide 39,000 square feet of additional space and will house some forty laboratories, as well as providing office and shop space. **Dr. James Hillier,** Vice President, RCA Laboratories, pointed out that it will help to relieve the substantially increased pressures upon existing laboratory space, which have resulted from the continued growth of the RCA Laboratories staff and the establishment at the David Sarnoff Research Center of advanced development groups associated with RCA's various manufacturing divisions.

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.

RCA Communications, Inc.

J. R. McDonald: from Operations Engr. to *Group Leader, Terminal Facilities, Installation Design*

L. P. Correard: from Design Engr. to *Group Leader, Automation and Terminal Systems Engineering.*

Electronic Components and Devices

N. C. Turner: from Engr. to *Engineering Ldr., Prod. Dev.* (J. Hilibrand, Ind. Transistor Design, Somerville)

A. H. Medwin: from Sr. Engr. to *Eng. Ldr., Prod. Dev.* (I. Kalish, Somerville)

G. Cohen: from Sr. Engr. to *Eng. Ldr., Prod. Dev.* (I. Kalish, Somerville)

A. E. Brown: from Engr. to *Engineering Ldr., Industrial Applications Lab.*

Electronic Data Processing

R. H. Jenkins: from Engr. to *Ldr., Design & Dev. Engineers* (R. Grapes, Tape Station Eng.)

S. T. Jolly: from Coord. Fab. to *Ldr. Design & Dev. Engineers* (R. Lockhart. Memory Dev.)

J. L. Miller: from Ldr., Design & Dev. to *Mgr., Optical Character Reading Machines* (A. J. Torre, Peripheral Prods. Eng.)

F. E. Brooks: from Engr. Design & Dev. to *Ldr. Design & Dev. Engrs.* (A. Beard)

J. D. Clarke: from Prin. Mbr. Dev. & Des. Eng. Staff to *Ldr. Dev. Eng. Staff* (H. N. Morris, West Palm Beach)

Home Instruments Division

G. F. Rogers: from Mgr., Comm. Adv. Dev. to *Mgr., Adv. TV Prod. Dev.* (E. M. Hinsdale, Jr., Mgr. TV Prod. Eng., Indianapolis)

D. J. Carlson: from Mbr. Tech. Staff to *Ldr. Design & Dev. Engrs.* (G. C. Hermeling, Mgr., Tuner & Remote Eng., Indianapolis)

J. M. Ammerman: from Engr., Prod. Design & Dev. to *Ldr., Design & Dev. Engrs.* (E. B. Cain, Mgr., Mech. Eng.—TV, Indianapolis)

RCA Service Company

N. L. Hanson: from Sr. Engr. to *Ldr., Missile Test Project System Analysis.*

A. E. Hoffmann-Heyden: from Sr. Engr. to *Ldr., Missile Test Project System Analysis.*

W. F. Kennedy: from Sr. Engr. to *Ldr., Missile Test Project System Analysis.*

P. N. Somerville: from Sr. Engr. to *Ldr., Missile Test Project System Analysis*

Helen Mann: from Sr. Engr. to *Ldr., Missile Test Project System Analysis*

J. E. Wakefield: from Engr. to *Ldr., Engineers* (T. G. Rutherford, Missile Test Project)

A. B. Freeman: from Ldr., Engineers BMEWS to *Mgr., Site Eng.* (F. Chess, Site Tech. Maintenance & Eng. BMEWS)

K. D. Dunahm: from Field Engr. to *Mgr., Data Translation* (J. VanCleve, Main Instrumentation—Missile Test Project)

H. D. Tilley: to *Ldr., Pulse Radar, Radar Engineering* (Patrick Air Force Base, Fla.)

STAFF ANNOUNCEMENTS

EC&D Industrial Tube and Semiconductor Division: The organization of the Power Tube Operations Department, reporting to **E. E. Spitzer,** Manager, is as follows: **R. B. Ayer,** Mgr., Quality Control-Power Tube Operations; **W. P. Bennett,** Mgr., Advanced Development Engineering-Power Tubes and Vacuum Components; **C. Hanlon,** Mgr., Super Power Tube Manufacturing; **J. W. Hollingsworth,** Mgr., Regular Power Tube Manufacturing; **W. N. Parker,** Staff Engineer; **R. T. Rihn,** Mgr., Operations Planning and Controls-Power Tube; **M. B. Shrader,** Mgr., Product Engineering-Power Tubes and Vacuum Components; and **P. T. Smith,** Mgr., Power Tube Applied Research Laboratory—Princeton.

EC&D Special Electronic Components Division: The organization of the Direct Energy Conversion Department, **L. R. Day,** Acting Manager, is as follows: **F. G. Block,** Mgr., Thermionic Products Engineering; **L. P. Garner,** Mgr., Battery Products Engineering; **R. L. Klem,** Mgr., Thermoelectric Products Engineering; and **P. P. Roudakoff,** Mgr., Marketing Development.

DEP-CSD, Tucson: **M. L. Touger** has been appointed Manager, Tucson Engineering, reporting to **O. B. Cunningham,** Chief Engineer. The organization of Tucson Engineering is **B. A. Trevor,** Senior Staff Scientist, **L. J. Flodman,** Mgr., Command and Control Devices; **D. B. Reeves,** Mgr., Tactical Devices; **D. R. Green,** Mgr., Systems and Equipment Integration; and **L. M. Wigington,** Mgr., Engineering Design Support.

Data Systems Center, Bethesda, Md.: **A. L. Malcarney,** Group Executive Vice President, RCA, has announced that responsibility for the Data Systems Center, Bethesda, Maryland, is assigned as follows: **D. C. Beaumariage** will continue as Manager, Data Systems Center, and will report administratively to **W. G. Bain,** Vice President, Defense Electronic Products. **C. A. Gunther,** Division Vice President, Technical Programs, will be responsible for functional control of the operations of the center.

RCA PROGRAMMING SYMPOSIUM

An RCA symposium on "Programming for Information Processing" was held recently at RCA Laboratories, Princeton, N. J. to emphasize the increased importance of programming in the computer systems industry and to provide an exchange of information among RCA technical and management personnel in the field. The symposium, organized by the Corporate Programming Study Committee, was attended by 130 invited persons from various RCA Divisions. (Similar corporate symposiums have been held on computer memories, integrated circuits, data communications, and tape systems.)

The need for R & D in programming was emphasized by **Dr. George H. Brown,** Vice President, Research and Engineering. Discussions on the Corporate requirements for computer programming, including those of RCA's Electronic Data Processing Service Centers, set the guidelines for the technical session.

Twenty-seven technical papers were presented, covering the spectrum from basic research to techniques used in operating systems in the field. *Company-private* abstracts of these papers are available—to those having a need to know—from the symposium chairman, **Harry Kihn,** Staff Engineer, Research and Engineering, at Princeton.

PROFESSIONAL ACTIVITIES

EDP Computer Advanced Development, Camden: **J. N. Marshall,** Manager, Computer Advanced Development, is serving as Chairman of the International Solid-State Circuits Conference to be held in Philadelphia, February 19, 20, and 21, 1964.

The Proceedings of the International Federation of Information Processing Congress, Munich, August 1962, published last month, contained a paper by **J. A. Brustman,** Manager, Computer Advanced Product Development, entitled "Past and Future of Digital Computer Circuitry," and the discussions of a panel on "Ultra High Speed Arithmetic and Control Techniques" of which Mr. Brustman was a member.

R. H. Bergman, M. M. Kaufman and **R. J. Linhardt** have been invited to contribute to a forthcoming book of the McGraw Hill Book Company, *Nanophile Digital Devices and Systems.—H. H. Spencer*

NBC, New York City: **W. H. Trevarthen,** Vice-President of Engineering and Technical Operations and **J. L. Wilson,** Director of Engineering at NBC left October 11, 1963 for a three week tour of Television and Radio facilities in Europe.—*W. A. Howard*

RCA Labs., Princeton: The following RCA men are working with the committees noted of the Princeton Section, IEEE: **O. E. Dow** (Section Chairman); **D. S. McCoy** (Section Vice Chairman); **J. D. Bowker** (Chairman, Membership); **J. C. Miller** (Chairman, Visiting Speakers); **S. F. Dierk** (Chairman, Publicity); **L. M. Zappulla** (Chairman, Arrangements); **B. J. Lechner, G. B. Herzog, Fred Herzfeld, R. F. Sanford,** and **C. M. Wine** (P. S. Magazine); **R. E. Quinn** (Chairman, Social Affairs); and **C. W. Mueller** (Chairman, Awards)—*C. W. Sall*

EC&D, Harrison: **Dr. Irving F. Stacy** from Harrison Engineering (C&P Lab.) was recently appointed Chairman of the "Professional Technical Group on Engineering Writing and Speech" for the New Jersey Chapter of the IEEE.—*P. Farina*

EC&D, Conversion Tube Engineering, Lancaster: The following men attended the meetings noted recently: **L. D. Miller,** IRIS Subcommittee Meeting (9/10, Baltimore, Md.); **L. A. Ezard,** JT4.2 Subcommittee Meeting (9/18, New York City); **L. D. Miller,** 10th National IRIS Symposium (9/30-10/2, Asbury, N. J.); **R. P. Stone,** 2nd National Symposium on Information Display (10/3, 4, New York City); and **R. D. Faulkner,** JEDEC Subcommittee Meeting (10/17, New York City)—*R. L. Kauffman*

DEP Applied Research, Camden: The following are serving as reviewers for the IREE Professional Technical Group on Instrumentation and Measurement: **J. P. McEvoy** (Superconductivity) and **L. W. Zelby** (RF and Microwaves).

B. Shelpuk appointed to Technical Committee on Thermoelectrics, ASHRAE (American Society for Heating, Refrigerating, and Air Conditioning Engineers), Sept. 1963.

Dr. James Vollmer, taped three radio programs for the Radio and TV Education activity of the Benjamin Franklin Institute. The programs will be broadcast over WDAS (1480) on three consecutive Sundays, November 17 through December 1. The first program was "Plasma, the Fourth State;" the second, Dr. Vollmer's viewpoints on education; and the third, a discussion of the difference in the pursuits of science, engineering, and technology. The programs will also be broadcast in Boston, Washington, and overseas.—*M. G. Pietz*

DEP, Princeton, N. J.: **Dr. N. I. Korman** attended the XIVth International Astronautical Congress, Paris, France (Sept. 25-Oct. 1). While at the meeting, he participated as Chairman, Communication Satellites, Session 2.—*G. E. Morris, Jr.*

RCA Victor Company, Ltd., Montreal: **Dr. F. G. R. Warren,** Laboratory Director, Systems Research has been appointed Chairman of the Technical Programme Committee for the Third Communications Symposium to be held in September, 1964, under the sponsorship of the Montreal IEEE.

On October 16th, **Dr. A. Carswell** of the Microwaves and Plasma Physics Research Laboratories addressed an IEEE meeting sponsored by the Montreal Chapter of the Professional Technical Groups on Microwave Theory and Techniques and on Antennas and Propagation. The presentation, a discussion of lasers and demonstration of a helium neon laser, was enthusiastically received.—*H. J. Russell*

B&CP, Meadow Lands: Meadow Lands started a company sponsored Transistor course on October 8, for 80 engineers and technicians. The course is based on lecture notes proposed by **A. Luther** and **R. Hurst** in Camden, will run for 11 weeks, and possibly more, depending on the number of special topics covered.—*N. C. Colby*

DEP-CSD, Cambridge, Ohio: Two members of Cambridge Product Engineering, Communications System Division, recently received recognition by the RCA Graduate Study Program Committee. **Donald Johnson** was awarded a certificate of satisfactory completion of the RCA Graduate Study Program. Don received his MSEE degree from the University of Pennsylvania prior to transferring to the Cambridge Activity. **Stanley Lorenze** started his graduate program at the expense of RCA this September. Stan is now working towards his MSEE degree at Ohio State University. **Raymond Larson,** a Leader in Cambridge Product Engineering, Communications System Division, was recently appointed a State Vice President in the Ohio Junior Chamber of Commerce.—*W. C. Praeger*

LASER SYMPOSIUM AT BURLINGTON

RCA recently presented a Laser Technology Symposium for approximately 60 men from the Army, Air Force, Navy, DOD Institute of Defense Analysis, NASA, MIT Instrumentation Laboratory, and the MITRE Corp. The Symposium was held at the DEP Aerospace Systems Division in Burlington, Mass. RCA accomplishments in laser and related electro-optical areas were described by scientists and engineers from ASD, DEP Applied Research, the DEP Missile and Surface Radar Division, and RCA Laboratories. The demonstrations included a laser distance-measuring device, a high power laser for upper atmosphere research, and a laboratory breadboard of an IR reconnaissance equipment that presented an image via fiber optics. In addition, laboratory test setups were demonstrated of a coherent green light harmonic generator, an airborne visual target locator, a laser amplifier, and an optical wave semiactive seeker.—*R. E. Glendon*

NEW NATIONAL SERVICE TELLS WHERE TO FIND NEEDED TECHNICAL INFORMATION

Today's technical and scientific information resources, because of their number and complexity, are often bypassed at great loss both in time and money. To help check this loss and assure effective use of such resources, the *National Referral Center for Science and Technology* was established last March in the Library of Congress under the sponsorship of the National Science Foundation.

The Center assists persons in search of technical information by responding to individual inquiries as to *where* what kind of information may be found, attempting in each case to pinpoint the information resources that best serve the need of the inquirer. It encompasses information resources whether they exist in Government, in industry, or in the academic world. Its function is entirely advisory; the Center does not answer technical questions directly, nor does it provide the documents.

The services of the National Referral Center are available without charge. Questions must be as clearly and precisely defined as possible and the requester should indicate the resources with which he is already familiar or has already consulted. To request referral service, phone 202-967-8265, or write the National Referral Center for Science and Technology, Library of Congress, Washington, D. C. 20540.

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E. Stanko, SVC. CO., PE-13067, N. J.
R. R. Welsh, DEP-MSR, PE-13136, N. J.

C. A. MEYER NAMED CHAIRMAN, EC&D EDITORIAL BOARD

Charles A. Meyer has been named as Chairman of the RCA ENGINEER Editorial Board for RCA Electronic Components and Devices. Mr. Meyer succeeds **John Hirlinger** in this function, who recently retired. (See story elsewhere on this page.)

Mr. Meyer will head up the EC&D Board of 12 RCA ENGINEER Editorial Representatives. He will continue as an RCA ENGINEER consultant Engineering Editor. Mr. Meyer's EC&D responsibilities as Manager, Commercial Engineering Technical Services include coordinating the paper's approval procedures for EC&D. He recently authored a paper for the RCA ENGINEER *Engineer and the Corporation* series entitled, "Effective Placement of Engineering Papers," (RCA ENGINEER, Vol. 8, No. 2, Aug.-Sept. 1962.)

Mr. Meyer received the BA from the University of Chicago in 1937 and the MA in English from Harvard in 1939. During World War II, after intensive training in electronics, he served as a radar and communications officer in the Army Air Corps. Part of this service was at MIT Radiation Laboratory on a guided missile project. In 1946, upon leaving the military service, Mr. Meyer joined Commercial Engineering, RCA Tube Division at Harrison, N. J. In 1954 he was appointed to his present position as Manager, Commercial Engineering Technical Services with the responsibility for the RCA Electron Tube and Semiconductor Products handbooks and technical manuals. As part of his duties, Mr. Meyer administers the technical papers approval procedure for RCA Electronic Components and Devices. Also, his group provides editorial and drafting assistance to the authors. He has for many years worked to stimulate the preparation of technical articles and to place them in appropriate periodicals. Mr. Meyer is a member of Phi Beta Kappa, a Senior Member of the IEEE, and a member of the IEEE-PTGEWS administrative committee since its inception in 1957.

DEGREES GRANTED

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RCA ENGINEER

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C. A. Meyer


J. Hirlinger

JOHN F. HIRLINGER, EC&D ED. BOARD CHAIRMAN, RETIRES

John F. Hirlinger retired on October 31, 1963 as Administrator, Technical Personnel Programs for RCA Electronic Components and Devices at Harrison, N. J. His major responsibility in this position was stimulating the professional development of engineers in the organization, and fostering a creative environment for professional employees. As part of this work, Mr. Hirlinger was Chairman of the EC&D Editorial Board for the "RCA ENGINEER" since it was established. He also served on the Editorial Board of *Trend*.

Mr. Hirlinger received his BSEE from Purdue University in 1924. During the same year, he joined the General Electric Company as a test engineer at the Schnectady plant. In 1925, he was transferred to GE's Nela Park, Cleveland plant as a design engineer. When certain GE facilities were acquired by RCA in 1930, Mr. Hirlinger joined the company and became Assistant Supervisor of Power Tube Development at the Harrison, N. J. plant in 1932. During 1943, he was appointed Product Manager, Power Tubes, at RCA's plant in Lancaster, Pa. Two years later, Mr. Hirlinger was named Manager, Engineering Administration, Cathode Ray and Power Tube Engineering. He became Administrator, Technical Personnel Programs for the RCA Electron Tube Division in September, 1952. He is a Senior Member of the IEEE and a member of the Professional Technical Group on Engineering Management.

CORRECTION:

In the last issue (Oct.-Nov. 1963, Vol. 9, No. 3) please note the following correction in the Lawrence-Dingwall paper. On page 18, column 2, third line from the bottom, the value should read:

"... amounts to 1.15%/100°C of temperature differential."

As published, the value is incorrectly printed as 1.15%/°C.

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