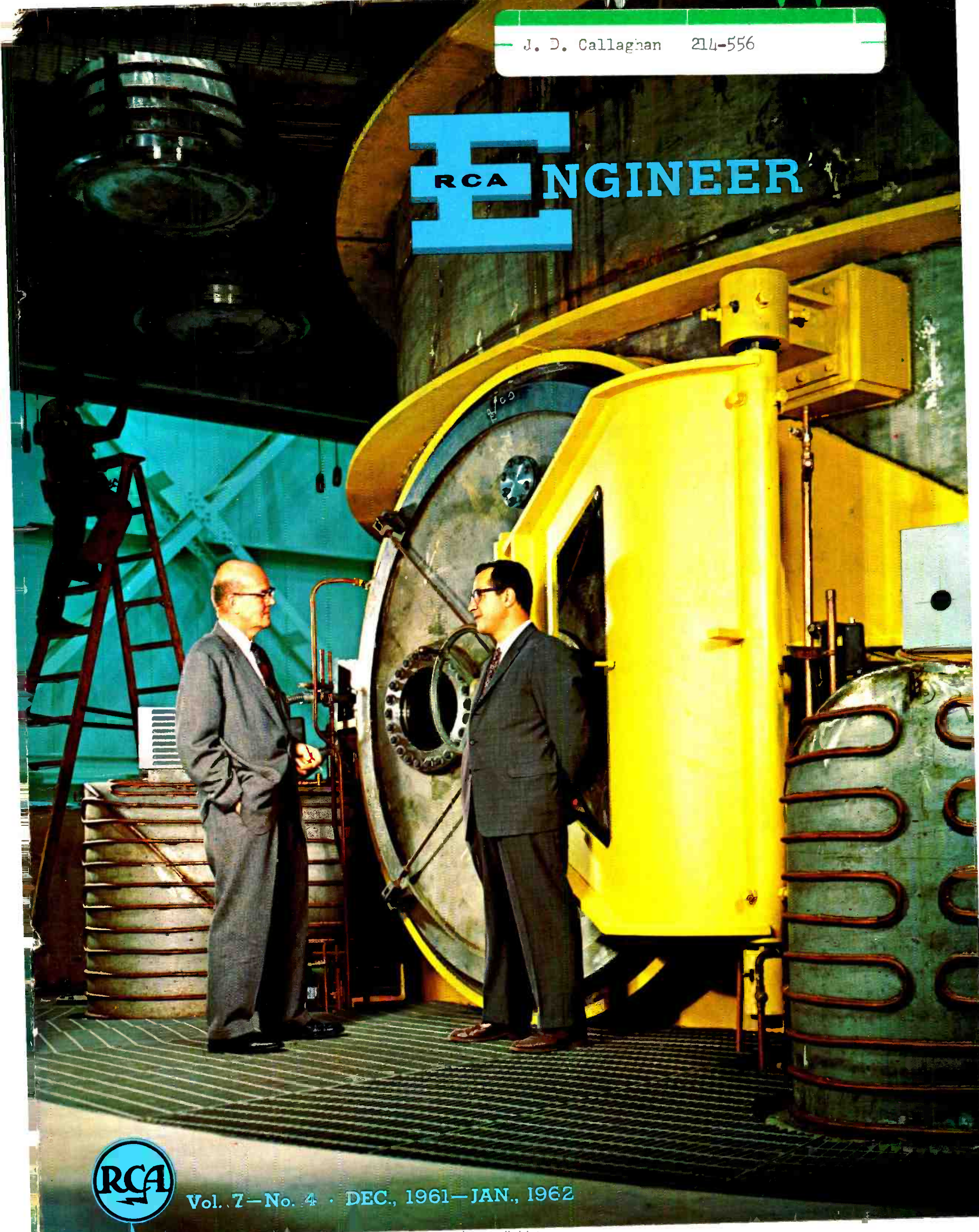
J. D. Callaghan 214-556

RCA ENGINEER



Vol. 7—No. 4 · DEC., 1961—JAN., 1962

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OBJECTIVES

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 engineering groups at RCA.

●

To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions.

●

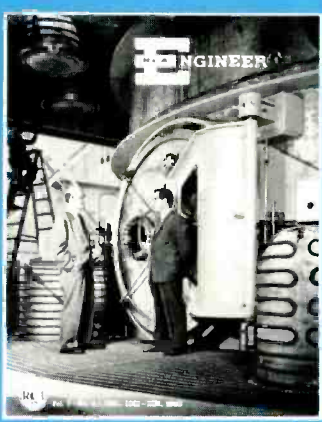
To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field.

●

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.



OUR COVER

The massive thermal vacuum chamber, a key component of the new Space Environmental Center at the Astro-Electronics, Div., near Princeton, N. J. Thermal and vacuum conditions of space are simulated in the 26-foot diameter, 20-foot-high stainless-steel chamber, with full-scale space vehicles lowered through its 24-foot-diameter cover and sealed inside for long periods of time. Shown at an access port are W. H. Brearley, Jr., Mgr. of Engineering Administration at AED, and F. J. Yannotti, Mgr. of the AED Environmental Center (and author of the article about it in this issue).

The Space Business and RCA

This issue of the RCA ENGINEER, with its concentration on space activities, might well raise for engineers the question as to why RCA has entered this unusual field.

It is true, of course, that industrial companies normally desire—and even require in today's economic climate—a continuing increase in profitable volume and a broadening base for their business. RCA's own history discloses a succession of such steps in the company's growth.

Business experience already has established criteria for evaluating any proposed new industrial venture. For example: *Is there a market with an anticipated continuity?* In the case of space activity, the answer is written in the nation's purposeful entry into space exploration and the readiness of Congress to provide the necessary funds.

Does RCA have the scientific capability and the manpower and financial resources that are required? The technical aspects of the question are answered by the successes of Project SCORE, the TIROS series, and other outstanding satellite accomplishments. The measure of corporate financial support is indicated by the investment in our Princeton Space Center, our newly-erected Space Environmental Center, featured on the cover, and our future building plans.

What particular features characterize our contribution in terms of product or service? The answers are many and varied, but two are especially important: the concepts of reliability and of complete systems-engineering responsibility.

RCA brings to satellites, space vehicles, and space probes a basic philosophy of reliability derived from years of experience with defense equipment. This experience has forged both a theoretical and a practical concept of reliability as a planned, integral part of design, manufacture and service of complex defense products.

The systems engineering concept forms an RCA "success pattern." Many of RCA's corporate achievements have resulted from the assumption of systems responsibility to fulfill completely the basic requirements of the customer. Examples include the original radio communications service and its evolution through radio broadcasting into television; modern transcontinental microwave communication systems; and the BMEWS network. Other examples will occur to many of you from your own experience.

A successful future can be compounded of these ingredients—if, as we expand our professional force, we continue to emphasize reliability and excellence of scientific performance not only as ultimate goals, but as day-to-day achievements.

Turning from this introspective viewpoint, the evidence is clear that RCA can again make a significant and timely contribution in fulfillment of the customer's requirements. This is an especially attractive and desirable course in this instance, where the customer is our nation and the essential need is that of scientific and military supremacy in space.

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

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RCA ENGINEER

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PERT

by **T. A. NUPP, Ldr.**
Programs Administration Data Conversion Engineering
Aerospace Communications and Controls Division
DEP, Camden, N. J.

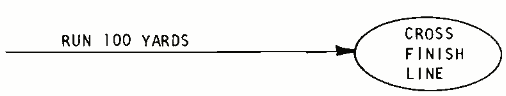
PERT is the best method known today for evaluating a complex R & D program. It is also the first *really new* technique since Gantt promoted bar charts, and it uses modern tools—digital computers. Spelled out, PERT is a *P*rogram *E*valuation and *R*eview *T*echnique. It was originally developed by the management-engineering firm of Booz, Allen and Hamilton under contract to the U.S. Navy; but today, its application is already widespread, and familiarity with the technique is fast becoming axiomatic in government-industry management of R & D programs.

JUST WHAT IS PERT?

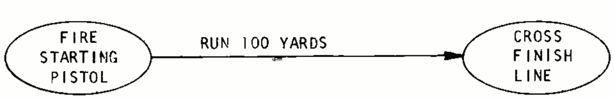
First, it is a network, or flow chart, or diagram, or anything you care to call a map of the time schedules of a total program. It is made up of events, activities, and time estimates. In PERT, an *event* is a point in time when something happens; an *activity* is a piece of work from one event to another; and the *time estimate* tells how long it is going to take to do the work.

Let's take a simple sports analogy, the 100-yard dash. The end point of the race, the objective, is to cross the finish line. In PERT language, this would be shown:

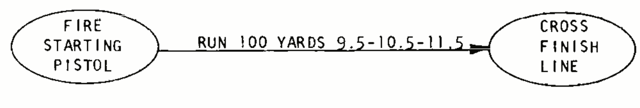
To have this event take place, there must be an activity which will result in the action *cross finish line*. This activity is, of course, *run 100 yards*. It would be shown PERT-wise as:



For the activity *run 100 yards* to take place, an event must start it: *fire starting pistol*. The PERT diagram now looks like:



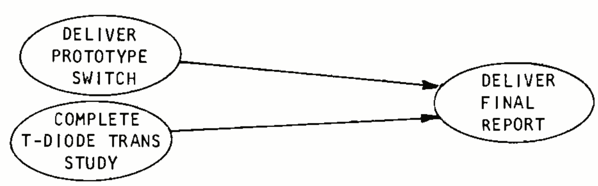
There remains the time estimate; here, PERT recognizes that estimates can't always be precise. There is the *most likely* estimate which occurs most of the time—99 times out of a 100—let's say 10.5 seconds. But there is also the *optimistic* time—the one that occurs once in a 100 times. For example, our runner is in top form, the track is fast, his reflexes are perfect, and he is helped by a tail-wind. As much as a second might be trimmed from his time, making it 9.5 seconds. On the other hand, all of the reverse fortunes might pertain and the runner would take the longest time of his career. This time is called the *pessimistic* time—let's say 11.5 seconds. The complete PERT diagram would now look like this:



THE PERT NETWORK

Let's go from sports to electronics and try a more complex diagram. A recent assignment entitled *develop sequential switch* involved a development and fabrication, a dependency on a supplier of transistors, and an independent parallel study ending in a report. (This project was actually undertaken by E. J. Mozzi and S. Novick of DEP-ACC Data Conversion Engineering.) The end objective was a report. So, the PERT network would begin with:

To reach the end event, two activities had to take place: A feedback from the customer about his opinion of the fabricated models, and the completion of the independent study. These activities were each preceded by an event—the point in time when the activity action began. The network beginning to form looked like this:



Stepping quickly over the detailed planning sequence, the complete network evolved for this project is shown in Fig. 1.

You will observe certain things about the network that did not exist in our simple sports analogy. First, the events are numbered for easy reference and computer identification. Second, there are "interdependencies". The completion of the breadboard (Event 007) depends upon the completion of *two* preceding events, 002 and 006. And, Event 007 is a vital milestone because 008, 009, and 016 cannot take place until 007 has taken place. Event 012 is another point where several activities come together to permit this event to happen. Third, there are certain calendar dates assigned to specific events: 001, 009, 019, 020.

At this point, the first letter of PERT—*P*rogram—is complete, and the electronic computer takes over to solve the *E*valuation portion of the technique.

Most types of modern computers have had PERT programs written for them. At a recent coordination meeting at the Navy Computer Center in Dahlgren, Virginia, over twenty program were listed. Many of the programs vary

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to give certain specific results. A popular program is known as the "Lockheed Activity Oriented Program for the IBM 7090 Computer." The distinguishing feature of this program is the "activity orientation." The computer talks about the *activities* in the network. The first program for the RCA 501 computer was "event oriented"; or, in ordinary language, the computer reports when an *event* is to be completed. By early 1962, an activity-oriented program will be ready. Both of these computers can handle randomly numbered events, so it doesn't matter how you number them, as long as there are no duplications. But a word of caution should be injected here. There are some computer programs that can accept events in ascending sequence only, in which case, a specific technique of network development is required, such as numbering events by 5's (000, 005, 010, etc.) so that in-between numbers are available for the forgotten events or changes.

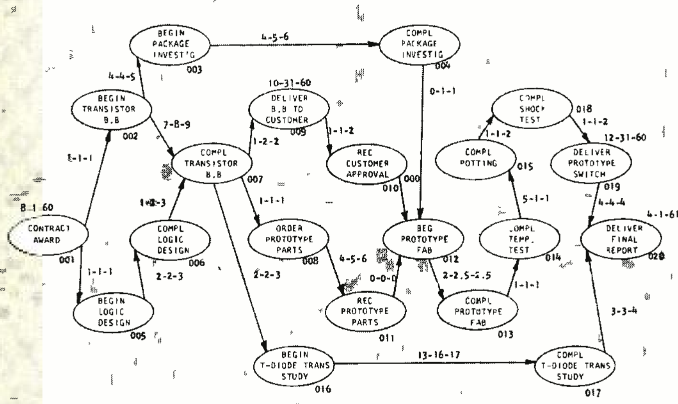
The computer evaluates the PERT network. It begins with the first date programmed, usually *contract award*, and runs along each path indicated by the activity arrows until it finds the longest path to an event, and then prints out the *expected date* for the completion of an event. This is more than a simple operation because all of the activity times—optimistic, most likely, and pessimistic—are converted to a single time by the formula $(a + 4b + c)/6$, called t_e, the *expected time*. Some events will have many paths leading to them, and the computer searches out the longest path and discards the others.

THE EXPECTED DATE

The expected date is that date the project leader can expect to complete an event. But is this date good enough? Is it too good at the expense of cost? Is it undesirable because of possible changes resulting from results of development? Is it unnecessary because it will tie up capital?

The computer helps to answer these questions by taking the end dates of the network and running *backward* through the many paths to the event in question. It subtracts from the calendar dates until it finds the longest path and then assigns a *latest allowable* date to the same event. This is the last date the event can complete and still have a 50-50 chance to satisfy contract commitments.

Fig. 1—PERT network for the sequential switch.



SLACK

When the latest allowable date is computed for each event, it is matched with the expected date for the same event. If the two dates don't meet (and they probably will not on the first attempt at network development), the difference is known as *slack*. If the expected date occurs before the latest allowable date, the difference is positive slack and may represent the possibility of delivery ahead of schedule. On the other hand, if the latest allowable date occurs before the expected date, the result is referred to as negative slack.

Negative slack shows the extent the plan falls short of the requirement of the customer. It is important to know this in order to replan portions of the work. If replanning will not remove the negative slack, the customer should be made aware of this so that he in turn can replan his own activities or possibly relax some requirements. Of foremost importance in examining slack and replanning is to faithfully estimate realistic time values. Any attempts to compress or extend time estimates to fit an assigned schedule will only result in trouble later in the program.

THE CRITICAL PATH

For each event on the network, the computer tells the expected calendar date, the latest allowable date, and the slack or difference between the two. Somewhere through the maze of events and activities is a path which represents the least slack (it might be negative or positive). This is known as the *critical path*—the series of activities and events that deserves first attention.

But, before talking about the attention-giving, or review, portion of PERT, a word about a couple of other computer features is indicated.

Those who developed PERT realized that people are fallible and may miss R & D time estimates by more than the range of the optimistic and pessimistic times. It is *not* a precise, seven-decimal-place instrument of prediction because the input data are not precise. But, some limiting guides are available for interpretation.

Built into the computer program is a *standard deviation* for each event. For example, consider a computer printout of a PERT network (not connected with the earlier example). The statistics of two events are these:

Expected Date	*Latest Allowable*	*Scheduled Date*	*Slack*	*Standard Deviation*	*Probability*
06/05/62	06/01/62	06/01/62	−0.5	1.2	0.33
09/24/62	10/01/62	10/01/62	+1.0	1.5	0.73

The printout says this: In the first case, the dates may be off by 1.2 weeks either way, and in the second case, the dates may be off by 1.5 weeks, so that neither slack picture is anything to get excited about. They are well within the accuracy of one standard deviation.

The other computer feature of interest is *probability*. The PERT concept is designed to say that if your expected dates and latest allowable dates are exactly the same, you have a 50-50 chance of meeting them within one standard deviation, or 50-percent probability. If you have some negative slack such as the −0.5 weeks shown above, your chances of success go down, in this case to 33 percent. Conversely, if there is positive slack, your chances go up, in the example above to 73 percent with one-week positive slack. When the positive slack exceeds the standard deviation, chances of success in your program are almost assured—that is, *if* you've satisfied the integrity of the system in your time estimates.

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Fig. 2—A portion of a printout of a sort by expected date.

REPORT DATE 10/14/61 — PROJECT REPORT — PAGE 06

EVENT	CRITICAL NEIGHBOR	LANDMARK	SCHEDULE DATE	ACTUAL DATE	EXPECTED DATE	LATEST DATE	SLACK	STD DEV	PROB
591211311	591211309	COMPL PMEL HANDBOOK ITEM 11	05/01/62		01/24/62	05/01/62	13.8	.7	1.
591211159	591211405	COMPL ASSEMBLY MODULE BRD EVAL MOD			01/25/62	01/01/62	- 3.4	.9	
591211533	591211405	COMPL ASSM MODULE BOARDS EVAL			01/25/62	01/20/62	- .7	.9	
591211158	591211159	START WIRING EVAL MOD			01/25/62	01/01/62	- 3.4	.9	
591211538	591211533	BEGIN WIRING EVAL MOD			01/25/62	01/20/62	- .7	.9	
591211647	591211640	COMPL BENCH TEST BEGIN INSP EVAL MOD			01/26/62	03/18/62	7.2	.8	
591211642	591211635	DELIVER TO SYST INT REL MOD	05/01/62		01/26/62	04/28/62	13.1	.8	1.
591211330	591211329	COMPL CHECK CFU TEST EQUIP			01/26/62	02/14/62	2.7	.7	
591211172	591211139	START P S ASSEM & WIRING REL MOD			01/29/62	03/09/62	5.5	.7	
591211641	591211634	COMPL BENCH TEST BEGIN INSP 1&2			02/02/62	04/30/62	12.4	.8	
591211192	591211172	COMPL ASSM START TEST REL MOD			02/06/62	03/17/62	5.5	.7	
591211308	591211307	COMPL TRAINING FIELD PER	05/15/62		02/06/62	05/15/62	14.0	1.1	1.

REPORT DATE 09/08/61 — PROJECT REPORT — PAGE 06

EVENT	CRITICAL NEIGHBOR	LANDMARK	ACTUAL DATE	EXPECTED DATE	LATEST DATE	SCHEDULE DATE	SLACK	STD DEV	PROB
591211016	591211015	COMPL VIBRATION TEST		08/06/62	08/13/62		1.0	1.5	
591211017	591211016	COMPL SHOCK TEST		08/20/62	08/27/62		1.0	1.5	
591211018	591211017	COMPL HUMIDITY TEST		09/17/62	09/24/62		1.0	1.5	
591211019	591211018	SHIP EVAL SYST ITEM 8		09/24/62	10/01/62	10/01/62	1.0	1.5	.73
591211513	591211509	COMPL CONTROL LOGIC		10/24/61	11/13/61		2.8	.2	
591211526	591211513	COMPL ELECT DESIGN		10/24/61	11/13/61		2.8	.2	
591211524	591211526	COMPL BOARD ASSM DWGS		11/28/61	12/18/61		2.8	.2	
591211532	591211524	BEGIN FAB MODULE BOARDS		12/04/61	12/24/61		2.8	.4	
591211519	591211509	COMPL SYSTEM LOGIC		10/23/61	11/13/61		3.0	.4	
591211115	591211107	DELIVER CFU MOCK-UP ITEM 6		09/09/61	10/01/61	10/01/61	3.1	.1	1.
591211165	591211420	COMPL MOD BRD 14-15		07/10/62	08/04/62		3.5	1.2	
591211171	591211165	START WIRING 14-15		07/10/62	08/04/62		3.5	1.2	

Fig. 3—A portion of a printout of a slack sort.

Thus, PERT is at your service as a powerfully useful tool that evaluates, in a matter of minutes, the many, many variables faced in an R & D project.

But, even though PERT is a powerful tool, up to this point only the *E*valuation portion of the program is complete. *The rest is up to you.*

Here, we get into the attention giving—or *R*eview—part of the technique, the third letter of PERT. The review comprises three important items: 1) periodic updating of the program; 2) analysis of the computer printouts; and 3) action on critical paths.

PERIODIC UPDATING OF THE PROGRAM

No R & D program is a routine job. It is a dynamic action, full of surprises, discoveries, and an occasional disappointment or delay. The monitoring technique should reflect these changes, and PERT does. There are seven updating codes by which changes can be made to a network or to the computer action. Here they are:

Code 1—introduces a new activity with its estimated times into the computer.

Code 2—changes time estimates if new developments indicate changes are necessary.

Code 3—(Air Force Code 4) reports an activity complete with the completion date.

Code 4—(Air Force Code 3) changes a schedule date.

Code 5—deletes an activity if you've made a mistake or change your mind.

Code 6—flags the computer to read out certain short paths which might be used to trade off time with a critical path.

Code 7—introduces a new starting date into the computer. Suppose a project is suspended for several months and when it is picked up again, you want to continue with your existing network. The activities being worked on at the time of suspension would be given the new starting date and the network would proceed as before.

Thus PERT is completely flexible and accommodates to just about any change which you might want to make.

The codes were developed to provide the means for prediction far in advance of actual accomplishment. The effect on the plan of a change of scope can be quickly predicted by introducing the change into the network. Discoveries which may eliminate sections of an R & D program can be introduced to show their effect on the total program. The network should be kept alive and updated every two weeks for fast-moving projects, but no less frequently than once per month.

ANALYSIS OF THE COMPUTER PRINTOUTS

There are standard *sorts* by which computer printouts supply information to a project leader. The most common are:

1) By *successor event:* This is a simple sequential sort, using the end event of an activity as the reference. The beginning event is called the predecessor and is not used in sorting.

2) By *expected date:* This is useful to remind leaders when events are due to be completed. The sample RCA 501 printout shown in Fig. 2 is an example of this sort which shows the chronological sequence of dates *you said you would meet.*

3) By *latest allowable:* This is a last-chance sort which tells the project leader the last day he can complete an event and still meet his contract commitments.

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4) The *slack* sort is perhaps the most important, because it signals the trouble areas and sorts the critical paths in the order of their difficulty. A sample is shown in Fig. 3.

There are many more special sorts and computer printouts, but they are not necessary to this basic discussion.

Computer printouts are of no value if you do not use them. The expected-date sort placed in the hands of each design engineer is a constant reminder of dates he must meet. The slack sort is valuable to help plan trade-offs, which are switches in resources from one path to another. For example, the most critical path might be running behind schedule, let us say 4 weeks. The slack sort would show −4.0 weeks for each event in this path. Further along in the slack sort there may be a path that is ahead of schedule, let us say 8 weeks. The slack column would show +8.0 weeks. The action the project leader may take is to take half the design effort from the +8.0 week path and assign it to the −4.0 week path, thereby improving his plan and probably getting the project back on schedule. As the network is revised and updated, new critical paths may develop. These paths are quickly traced by the computer so that corrective action can be taken far in advance of contractual commitments.

WHERE DO WE GO FROM HERE?

The PERT system and the many variations it has sired appear to be here to stay until a better program-monitoring technique comes along. It is used by all of the government defense departments and by private industry. It is effective for programs of short duration, such as the sequential switch illustrated, and for mammoth weapons systems such as POLARIS and DYNA-SOAR which involve hundreds of industries working toward a common objective. The PERT networks for these total systems involve close to 50,000 events — so large that *only* computers can take a total look at them and prepare a complete evaluation.

PERT FOR PROPOSALS

PERT is becoming a useful technique for project planning of proposals. It is becoming common practice for customers to request a PERT network with a proposal in order to check the feasibility of the requested schedule and to appraise the ability of a company to plan a complex project. One company has a planning team made up of engineers experienced in estimating activity times to do the job. Their prime function is to demonstrate planning ability by the use of the PERT technique. One of their efforts for a $10 million proposal involved 2,000 activities. Recently, RCA submitted a series of proposals in which sixteen PERT networks were developed in response to the customer's requirements.

PERT FOR COST CONTROL

There is an attempt being made to incorporate cost control into the PERT concept. The research was conducted by Dr. Sterling Livingston of Harvard University under a Navy contract. As this article is written, a trial run of the results of the research is being conducted by a large missile manufacturer under Navy funding. When the technique is perfected, it is likely that manuals will be issued describing the system.

Running quickly through the quaint names which cryptically describe the spawn of PERT, here are a few:

PROMPT — *PRO*gram *M*anagement *P*lanning *T*echnique is PERT applied to the management of a program.

LESS — *L*east Cost *ES*timating and *S*cheduling appraises the value of adding cost to save time and vice versa. Someplace, there is a point where you get the most for your money.

PRISM — *P*rogram *Rel*ability *S*ystem for Technical *M*anagement monitors the reliability of a piece of hardware or a weapons system as the research develops and predicts reliability in advance of completion of the work.

PACT — *P*roduction *A*nalysis *C*ontrol *T*echnique adds the computer to the Line of Balance Technique and increases a hundred times the number of production parts or subassemblies you can monitor.

These techniques are being carefully tested and appraised by government agencies. If they are sound, you will hear more about them and will be expected to use them.

The time of the bar chart is rapidly passing. As R & D programs become more complex, the long familiar chart which fits the customer's schedule is no longer adequate to demonstrate the contractor's ability to plan.

It is evident that we are in an era of intense interest in the capability of contractors to plan skillfully — The PERT system and its successors will be the devices to appraise these capabilities.

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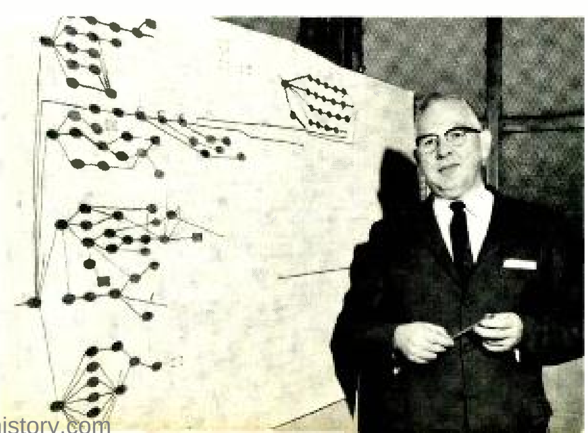
7. *Production Analysis Control Technique*, Special Projects Office, Program Evaluation Branch

T. A. NUPP received his BS in Industrial Engineering from Pennsylvania State University in 1933. Mr. Nupp spent 25 years as an industrial engineer for processing and manufacturing companies in the field of financial controls and just prior to joining RCA, was Chief Industrial Engineer of the Semi-Conductor Division of the Raytheon Manufacturing Company. He joined RCA in 1958 as a Leader in the Special Projects Activity of the Time Division Data Link program, responsible for value analysis, cost reduction, producibility, and program standard costs. He was also responsible for liaison between the Camden and Burlington Engineering Departments for production and delivery of the DRR-1 system for the BOMARC. He was subsequently assigned the responsibility for project coordination and facility liaison for all air-borne TDDL production. He is currently supervisor of Programs Administration for ACCD Data Conversion Engineering. For the past year, he has been administering all ACCD-Camden PERT programs, and has served as a consultant to other RCA Divisions establishing their PERT programs. He regularly attends the coordination meetings of the Navy Weapons System Projects Office—Special Project 12—the group originating the PERT concept and administering it on the POLARIS program.

Fig. 4—The author and an actual PERT network diagram; many such complex diagrams may be required for a whole project.



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SPACE TECHNOLOGY

. . . Some Important Efforts and Business Implications for RCA

Fig. 1 — The RELAY communications satellite.

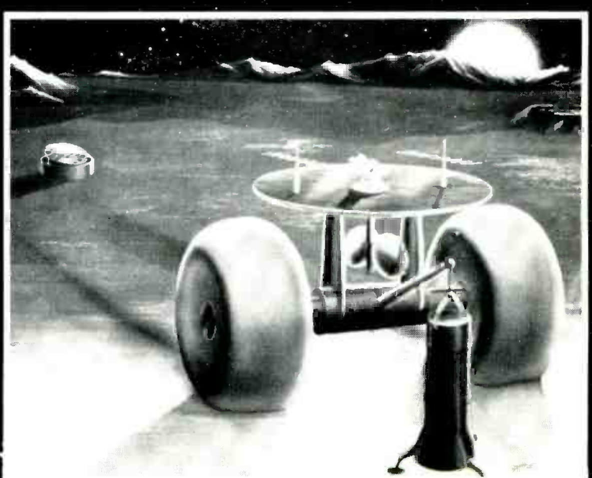

Fig. 2 — An unmanned mobile vehicle for lunar exploration.

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by **C. E. MARTINSON, Administrator**
Market Planning
Astro-Electronics Division
DEP, Princeton, N. J.

SINCE THE BIRTH of the space era with the successful launching of the first Sputnik in 1957, the U. S. has spent several billions of dollars on its space efforts, and the nation's space objectives now rank among the highest in priority. Many important technical accomplishments have already been made, and many difficult missions have been defined and scheduled for the years ahead: RCA is destined to play an important part in accomplishing these missions. (Figs. 1 and 2 rather dramatically illustrate two among many efforts which today are practical realities to RCA engineers.)

THE NEAR-SPACE ENVIRONMENT

The first important discovery using an artificial satellite was made by James Van Allen on the staff of the State University of Iowa. Instruments carried by EXPLORER I (February 1958) designed to measure cosmic rays at about 30 counts/sec. was literally overwhelmed by rates exceeding 100,000 counts/sec. These rudimentary observations suggested enormous intensities of electrically charged particles temporarily trapped in the geometric field of the Earth, in a region near the equatorial plane where there was no previous hint of their existence. The early results have been confirmed and substantial literature on the subject now exists.

The intensity structure of the trapped radiation exhibits two distinct and widely separated regions: the *inner zone* and the *outer zone* (Fig. 3). Each zone is approximately a figure of revolution about the magnetic axis of the Earth. The maximum intensity of particle flux in the inner zone occurs on the magnetic equator and at a radial distance from the center of the Earth of 10,000 km (3600 km above the Earth's surface). The magnetic forces so dominate the inertial ones that the two belts of fast moving, spiraling particles are effectively attached to the solid Earth. Thus, since the magnetic axis of the Earth is tilted about 11° to its axis of rotation, the radiation belts wobble up and down with a 24-hour period, as viewed from a suitable vantage point in space.

The inner and outer zones are separated geometrically by a region having a minimum radiation intensity. The outer zone is a huge region with maximum radiation intensity at a radial distance (quite variable) of about 24,000 km in the equatorial plane, with an outer limit of some 90,000 km.

Many obscure features remain which prevent a full quantitative understanding of the processes involved with drifting trapped electrons and protons, and the origin and source of both the inner and outer zones. There is, particularly, a lack of information about the intensities of low-energy protons and electrons in the outer zone.

Because of the probable importance of these components in producing geophysical effects (heating of the atmosphere, aurorae, air flow and magnetic storms) and because of the importance of these effects in planning manned space missions, it is probable that this area of scientific endeavor will be strongly supported.

LUNAR AND PLANETARY EXPLORATION

Of the many challenging problems connected with lunar and planetary exploration there are two which stand out as the most challenging and promising: One, the possibility that direct sampling and probing of the surface and crust of the Moon may help to discover clues to the origin, mode of formation, and prehistory of the solar system; and two, of even greater interest, the possibility that direct exploration of Mars may place us in contact with extraterrestrial forms of life whose study may help solve the problem of the origin and evolution of life under different planetary environments.

The post-Gagarin acceleration of the U. S. space program greatly expanded effort on the first problem, and a number of lunar projects are underway as a result. RCA is participating or preparing to participate in solving most of these problems. Since a project-by-project discussion of this vast national effort is not feasible, a more basic discussion will be given of the lunar observation techniques and possible types of scientific experiments applicable to most of the projects now planned.

Fundamental information on the structures of the lunar and planetary atmospheres, such as chemical composition, gas density, and atmospheric pressure characteristics, can be provided by photometric and spectrophotometric observations of the reflected solar light as a function of phase angle (that angle between the direction to the Sun and to the Earth) as seen from the planet. Photoelectric observations of the stars occultations are a powerful means of determining the structure (total pressure, density gradient, temperature, etc.) of the upper atmospheres of planets. Polarimetric observations are subtle and penetrating indicators of the nature and structure of planets' surfaces and atmospheres. Spectroscopic observation is the most direct technique, short of sampling on the spot, for determining the chemical composition of planetary atmospheres. Radiometric observations of the infrared radiation through thermal receivers, such as the thermocouple, are the most powerful methods for determining planetary temperatures. Radio observations at centimeter wavelengths are growing in importance determining the surface temperatures of planets with dense atmospheres (such as Venus) not penetrated by ordinary infrared radiation. These same observation techniques could determine electron densities in their ionospheres if these densities should prove to be the origin of the observed radiation.

The full range of possible experiments in a well-organized lunar and interplanetary program would encompass all of the modern scientific disciplines. Very briefly, these experiments and programs are:

1) *Interplanetary probes* on one-way flights during period of closest approach will include a search for magnetic fields and will provide television pictures of the surface, observations of the luminescence of the atmospheres on the night-time side of Mars and Venus, passive detection of infrared thermal and non-thermal emission, and active ionospheric radio sounding and radar probing.
2) *Artificial satellites* (orbiters) will obtain detailed optical mapping and finer photometric, spectroscopic, infrared, microwave, radar, and magnetic surveys.
3) *Penetrating probes*, crash-landing with subsequent loss of communications, will make direct atmospheric measurements.
4) *Non-destructive crash landing* without communication loss will include, at first, relatively simple observations such as passive and active seismic recordings and high-resolution television pictures of the impact area.
5) More-sophisticated *soft-landed equipment* which will report the basic elements of local climate (surface temperatures, humidity and pressures, day and night thermal radiation) and television pictures of local terrain.
6) *Mobile equipment* of fairly complex design (Fig. 2) for extended direct exploration and sampling, will be soft-landed.
7) *Manned exploration* will occur as the final phase of exploration.

PLANETARY EVALUATION

Early data from lunar shots and deep-space probes to Mars and Venus will probably go through an evaluation before the distant space exploration program becomes firm. The Moon, barren of atmosphere, appears unlikely to harbor life. But we know nothing of the conditions beneath its exposed surface. The Moon may be especially interesting as a gravitational trap for meteoritic material accumulated from space over many eons, unaltered by the action of atmos-

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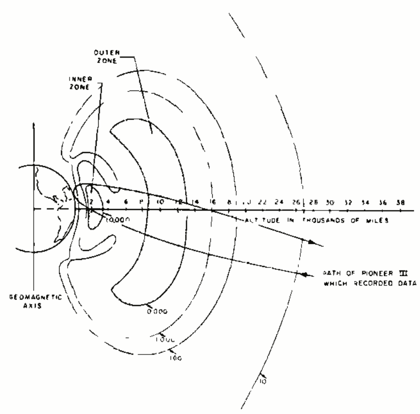


Fig. 3 — Van Allen radiation-belt intensities plotted with geomagnetic axis of the Earth as an axis of symmetry.

phere. Mercury appears much like the Moon physically, and because of the absence of corroding solar radiation, may be a better repository for meteoritic material.

Of the nearby planets, Mars offers the best chance for finding life. Although water and oxygen are scarce, the range of temperature is moderate. Much of the evidence has been at best only suggestive. Recent observations of the infrared reflection spectrum appear to indicate the presence of C-H molecules in the dark areas. A study of this phenomena and a probe could provide crucial data not available through Earth observations. Venus seems less likely to contain a recognizable form of life. Its surface temperature is apparently higher than the boiling point of water. However, it would be intemperate to make dogmatic conclusions until the planet has been mapped in more detail.

The large planets are too distant for early examination but they are not without interest. Conditions there would favor the accumulation of organic material, and probes to Saturn and Jupiter may therefore be eventually attempted.

METEOROLOGICAL SATELLITE SYSTEMS

One of the early applications of a space system was the TIROS meteorological satellite developed for NASA by RCA. Although further significant improvements in meteorological analysis and forecasting will most likely result only from an expanded research program to which meteorological data will contribute, cloud data obtained by the TIROS satellites has already been used to a limited degree in present meteorological operations. The TIROS I observations are particularly valuable in covering the vast distances on weather maps existing between conventional observing stations over the oceans and the data-sparse areas of the world. The infrared radiation data from TIROS II will also be useful operationally when rapid processing and analysis techniques are established. For example, the infrared measurements made in the 8-to-12-micron water-vapor "window" show promise of indicating, in a gross sense, the world's cloud distribution at night, thereby complementing the existing daytime cloud observations obtained by the vidicon type of television cameras.

The quasi-polar orbit planned for the NIMBUS second-generation meteorological satellite and its earth-stabilized design will enable an entire Earth coverage twice a day. The ultimate design for an operational meteorological satellite system will involve four satellites in an equatorial orbit and at a synchronous altitude of 22,300 miles. This system will view all of the earth's surface continuously in the zone between 60° north and south latitudes. These satellites might be equipped with low-resolution cameras to provide a new global cloud map (except for polar areas) every few minutes to any station having the proper receiving equipment and located within "radio visibility" of one of the four stationary satellites. Other cameras capable of viewing smaller areas in greater detail also might be included in the satellites.

COMMUNICATIONS SATELLITES

A second practical use of a space system, and potentially one of the most important is long-distance communications via satellites. Two problems exist in developing this specific application of satellite systems. The first is a technical one of choosing the optimal system configuration (active vs. passive, low altitude vs. high, etc.). The choice is complicated by the difficulty of making a three-sided time match between decision-time-to-proceed (on development of an operational system), development lead-time, and advancing technology. The other problem, though nontechnical in nature, is also intimately associated with future development of satellite communications, and is concerned with the eventual operating organization of the satellite communications system.

The RELAY communication satellite system (Fig. 1), now under development for NASA by RCA, is the first major step towards establishing an operational system—although it is, in fact, a large-scale experiment. The primary objectives of this project are to investigate the technical problems of transoceanic communications via satellites and to establish the feasibility of basic concepts.

The forecast for satellite communications is very bright. The present size of all international communications business is about $175 million. In the 1970's with a satellite system in use, annual operating revenues may reach the $1 billion mark.

POWER SOURCES AND CONVERSION

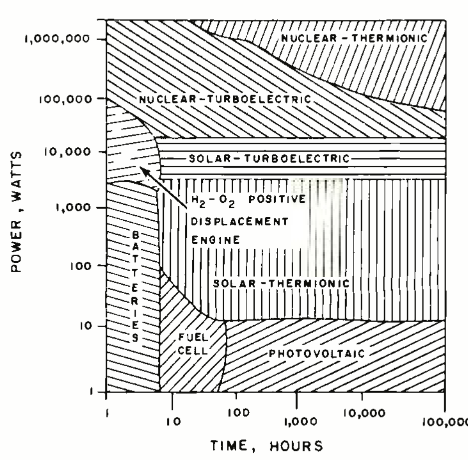
Although the topic of power sources and conversion is not really an application of space systems, it is an important aspect of space systems. Every space vehicle needs an internal power supply for operating its instruments, for transmitting its information, for comfort and survival of a crew, and for many other purposes. Most space missions seem to have a relatively high peak-power demand with a relatively low average demand, which establishes one of the basic characteristics of a space power source, *flexibility*.

Fig. 4 shows a spectrum of future power sources and power conversion devices and a probable use schedule over the next 5 to 10 years. Light-weight batteries, used extensively for current space vehicles, will continue to be used for short-duration, low-power applications. Other means of chemically generating power by fuel cells will continue to be refined. There is presently under development a biochemical fuel cell that produces electrical energy directly from decomposing organic matter.

A cell using algae as a source of both oxygen and organic matter for fuel could probably produce electricity indefinitely from solar energy alone. The use of various positive displacement engines appears promising for somewhat higher power levels. Solar-energy sources are generally effective for longer durations; they are still relatively high in weight per unit of power output and also in cost, though they are simple and reliable.

Current vehicles make extensive use of solar cells based on the photovoltaic principle. The thermal energy contained in solar radiation can also be used in a thermal cycle engine by concentrating the Sun's radiation through an optical system on a receiver; this will find application at higher power levels. For long-duration, high power levels, a nuclear reactor seems essential, and either a

Fig. 4 — A use schedule of future power sources.



turboelectric or a thermoelectric conversion method looks feasible.

Research and development is underway in areas of power sources and power conversion, and it is too early to rule out any one of the described methods. The most advanced version currently under development is a nuclear-energy source with a mercury-vapor alternating power-conversion system and a liquid-metal-cooled reactor. It is anticipated that this power source will be used to drive the first electrical propulsion system for interplanetary operation in the late 1960's.

POSSIBLE MILITARY SPACE MISSIONS

So far, no firm military requirement has yet arisen for a complete space weapon system. However, the present Administration has established a policy of increased emphasis on the military role in space; the 1962 budget reflects this attitude.

Present Air Force R&D programs are developing a space reconnaissance system (SAMOS), a ballistic-missile early-warning system (MIDAS), and the SATELLITE INSPECTOR program in which RCA is participating. Several studies have investigated other possible military space missions such as the military value of a lunar base, a ballistic-missile intercept system, and many others.

While security limitations do not permit detailed discussion of most existing programs, it is interesting to mention one futuristic concept of a possible military mission: Such a concept might be a "Space Polaris," in which a system of armed, maneuverable space vehicles cruise in space under military control (perhaps located on the Moon or in a space station) ready to stage a retaliatory attack upon command should Earth bases be attacked first. Such a system would have a high degree of invulnerability and represent one possible countermeasure to the eventual solution of the present antisubmarine-warfare problem.

GROWTH OF THE SPACE MARKET

The present space market comprises two customers: The Department of Defense (the Air Force has about 90 percent of this segment of the market), and the National Aeronautics and Space Agency (NASA). The market trend since 1958, which marks the beginning of the U. S. space program, has been definitely upward and has increased sharply this year, due in part, to the impetus given by the Soviet's first manned orbital flight.

Fig. 5 shows the space market (including military and civilian) from 1960 to 1966. The projection from 1962 to 1966 is based on space spending of over $15 billion dollars (cumulative) in the five-year period. This is a *conservative* figure, since at least one interpretation of the President's May message to Congress, commenting on the national space program, estimated a total expenditure in the same period of $25 to $30 billion. The estimate shown would correspond to an annual spending rate in 1966 of over $4 billion.

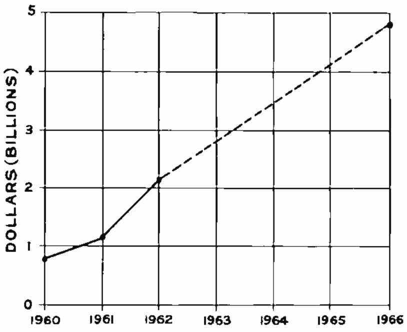


Fig. 5 — Military and civilian space market, 1960-66.

Consideration of factors discussed in the next section convinces the writer that the annual spending rate *could be double* this figure by the end of the 1960's. These figures are, of necessity, loosely defined to include only those funds available for industry support. This support would include R & D activities during the early phase, gradually phasing into operational activity during the latter portion of the period.

IMPLICATIONS FOR FUTURE RCA BUSINESS

Some insight into the potential of the space business may be gained by comparing it with the automotive and missile industries: The advent of the internal combustion engine caused the industrial revolution which produced the automotive industry. Research, in our present economy, is now experiencing a phenomenal growth and also could be considered as representing an industrial revolution. While it is true that a large share of this research has been devoted to missiles, the nation's missile research phase is now almost complete, and space instead of missile technology constitutes perhaps the most vital part of the nation's research program.

While the space industry has similarities with both the automotive and missile industries, it possesses certain characteristics advantageous to RCA's objectives that neither of those industries possess. For example, space applications have given birth to tremendous commercial potential (i.e., communications satellites) and also are revolutionizing military possibilities. While the major missile developments were achieved within the framework of the aircraft industry, the critical requirements of space exploration are electronic in nature. Finally, the size of the space industry is expected to be comparable in size to the automotive and missile industries in 5 to 10 years—an annual gross revenue of between $5 and $10 billion dollars.

Based on these considerations, RCA's past and present significant contributions to the space program, and the vast RCA versatility and depth in electronics, the author predicts that RCA's space business at the end of the decade will equal to all the rest of its defense electronics business.

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CARL E. MARTINSON received his BS in Chemical Engineering in 1938 from Lehigh University with special honors. In 1939 he took postgraduate courses at Columbia University and Brooklyn Polytechnic Institute. In 1954 he received an LL.B. degree from Georgetown University. In 1941, on duty with the Army, he became Executive Officer of the Rocket Branch, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, and participated in the engineering planning of a rocket firing range. In 1943 he became Technical Assistant to the Military Attache at the American Embassy in London, responsible for reporting to the War Department about R & D activities on British guided missiles and rockets. He also made assessments of enemy capabilities from intelligence reports. He is now a Colonel in the Army Reserve. In 1947, after leaving the Army, he engaged in operations research for the Institute of Air Weapons Research at the University of Chicago, as head of the guided-missile group. In 1951, for five years he served as a civilian Scientific Warfare Advisor in the Weapons Systems Evaluation Group in the Office of the Secretary of Defense, and for two years in the same capacity for the Institute for Defense Analyses. This group advises the Secretary of Defense on alternative choices of major weapons systems and their most efficient operational employment. He joined the Astro-Electronics Division of RCA in 1958, where he was engaged for two years in advanced studies of various phases of satellites systems until he assumed the duties of the Market Planning function a year ago. He is a Senior Member of the Operations Research Society of America and a member of the American Rocket Society.

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SPACE-AGE RELIABILITY

S. STERNBERG, Chief Engineer
Astro-Electronics Division
DEP, Princeton, N. J.

THE RELIABILITY of equipment systems has always been of major concern to equipment designers and manufacturers—particularly in the defense industry. As equipment systems have become increasingly complex, company organization and procedure have been formalized to ensure that these systems meet the reliability requirements. In present major defense-engineering companies, large groups of people report to top-management echelons with specific and sole organizational responsibility for product assurance, reliability, and quality control.

RCA has pioneered and made major contributions in both the development and implementation of product-assurance management control. In brief, the techniques include the use wherever possible of preselected "standard" parts; inclusion of reliability specifications for "nonstandard" (ordered) parts; adherence to construction, assembly, and wiring standards; quality-control auditing at various levels in equipment manufacture; specifications for testing; and the maintenance of performance records which provide the feedback control on the over-all reliability system. In addition to the above, a body of linear statistical theory has been organized to support this effort by establishing measures of reliability (such as mean-time-to-failure).

The advent of space technology and spacecraft systems has emphasized this kind of product assurance activity. As long as a system is made up of many parts and assembled in a wide variety of ways by large organizations of people, reliability controls and practices will be necessary. *But what additional or different reliability problems will be encountered as a result of Space Age missions?* Since much of the organized reliability effort is concentrated in the direction of components control, let us examine a few component characteristics presently considered in our standard parts listing.

COMPONENTS IN A SPACE ENVIRONMENT

The parts we are now using in our space electronic systems have been developed for use on this good earth. It is no coincidence that the design of temperature controls in space systems centers about room temperature; that form factors of many components are so designed as to control hot spots by air convection; that packaging techniques pay special attention to sealing out moisture; and that structural configuration and materials are measured by strength-to-weight ratios. Complexities are measurably increased in vacuum devices by the requirement for long-term maintenance of low gas pressures. Imaging systems peak in the white-light part of the spectrum.

Compare this list of design factors with a space environment of extremely low pressure, zero gravity, wide temperature extremes, short-wavelength energy, and high-energy particles. The mismatch is painfully obvious. Present component design is not optimum for maximum reliability in a space environment. A minimum of environmental control and a maximum of environmental compatibility is necessary to meet the requirements of long-term, unattended operation.

The increased emphasis on space technology—and the increased national budget—will most certainly lead toward the development of a *new line* of components affording a better match between their design and their operational environment.

These parts, most efficient in space, may be extremely inefficient on earth. All that would be required of these space components prior to launch is stability and nondestruct characteristics in the atmosphere, and an ability to be tested on the ground (to ensure system operation). A specific example is always helpful to give substance to generalization.

In 1955, RCA started developing a component now called *dielectric storage tape*. This tape was to register photo images temporarily (perhaps for months), store a latent image of electrostatic charges, and be both erasable and reusable. Today, at AED this space component (Fig. 1) is a reality. It is simple, works best in a vacuum, is not critically sensitive to high-energy particles, and does not have any fast-moving mechanical parts to present lubrication problems. Interestingly enough, even though ideal for its intended use in space, it does not, at this time, appear to be a serious competitor for any earth-bound counterpart.

TESTING FOR RELIABILITY

Another new field in Space Engineering is the design of tests to ensure operational reliability. Simulating the space environment is a major problem.

The most important simulation is that of temperature and pressure conditions—the so-called *thermal-vacuum* tests. For these, a chamber is pumped to a low enough pressure to ensure that all exchange of heat energy is by radiant means. A pressure of 10^{-5} mm-Hg will leave few enough air molecules to ensure that convection cannot effectively exist. The walls of the chamber are cycled between hot and cold extremes (a typical temperature range is 0 to 50°C), simulating the effect of the sun and temperatures in outer space. As the space-designed equipment operates, the temperature of its parts is determined primarily by form factors, position with

SIDNEY STERNBERG, earlier as Manager of Satellite Projects at AED, directed much pioneering development of space systems and equipment. Under his direction, AED developed and produced space and ground equipment for the "Talking Atlas" satellite (Project SCORE), and the TIROS meteorological satellite system. TIROS has demonstrated a high mark for reliability of space power, stabilization, structure, and instrumentation. As Chief Engineer of AED, Mr. Sternberg is now actively leading many new study and development projects. Among these are lunar probes, plasma acceleration methods, communications satellite systems, and advanced meteorological systems. Mr. Sternberg came to AED in 1958, at its inception, from the RCA Laboratories, where he had been in charge of satellite studies and space research programs starting in 1955. Before becoming concerned with space technology, he was engaged in both analog and digital computer research. He received the RCA Laboratories *Research Achievement Award* both in 1953 and 1955, the American Astronautical Society *Certificate of Achievement* for contributions to TIROS in 1961, and has several assigned U.S. Patents. Prior to his affiliation with RCA, from 1946 to 1950 he was with the Office of Naval Research, where he contributed to work in computer technology. During World War II, he was a radar officer in the U.S. Navy. He received his BS in Physics from the City College of New York in 1943, and an MSEE from New York University in 1949. Mr. Sternberg is a *Fellow* of the American Rocket Society and past President of the Princeton Section, a Member of Sigma Xi, and is a Senior Member of the IRE. He has contributed many technical papers in the satellite field and has participated in international conferences on the subject both at home and abroad.

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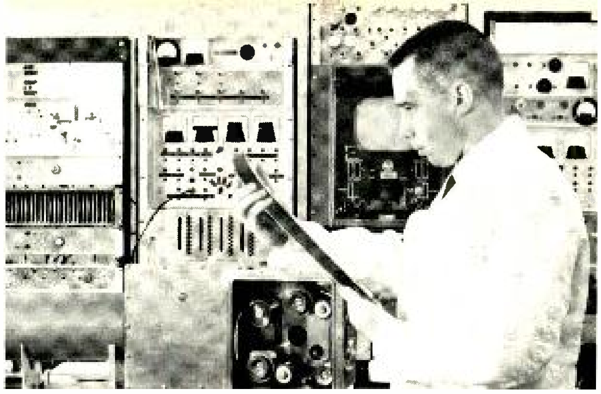

Fig. 1—R. A. Couch, AED Engineering, displays a strip of dielectric tape above a laboratory model of a camera designed for its use.

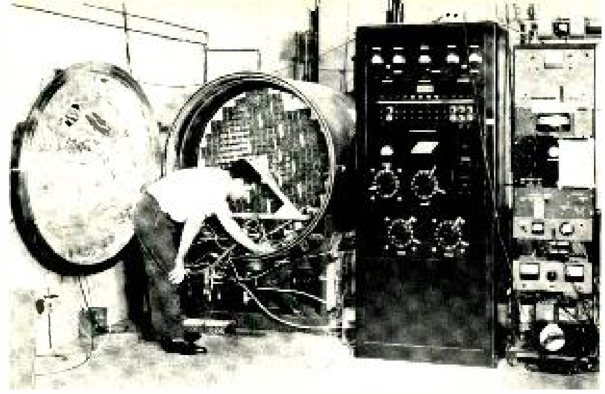

Fig. 2—An early thermal-vacuum chamber at AED.

respect to other parts, heat conductive paths, and "color" (which determines the absorptivity/emissivity ratio). One of the earliest thermal-vacuum chambers (Fig. 2) was built and instrumented by AED in 1958 to test the TIROS satellites. The reliability of the TIROS series attests to the adequacy of the simulation and testing. (See Corrington, this issue). In preparation for larger spacecraft of the future, a new thermal-vacuum facility has been designed by AED, and is presently being completed under the system management of the DEP Major Defense systems Division. (See Yannotti, this issue).

However, there are still many questions on environmental simulation left to be answered. *How real is the simulation? A confined volume can never truly simulate the expanse of outer space, but to what degree is this error significant? How much of the solar energy spectrum must be simulated to provide an adequate test? How long a thermal-vacuum test is required to ensure meeting space operations requirements?* It is presently popular to force an equipment system to live through more extreme conditions than it will meet in space under the assumption that this becomes a more exacting and, therefore, better test. *But what is the correlation between this test and mean-time-to-failure?* This latter test is analogous to "accelerated life testing" which, although it has been considered for many years in component testing, is still not accepted by most reliability statiticians except in very limited and simple experiments. I list these questions only to indicate that there is much to be learned in Space Age reliability testing, and I am certain the next few years will give rise to many answers.

SYSTEM DESIGN APPROACH TO RELIABILITY

An aspect of the total problem that has not received the attention commensurate with its importance is the influence of the initial system* design on the final reliability of equipment. There are no formal procedures for auditing professional creative contributions. However, it is this contribution by the engineer that introduces the first major reliability factor:

It is the understanding and inventive application of both the principles of physical science and system logic that make possible the simple-equipment solution to a problem. The simplest† equipment system is the most reliable equipment system.

To illustrate this point I will refer to two programs: 1) TIROS, developed by AED, and 2) EXPLORER XI, developed by the Marshall Space Flight Center. Physical principles of the dynamics of spinning bodies were inventively applied in both cases to simplify component subsystems, and improve reliability.

The TIROS system is required to take pictures of the earth's cloud patterns from an earth-orbiting satellite. Assuming no prior knowledge of the existing system, let us examine an approach for solving this mission. To take pictures of a given scene, it would be desirable to point the camera directly at the illuminated object, with a minimum of camera motion. By pointing in a direction parallel to the earth's local vertical at every position in orbit, this goal would be accomplished.

But compared to other systems in the payload and relative to the carrier-rocket capability, the stabilization system required to point the satellite is complicated and heavy, and requires large amounts of electrical power for its operation. A high-power solar-energy-conversion supply would, at present, also be complex and bulky; and would require a complicated widespread structure to collect sufficient energy, to radiate waste heat, or both. The addition of systems adding such size and weight to the payload would require a proportionately larger and more complicated rocket system. Although these statements are over-simplified for the sake of brevity, it is nevertheless true that finding a solution for TIROS which allowed picture-taking through a spin-stabilized body, thus eliminating the first complication in the chain (that of earth-oriented stabilization) has served the purpose of simplicity and reliability in the TIROS system.

In EXPLORER XI, the gamma-ray experiment required the scanning of stellar space. To accomplish this scanning, a rotation of the satellite in the propeller mode was utilized. The rocket system used to inject the satellite into orbit required spin stabilization about its figure axis during launch. This figure-axis spin was converted to a rotation in the propeller mode (tumbling) by the action of a *precession damper*.‡

THE SPACE-AGE CHALLENGE

The Space Age has greatly increased the need for an engineering-system-design approach to reliability. Never before has there been as general a requirement for long-term unattended operation of nonrepairable equipment.

This, of course, places increased demands on all factors contributing to reliability. The engineer is thrown into a design environment for which there are few handbooks and in which many previous standards are obsolete. He must develop by applying engineering science, new design intuition, and many new design standards. The engineer must extend his knowledge in the depth of physical science and the breadth of system logic to ensure that the system design is a strong positive influence on the final reliability of the total equipment system.

These are the responsibilities and challenges that *the RCA engineer alone* must assume, if RCA is to be the predominant industrial organization in Space-Age systems and hardware.

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* *System* here designates a total collection of parts or equipment that when working together, performs in accordance with a defined purpose or mission.

† In this concept, redundancy is not considered an element of complication.

‡ A spinning body in free fall (or in orbit) will continue with its original spin motion only if it is perfectly rigid. If the spin has a slight wobble and if the wobble causes a relative motion of the body parts, then friction occurs and the type of spin changes. It has been established that such a spinning body seeks the spin mode having the largest moment of inertia. In the case of EXPLORER XI, this was the desired propeller mode. To hasten the change, a precession damper was supplied, consisting of a doughnut-shaped cavity partially filled with mercury. The result was a very simple, reliable scanning system.

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THE NEW AED SPACE ENVIRONMENTAL TEST BUILDING

Space components, subsystems, and whole vehicles require extensive environmental tests to ensure operational reliability. To enhance the Astro-Electronics Division's capabilities to simulate space conditions in developing the new generation of space vehicles, a new environmental test center has been completed —one of the most modern and complete in the U.S.

by **F. J. YANNOTTI, Mgr.**
Space Environmental Center
Astro-Electronics Division
DEP, Princeton, N.J.

THE NEW 20,000-square-foot AED environmental facility allows RCA engineers to simulate closely the environments of outer space. It is designed to handle much larger and more-sophisticated space vehicles than those launched by the U.S. in the past. The Center, completed this Fall, is located at the main AED facility near Princeton, N.J. (See accompanying photos and front cover.)

VACUUM CHAMBER

The most spectacular environmental equipment involved is the large vacuum chamber. It has an internal clear height of 20 feet and diameter of 26 feet. A pressure of 5×10^{-8} mm-Hg can be attained in 24 hours with a 3500-pound payload in the chamber. It can operate at this pressure continuously for three months and is so designed that its capability can be extended to 10^{-9} mm-Hg in the future.

The vacuum system, designed by RCA, consists of two large roughing pumps, two blowers, and several 32-inch diffusion pumps. The chamber itself is essentially a vertical cylinder with a convex top and bottom. The entire shell is constructed of 1-inch stainless steel supported on four vertical columns and reinforced with several steel belly-bands. The chamber top is sealed with a 24-foot-diameter cover that can be lifted and transported on two tracks. The weight of the cover is supported primarily on the tracks, and only enough weight is transmitted to the chamber to effect a seal.

Besides the vacuum capability, the chamber is also equipped with a thermal shroud covering the entire inside surface of the chamber. This shroud is the tube-in-sheet-copper type and is divided into six separate circuits. Brine is circulated through these circuits, and temperatures from −100°F to +250°F can be independently controlled in each of the six circuits. This heat sink simulates the hot and cold environments of space.

The interior of the chamber contains a steel floor grating that is removed during the tests. To get the desired vacuum in a reasonable time, all such excess equipment must be removed from the chamber — especially equipment which might collect and hold dust particles and small debris. Personnel entering and leaving the chamber before and after the tests must wear surgical-type clothing to maintain cleanliness.

FRANCIS J. YANNOTTI received his BSEE from Newark College of Engineering in 1948. Upon graduation he instructed at Hudson Technical Institute. In 1951, he accepted a position at Curtiss Wright Corp. where he did instrumentation and test engineering on aircraft propellers and mechanisms. He joined the RCA Tube Division at Harrison, N.J., as an Equipment Development Engineer in 1952, where he worked in development of laboratory and factory equipment for receiving tubes. In 1954, he was made Manager of that group. An Advanced Equipment Development Group was formed in 1955 and Mr. Yannotti was named Manager, Electrical Advanced Equipment Development. This group developed the first practical high-speed, automated test machinery used in receiving tube manufacturing. Mr. Yannotti joined the Astro-Electronics Division in March 1961 as Manager, Space Environmental Center. He is a member of the faculty at Newark College of Engineering, Special Courses Division, and a member of the Institute of Environmental Sciences.

While this chamber allows engineers to test large space vehicles, thermal-vacuum environment testing also can be accomplished with smaller, less elaborate equipment. For example, the TIROS vehicles were tested in an existing 4-foot-diameter chamber. Many of the TIROS components and subsystems were tested in still-smaller facilities like bell jars.

NATURAL ENVIRONMENTS

Low Pressures

A low-pressure environment produces many peculiar effects on space vehicles. A significant cause of these peculiar effects is the reduction of the *mean free path*, the average distance travelled by molecules before collision with each other. The mean free path determines many of the energy-transfer characteristics in gases, for example, sound propagation, vapor pressures, thermal conduction, lift, and drag. The mean free path at sea level is 6.16×10^{-6} cm. At an altitude of 200 km, the mean free path is over 1,000 feet.

At an altitude of 90 km, the pressure is 10^{-3} mm-Hg, and lift and drag forces approach zero. The transfer of sound energy approaches zero at an altitude of 125 km and 10^{-5} mm-Hg. These low pressures present other problems. For example, heat transfer is by radiation only; therefore, absorptivity and emissivity become important, since the actual temperature of a satellite depends upon the ratio of incident radiation (solar) energy to that reradiated back into space.

Vaporization of materials is also a problem, presenting some unique problems of lubrication in space. Even the more solid lubricants can vaporize quickly at pressures of 10^{-8} mm-Hg. For lower pressures, materials become too clean because the natural antifriction materials disappear completely, and coefficients of friction can increase 100 times.

Thus, in the simulation of space conditions, it is necessary to conduct thermal tests in vacuum, since thermal-energy transfer in space is exclusively by radiation.

Thermal

Solar energy consists of corpuscular and electromagnetic radiation. Corpuscular radiation consists of high-energy particles which contribute little to the space-vehicle thermal environment. Electromagnetic radiation has an energy distribution from 1 to 2000 angstroms, with most of this in the visible and infrared regions. Therefore, it is sometimes reasonable to reproduce only a portion of the solar spectrum to simulate the solar thermal effects.

New advances in environment simulation now allow approximation of the

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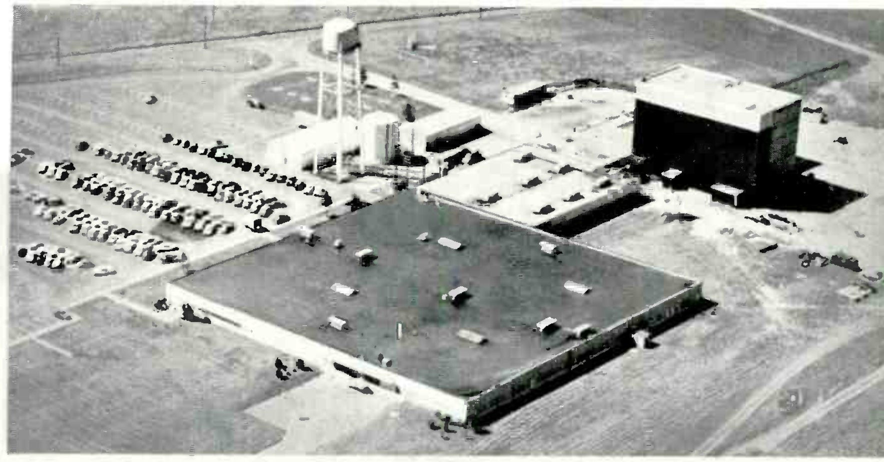

Fig. 1—Aerial view of the "RCA Space Center," the Astro-Electronics Division, near Princeton, N.J. The new Space Environmental Test Building is the high structure at top right.

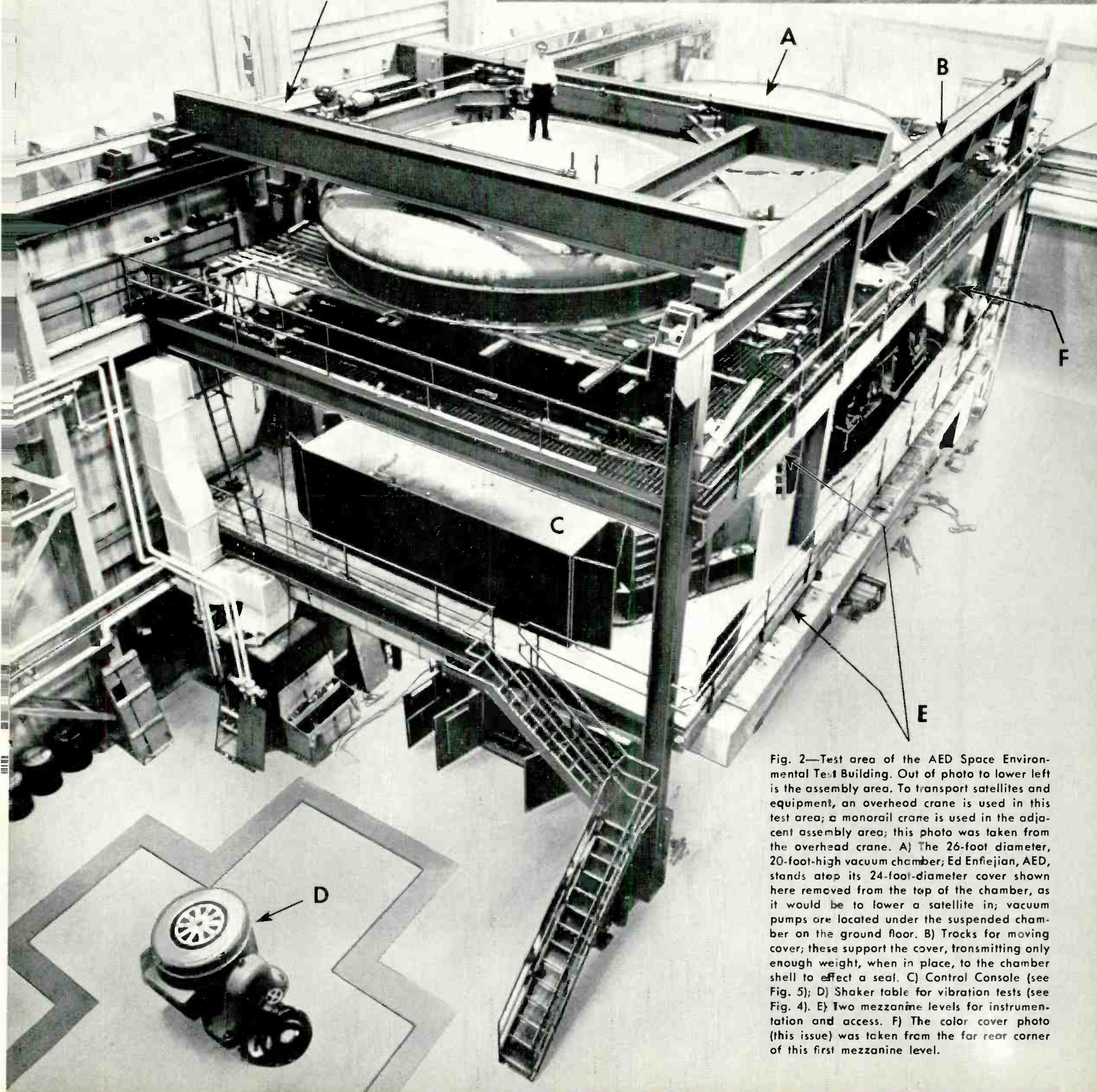

Fig. 2—Test area of the AED Space Environmental Test Building. Out of photo to lower left is the assembly area. To transport satellites and equipment, an overhead crane is used in this test area; a monorail crane is used in the adjacent assembly area; this photo was taken from the overhead crane. A) The 26-foot diameter, 20-foot-high vacuum chamber; Ed Enfiejian, AED, stands atop its 24-foot-diameter cover shown here removed from the top of the chamber, as it would be to lower a satellite in; vacuum pumps are located under the suspended chamber on the ground floor. B) Tracks for moving cover; these support the cover, transmitting only enough weight, when in place, to the chamber shell to effect a seal. C) Control Console (see Fig. 5); D) Shaker table for vibration tests (see Fig. 4). E) Two mezzanine levels for instrumentation and access. F) The color cover photo (this issue) was taken from the far rear corner of this first mezzanine level.

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solar spectrum. Such systems generally use mercury-xenon lamps or carbon-arc lamps and produce a collimated energy source through a complex optical system. These systems can produce energy densities of 200 to 500 watts/ft.[2] The cost of these systems is quite high, with prices starting at about $1 million.

Most early space vehicles have had relatively simple structural shapes, for example the uniform 18-sided polyhedron of TIROS. The absence of complex shadow effects made true solar simulation unnecessary as a means of producing the thermal environment. However, as structures become more complex it may become necessary to use more-sophisticated solar simulation for accurately producing shadow effects and the effects of the full solar spectrum on some materials. AED is therefore now considering such a solar-simulation system for the large vacuum chamber.

One approach is to add the solar-simulation system to the 24-foot-diameter cover of the vacuum chamber. While this would not alter the chamber itself, it would increase the cover weight to over 60 tons. Thus, to allow for this potential addition, the cover lift and transport mechanism was designed to handle this additional weight.

Sometimes, thermal environment must be simulated in an atmosphere rather than in a vacuum; or, a thermal environment might be desired with humidity. Both of these conditions represent thermal environments which a space vehicle might encounter prior to launch. Conventional thermal boxes and thermal-humidity chambers are available to simulate these conditions, but are limited in size. Therefore, the new AED environmental center includes a large, walk-in chamber with a temperature range of −85° to +250°F, and a range of 5- to 95-percent relative humidity. Since the temperatures reached by an orbiting vehicle can usually be controlled to a reasonable range by judicious selection of materials and finishes of its shell, a range of simulation between −100° to +250°F is usually quite adequate.

INDUCED ENVIRONMENTS

Vibration

There are several sources of both random and sinusoidal vibrations: 1) during countdown, from rotating components, such as pumps and generators; 2) at the instant of firing, obviously severe vibratory loads on the whole system; 3) immediately after firing, several other vibratory loads caused by turbines, engine thrust, acoustic pressures, and steering forces; 4) during early flight, from fuel sloshing, wind, aerodynamic forces, and shock waves; 5) during advanced stages of flight, vibratory stresses from capsule separation.

Vibrations between 5 and 20,000 cps are significant because they affect structural strength, with frequencies from 5 to 500 cps usually most damaging. Vibration can cause fatigue failure of mechanical parts, loosening of parts, short circuits, noise, objectionable operating characteristics, etc.

In environmental testing, the vibration pattern experienced during flight cannot be exactly simulated, since this pattern is extremely complex and almost impossible to reproduce. The pattern essentially consists of random vibrations within the vehicle caused by machinery, etc.; random vibrations outside the vehicle caused by lift and drag; and sine-wave vibrations caused by natural resonances.

A good means of approximating the natural resonances and the random vibrations within the vehicle is to induce random vibrations on an electro-dynamic shaker tester while sweeping through the audio spectrum with a sine-wave input to the shaker tester. The random vibrations caused by drag and lift can be simulated by employing acoustic energy.

The AED environmental center is equipped with one of the largest shakers in existence, an oil-cooled, electrodynamic unit with a maximum displacement of 1 inch that can produce 28,000 pounds of peak force. The amplifier to the exciter can deliver 140 kw over a 25- to 10,000-cps frequency range. The many narrowband filters in this unit either boost or attenuate signals, thereby shaping the output response.

The shaker is controlled from a central console which contains a logarithmic-sweep wideband oscillator providing automatic frequency cycling through the audio band. Appropriate servos in the system control acceleration, velocity, or displacement. A spectrum analyzer monitors the random-vibration output. The shaker system and its associated controls are designed for operation with an additional shaker in the future.

Shock

Another of the induced environments is shock, occurring when there is a sudden change in load, velocity, or movement. The rapid accelerations present after a launch produce severe shock; a typical value is 50 g in 11 milliseconds, although booster-separation shocks of 200 g have been measured.

Generally speaking, the simulation of this environment presents no great problem. Various methods of producing controlled shock have been employed including impact, explosive charges, and pendulums. At AED, an impact-type shock tester is used which can easily simulate 250 g with rise time of 6 milliseconds.

One of the unknowns of shock environment is the impact effects of high-speed particles on the space vehicle. This problem requires more research before adequate simulation methods are formalized. Establishment of more accurate values of shock levels produced through normal handling, transportation, and booster separation is also a problem.

Acceleration

Acceleration (another induced environment) normally encountered by the space vehicle is from 10 to 15 g. Such accelerations produce strains and/or displacements which can cause fracture of structures or movement of parts with resultant damage.

It is impractical to simulate acceleration in a straight-line motion for most applications because of the great physical space and cost involved. (An example of such a facility would be a rocket sled.) Therefore, most simulation of the acceleration environment is accomplished in a rotary accelerator. AED's rotary accelerator has been used to produce accelerations on many of its space programs. This facility has a load rating of 2500 g-pounds and will accommodate test specimens up to 100 pounds, with volumes to 18 cubic inches.

CHALLENGE OF THE FUTURE

Besides the environments that have been discussed, there are many others of great signficance: gravity; high-intensity noise; effects of comets, meteors, dust clouds, and plasma; nuclear, solar, and Van Allen radiations; and magnetism.

It is now impossible, or almost impossible, to simulate many of these. Zero gravity, for instance, can only be produced for short periods. As the state of the art advances these environments might be produced more accurately and simultaneously.

Advancing the state-of-the-art in techniques of scaling—achieving equivalent test data by using scaled-down equipment and specimens—presents intriguing challenges. The goal could be millions of dollars saved annually.

Achieving necessary reliability through more effective subsystem testing so as to reduce size, complexity, and cost of facilities presents an enormous challenge.

A chief factor in successful design and fabrication of space-vehicle systems is achievement of the highest degree of over-all performance reliability. Certainly, environmental testing contributes.

The philosophy of injecting reliability into a product early in its life, during design and fabrication, is just as applicable to space technology as it has been in so many technologies through the years.

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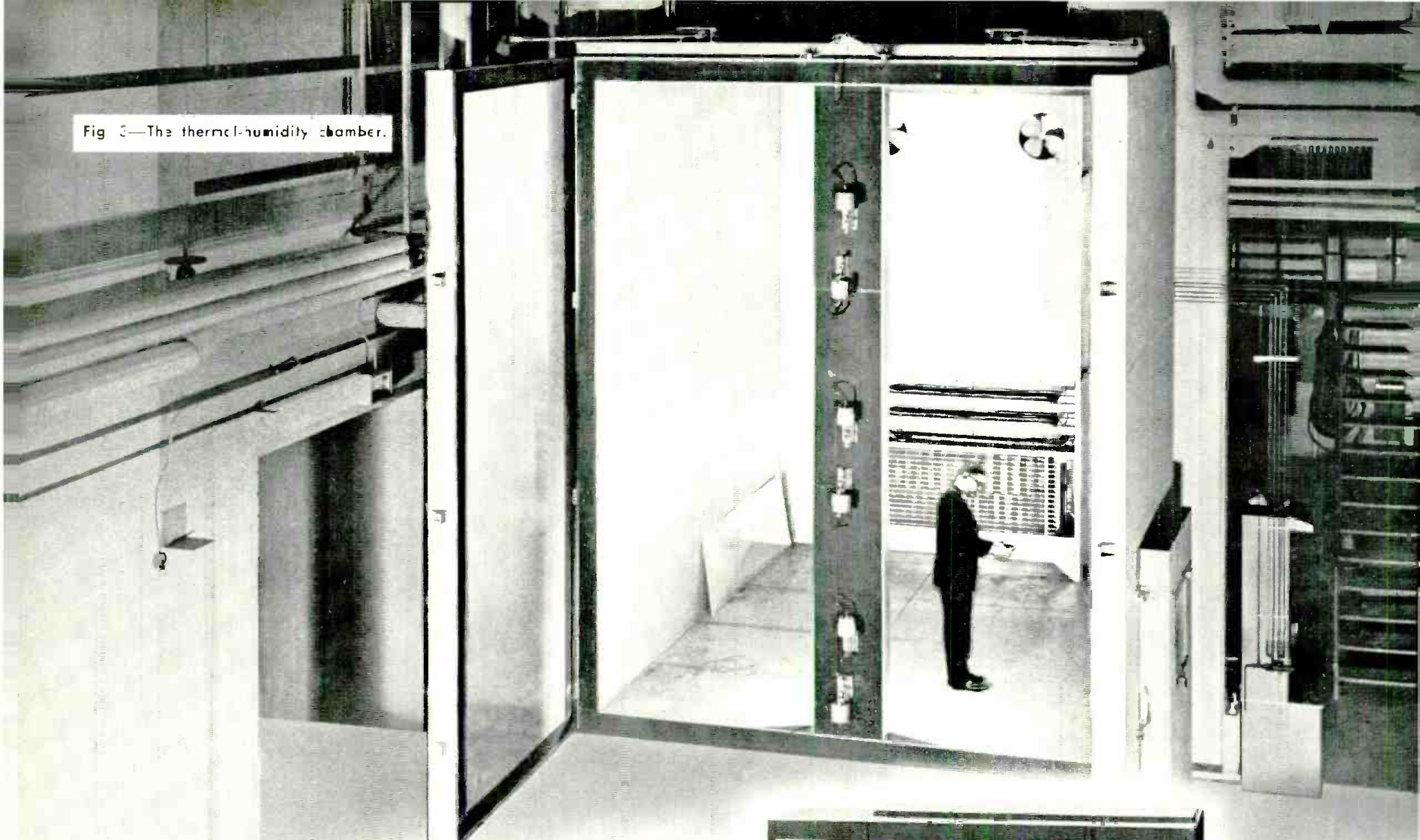

Fig 3—The thermal-humidity chamber.

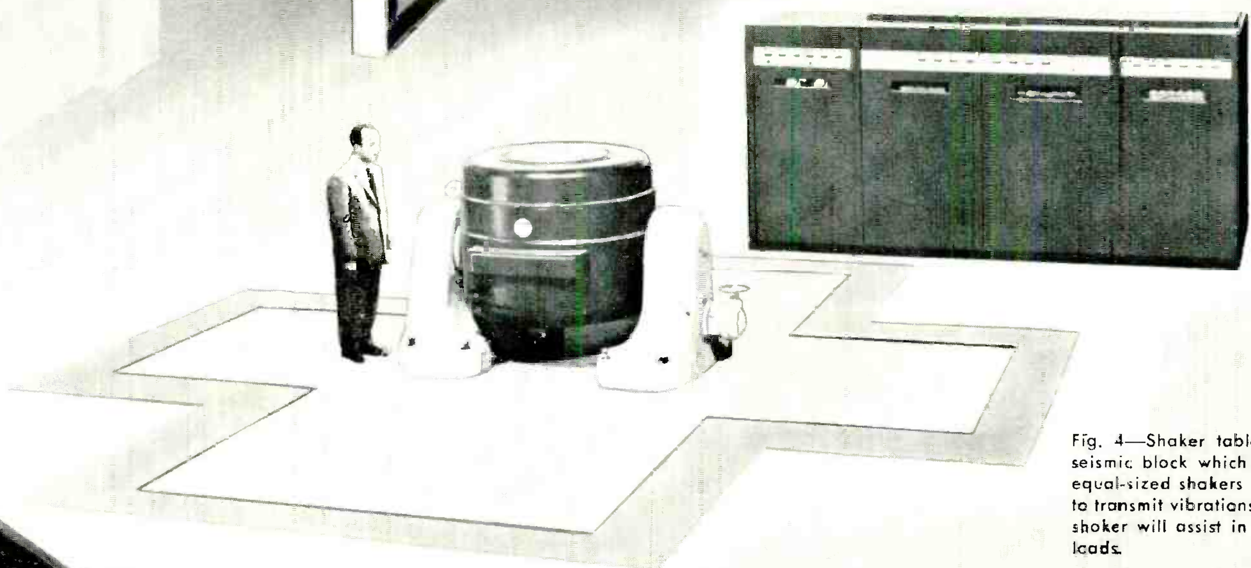

Fig. 4—Shaker table, mounted on special seismic block which can accommodate two equal-sized shakers plus a "slippery table" to transmit vibrations horizontally. A second shaker will assist in vibrating future heavy loads.

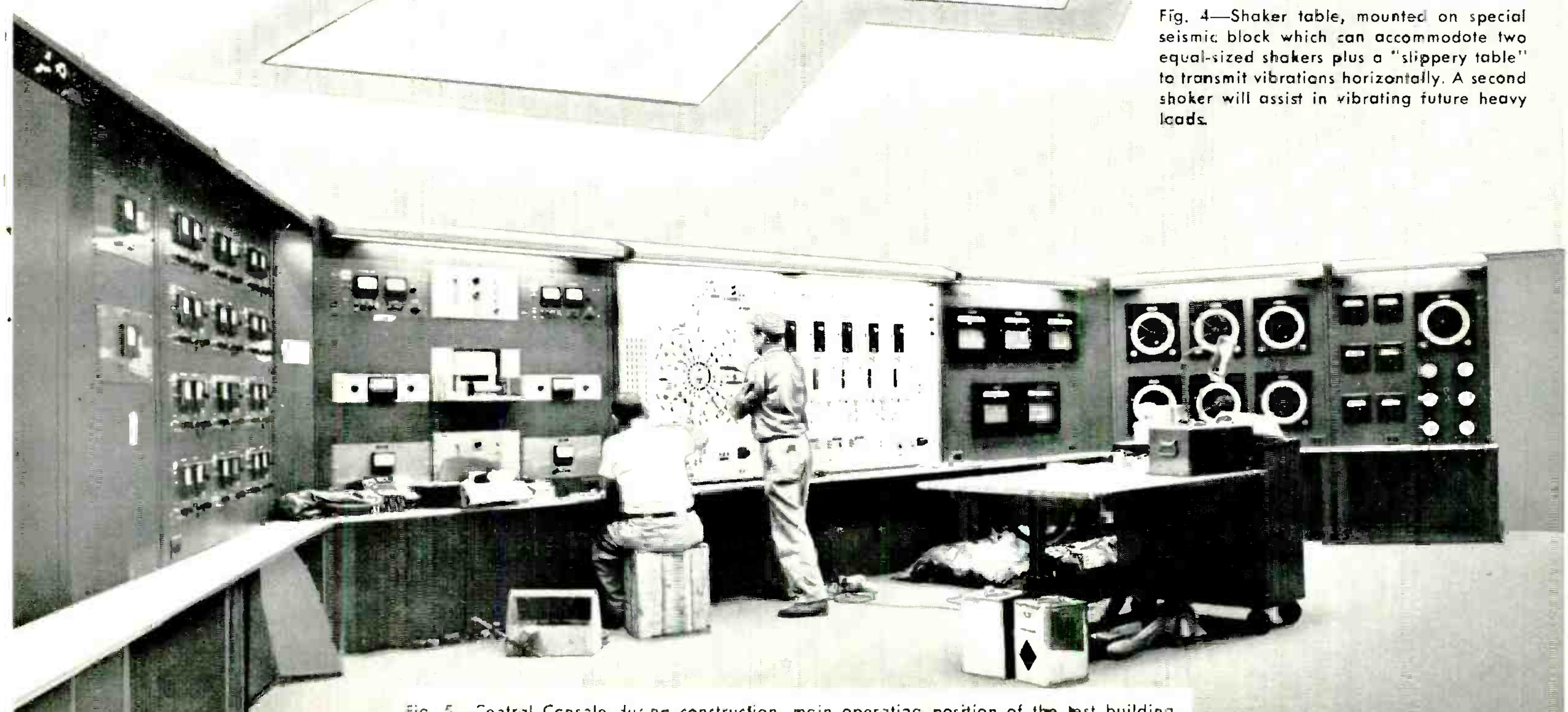

Fig. 5—Central Console during construction, main operating position of the test building. Recorders, interlocks, etc. allow either manual or automatic operation through the console.

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PROPULSION AND GUIDANCE FOR A SOFT LUNAR LANDING

by **B. P. MILLER**
RANGER *Project*
Astro-Electronics Division
DEP, Princeton, N. J.

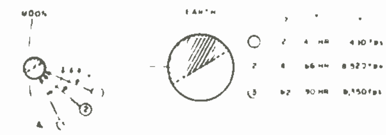

Fig. 2—Vertical-impact trajectories.

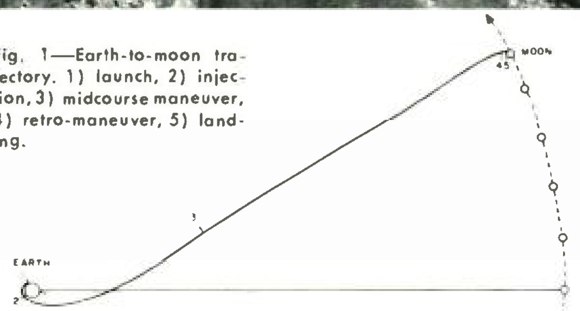

Fig. 1—Earth-to-moon trajectory. 1) launch, 2) injection, 3) midcourse maneuver, 4) retro-maneuver, 5) landing.

To land sophisticated instruments and eventually men on the moon necessitates a soft landing of the spacecraft—a controlled deceleration from trajectory velocity of several thousand fps to a reasonable impact velocity of less than 50 fps. Success depends upon accurate measurement of trajectory parameters and precise control of retro-thrust devices as the spacecraft approaches. Instruments carried in the spacecraft to control this maneuver may include a computer and optical, radar, and TV sensors.

LARGE ROCKET BOOSTERS have brought lunar exploration from the realm of scientific fantasy into the foreground of engineering practicality. This was dramatically underscored when on September 14, 1959, the Russian LUNIK II impacted on the surface of the moon. Then, during October 1959, LUNIK III circumnavigated the moon and provided the first photographs of its hidden side.

Manned exploration of the moon by the early 1970's is a major goal of the present United States space program. To support this goal, NASA (the National Aeronautics and Space Administration) has begun development of a family of unmanned lunar probes under the RANGER and SURVEYOR programs, and has initiated design studies of the APOLLO spacecraft that will transport men to the moon.

Instrumented circumlunar probes and high-velocity impacting probes similar to the Russian LUNIKS will provide much scientific information. The NASA RANGER program plans a limited-payload lunar landing at an impact velocity that may approach several hundred feet per second (fps).* However, sophisticated scientific payloads must be landed for really detailed lunar studies. Such payloads cannot economically be designed to be operable after a high-velocity impact. Therefore, the vehicle must decelerate from a lunar approach velocity of several thousand fps to a landing velocity of less than 50 fps. The absence of an appreciable lunar atmosphere dictates deceleration by retro-rocket techniques. This soft-landing maneuver requires accurate measurement of the lunar-approach trajectory parameters and precise control of the retro-propulsion.

THE APPROACH TRAJECTORY

Fig. 1 shows the over-all sequence of events as a spacecraft travels from the earth to the moon. The vehicle is accelerated by a booster, through alternate periods of propulsion and coasting in the vicinity of the earth, to a planned velocity of approximately 36,000 fps—the *injection velocity* at which the spacecraft enters an actual lunar trajectory. At a predetermined midcourse point in the trajectory, a velocity-vector correction is computed from tracking data and the spacecraft maneuvers to reach

* NOTE: Four additional RANGER spacecraft have been added to the currently existing RANGER Lunar Exploration program by NASA. The California Institute of Technology, Jet Propulsion Laboratory, is carrying out the unmanned lunar and planetary program for NASA. Mission of the four new RANGERS will be to send back to earth stations high resolution television pictures of the lunar surface up to the moment the spacecraft impacts on the moon. The Astro-Electronic Division has been selected to develop the television subsystem which will be carried by the RANGER spacecraft.

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the moon's vicinity at a specified time, position, and approach velocity.

Although nonvertical landings have been proposed for some manned vehicles, the vertical impacting trajectory has been suggested for the majority of unmanned, soft-landed, exploratory missions and will be used here to illustrate the problems of lunar landing. Fig. 2 shows the possible combinations of the earth-to-moon transit time, approach velocity, and impact location for vertical impact trajectories. In general, both the injection velocity and the lunar approach velocity increase with decreasing transit time, and transit times less than about 40 hours result in a marked decrease in the deliverable payload weight. Although the velocity requirements are decreased by trips requiring more than about 90 hours, these longer transit times impose stringent requirements upon the injection accuracy and thus are usually not considered.

Other factors may further restrict the choice of trajectories, such as line-of-sight communications between an earth-based station and the descending vehicle. However, the velocity of the spacecraft in the vicinity of the moon will probably not be less than about 8200 fps for the usual (vertical-impact) transit trajectories, and may reach 10,500 fps. Therefore, soft landing of the spacecraft requires controlled deceleration to the desired touch-down velocity of less than 50 fps.

BASIC PARAMETERS OF LUNAR SOFT LANDING

The total spacecraft mass delivered to the vicinity of the moon at lunar approach velocity will consist of payload, rocket motor, propellants, and guidance equipment required for the soft-landing maneuver. Some of the rocket methods to provide the retro-thrust for soft landing include:

1) a fixed-thrust rocket motor with a single burning phase;
2) a multiple burning, or pulsed, rocket;
3) a variable-thrust rocket motor;
4) combinations of the above.

For the trajectories considered, the approach velocity is parallel to the lunar-radius vector, and the retro-maneuver occurs within a few hundred miles of the lunar surface. Under these conditions, the equations of motion for the soft-landing maneuver can be expressed as:

$$V_{fi} = V_{oi} + g_E I_i \ln\frac{m_{oi}}{m_{oi} - \dot{m}_i \Delta t_i} - g_{mi} \Delta t_i \qquad (1)$$

$$h_{fi} = h_{oi} + V_{oi} \Delta t_i - \frac{g_{mi} \Delta t_i^2}{2} + \frac{F_i \Delta t_i}{\dot{m}_i} - \frac{F \Delta t_i}{\dot{m}_i}\left(1 - \frac{m_{oi}}{\dot{m} \Delta t_i}\right) \ln\frac{m_{oi} - \dot{m}_i \Delta t_i}{m_{oi}} \qquad (2)$$

Where: F = thrust, g = acceleration of gravity, h = altitude, I = specific impulse, m = mass, $\dot{m}$ = mass rate of flow, t = time, V = velocity, and subscripts f = final, i = i^{th} time period, and o = initial.

In Equations 1 and 2, the time increment corresponds to the burning time for the fixed-thrust mode, or to a convenient time interval over which the propulsion parameters are averaged for the variable-thrust mode. If the rocket motor is not operating during the time increment, the equations are reduced to:

$$V_{fi} = V_{oi} - g_{mi} \Delta t_i \qquad (3)$$

$$h_{fi} = h_{oi} + V_{oi} \Delta t_i - \frac{g_{mi} \Delta t_i^2}{2} \qquad (4)$$

Note from the dynamics of the landing maneuver (Equations 1 and 2) that the additional increment of velocity due to the acceleration of lunar gravity is minimized if the rocket burning time is infinitesimal and the retro-maneuver is performed just before the spacecraft reaches the lunar surface. In the terminology of rocket propulsion, when the rocket burning time is infinitesimal the propulsion maneuver is described as *impulsive*. Thus, by minimizing the velocity due to the acceleration of lunar gravity, the impulsive type of retro-maneuver *minimizes* the weight of propellants needed to cancel the approach velocity and *maximizes* the payload weight delivered to the lunar surface.

However, the impulsive maneuver implies an infinite mass rate of flow of propellants, and therefore an infinite thrust and deceleration. It is obvious that there is an upper limit to deceleration that the payload can tolerate. Therefore, any soft-landing maneuver has a maximum value of retro-thrust, a minimum rocket burning time, and a minimum ignition altitude. For the approach trajectories shown in Fig. 2, the minimum percentage of the spacecraft mass that must be allocated to propellants (the *propellant fraction*) for the impulsive retro-maneuver ranges from about 48 percent for the 90-hour transit to 57 percent for the 40-hour transit, assuming a liquid H_2 and liquid O_2 propellant-oxidizer combination.

GUIDANCE AND PROPULSION PROBLEMS

The soft-landing propulsion and guidance problems can be illustrated by the fixed-thrust retro-maneuver with a single burning phase. Although this method is not practical to ensure a true soft landing, its analysis provides insight into the problem. More-sophisticated and feasible techniques will then be discussed.

In this case, the altiude and velocity must go to zero simultaneously at the instant of propulsion cut-off. Fig. 3 depicts the variation of the vehicle propellant fraction and the rocket burning time (as a function of the rocket thrust level) to land a mass of 100 slugs (about 3220 earth pounds) on the surface of the moon with zero velocity at zero altitude. Increasing mass has the effect of increasing the thrust level and the propellant fraction required for soft landing. Note that the propellant fraction and burning time decrease, and the thrust increases as the altitude for the initiation of the retro-maneuver moves closer to the lunar surface at a constant approach velocity.

According to Fig. 3, a soft-landing maneuver with a rocket motor having a single burning phase and fixed thrust requires starting the retro-maneuver at a predetermined altitude for a given approach velocity and rocket design. In practice, the guidance requirements for this type of retro-maneuver are somewhat stringent and difficult to fulfill. The device used to initiate the retro-rocket burning at a prescribed altitude, whether it be a radar or optical instrument in the spacecraft, or an earth-based command, is subject to measurement

Fig. 3—Vehicle propulsion parameters.

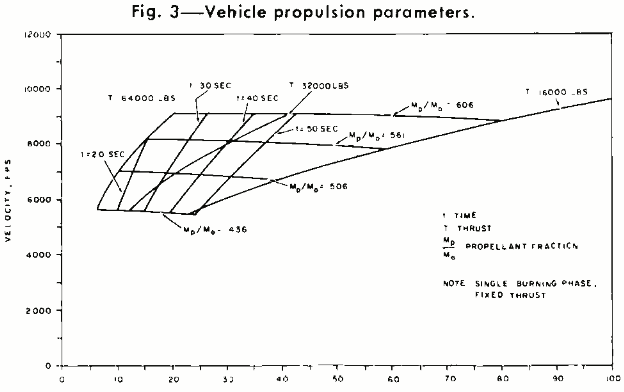

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TABLE I—TYPICAL SYSTEM ERRORS

Initial Conditions:	
h_i	100 naut mi
V_i	10.000 fps
Spacecraft Parameters:	
m_i	77.7 slugs
T_i	5,000 lbs
I_{sp}	300 sec
Std. Values of System Errors:	
ΔV_i	$\pm$ 10 fps
ΔH_i	$\pm$ 500 ft
ΔT_i	$\pm$ 5 lbs
$\Delta \dot{m}$	$\pm$ 5 x 10^{-4} slugs/sec
Δt	$\pm$ 0.1 sec

errors. If the retro-firing begins too soon, the spacecraft may reach zero velocity at some altitude above the surface and then fall freely to the surface. Conversely, if the retro-firing is delayed, the payload will strike the surface with some fraction of its initial velocity. For these reasons, a single-burning-phase, fixed-thrust-descent rocket would probably be designed to reach zero velocity a few feet above the surface and then to fall freely under the acceleration of lunar gravity for an impact at a nominally low velocity.

Other errors in the measurement or control of rocket parameters, such as thrust level, mass efflux of propellants, burning time, and the deviation of the actual approach trajectory from the desired nominal trajectory caused by injection errors and uncertainties in orbital determination, can similarly affect the success of the landing maneuver. For example, a typical single-burning-phase, fixed-thrust, retro-maneuver system analyzed by AED must produce the soft-landing conditions of simultaneous zero velocity and altitude from initial conditions of a vertical descent velocity of 10,000 fps and an altitude of about 100 nautical miles. The spacecraft mass at this altitude is 77.7 slugs (about 2500 earth pounds). The retro-rocket employs a propellant combination yielding a specific impulse of 300 seconds and a thrust level of 5000 pounds. The retro-maneuver is started by a command from a radar altimeter having a standard error of 500 feet at the initial altitude. The descent time to the lunar surface is nominally 100 seconds.

Based upon the standard errors for this system, as summarized in Table I, the velocity of lunar impact could easily approach 240 fps. Thus, guidance and propulsion control problems preclude the possibility of achieving a truly soft landing with a single-burning-phase, constant-thrust descent program.

FEASIBLE SCHEMES FOR SOFT LANDING

At least three propulsion and guidance schemes appear to be feasible for achieving lunar soft landings. Each of these entails more-complex guidance and propulsion equipments than the previously discussed constant-thrust descent. They also require a greater propellant mass fraction for the same initial conditions.

Dual-Burning-Phase Descent

The dual-burning-phase descent uses a restartable rocket motor that begins the initial retro-firing at a slightly higher altitude than the single-burning-phase case. In the dual system, the first phase removes all but about 500 to 1000 fps of the descent velocity, with nominal burnout occurring at a lunar altitude of about 25,000 feet. The first phase of the retro-firing requires only a coarse optical or radar sensing of the altitude and velocity for initiation.

The altitude for conclusion of the first burning phase is selected to permit using a precision radar altimeter with reasonable weight and power requirements. The spacecraft then falls freely from the nominal first-phase cut-off altitude, and during this period of free fall the radar altimeter measures the altitude and vertical descent rate. Television instrumentation, if used during free fall, can visually inspect the landing site; and if necessary, a lateral maneuver can be performed to select a more desirable landing area.

A vehicle computer determines the firing time and duration for the second propulsion phase of the soft-landing operation, and the second phase imparts an impulsive velocity increment to the spacecraft just prior to impact. Studies of this method of descent have shown the feasibility of limiting the velocity at impact to approximately 25 fps *(JPL Res. Summary, No. 36-4, 15 August 1960)*.

Multiple-Phase, or Pulsed-Mode

The pulsed mode of operation is a logical extension of the dual-burning-phase descent. It permits measuring the descent parameters and correcting the thrust program after each period of rocket-motor operation, at the expense of increased propulsion system complexity. Each propulsion period may have a different thrust level and duration, and the required thrust program for the soft landing is recomputed periodically during the propulsion system off-time by the vehicle computer.

Variable-Thrust Rocket Motor

The variable-thrust rocket motor provides a continuously variable thrust profile (to within about 10 percent of the maximum thrust) by varying the flow of propellants through the thrust chamber. Like the pulsed descent, this system requires observed velocity and altitude measurements for comparison with a standard descent profile. Error signals generated in the vehicle computer generate the thrust program.

CONCLUSION

The soft landing of a payload on the surface of the moon will require accurate measurement of the trajectory parameters as the spacecraft approaches the vicinity of the moon. Control of the rocket propulsion during the retro-maneuver is necessary for a soft landing, with a dual-burning-phase descent considered as a minimum requirement. Instrumentation for soft landing consists of optical and radar devices for altitude and velocity measurements, a computer for thrust-program computation, and television equipment for visual inspection of the landing site during the descent maneuver.

BERNARD P. MILLER received the B.S. in Aeronautical Engineering from Pennsylvania State University in 1950, and did postgraduate work in Aeronautical Engineering at the U.S. Air Force Institute of Technology in 1953-1954 and Princeton University in 1957-1959. During 1950 he was employed by H. L. Yoh Company. From 1950 to 1953 he was assigned to the Aircraft Laboratory, Wright Air Development Division, as project engineer for the development and flight-testing of special ordnance equipment. After his work at the Air Force Institute of Technology in 1954, he taught at the U.S. Naval Academy, Annapolis, as an instructor of Fluid Mechanics and Thermodynamics. In 1956, he was appointed Head of the Thermodynamics group of the Academy's Dept. of Marine Engineering. He joined the RCA Special Systems and Development Department in Princeton in 1957, and transferred to the Astro-Electronics Division in 1958. There, on Project JANUS he engaged in trajectory and orbital anlysis and determined propulsion system requirements. In 1959, he was project engineer for RCA's participation in SR-192, Strategic Lunar Systems, responsible for analysis of system requirements and other studies. Mr. Miller has been project engineer for RCA's participation in SR-178, Global Surveillance System, responsible for the technical direction of studies of the system concept, advanced sensors, data processing equipment, check-out equipment, and communications. He is now working on the new RANGER Project. He is a member of the Institute of Aerospace Sciences and is a registered professional Aeronautical Engineer.

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SIDNEY METZGER received the BSEE from New York University in 1937, and his MEE from Polytechnic Institute of Brooklyn in 1950. From 1939 until 1945 he worked for the U. S. Army Signal Corps Laboratories at Fort Monmouth on radio communications equipment. From 1945 to 1954 he was at the ITT Laboratories as division head in charge of commercial and military multiplex microwave systems. In 1954 Mr. Metzger joined the RCA Laboratories at Princeton where he worked on communications problems for military systems. He transferred to the Astro-Electronics Division when it was formed in 1958 and is now Manager of Communications Engineering. He was in charge of the group which supplied the satellite and ground based radio equipment for Project SCORE (the "Talking ATLAS") in 1958; was responsible for the communication system and equipment for TIROS; and is now responsible for the communications system and equipment for Project RELAY. He is a Senior Member of the IRE, a Senior Member of the American Rocket Society, and a member of Tau Beta Pi and Sigma Xi.

DAVID S. RAU was assigned to the Rocky Point high power transmitting station as one of RCA's first student engineers. He had graduated from the U. S. Naval Academy in 1922 with degree of Bachelor of Science. After a period as Chief Engineer of the Radio Corporation of the Philippines, a wholly owned subsidiary, and further duty at major radio stations, he was assigned to the New York Headquarters staff of RCA Communications, Inc. as a Station Design Engineer. From this duty he advanced to his present position of Vice President, Engineering. He spent the World War II period on active duty in the office of the Director of Naval Communications as head of the Shore Radio Stations section. He was promoted to Captain, USNR, in this billet and Commended by Secretary of the Navy, James Forrestal for his work. He is an IRE Fellow, a member of Board of Editors for the *RCA Review* and for the RCA Institutes.

Future international communications demands—telephony, telegraphy, data transmission, television—are seen as exceeding the economically practical capacities of today's conventional transmission methods. Satellite communications relays are of great interest as a solution, since their transmission characteristics provide economic and technical advantages over additional transoceanic cables and/or earth-bound radio links. These technical concepts are described herein, while the following companion articles by Edwards and Hawkins consider the operational and the legal aspects, respectively, of satellite communications systems.

SATELLITES FOR INTERNATIONAL COMMUNICATIONS
...Technical Concepts

S. METZGER, Mgr.
Communications Engineering
Astro-Electronics Division
DEP, Princeton, N. J.

and

D. S. RAU, Vice President
Engineering
RCA Communications, Inc.
New York, N. Y.

SEVERAL YEARS AGO, the Operations and Engineering staff of RCA Communications, Inc., New York, observing the rapidly expanding demand of communication services, began planning systems and methods to meet this demand. Discarding the highly publicized forward-scatter techniques as too costly and too difficult from the logistics standpoint for a chain of stations over the North Atlantic, it became apparent that for the immediate future we would have to squeeze out more channels from the already congested high-frequency spectrum.[1] Single-sideband operation with time-division multiplex contributed considerably towards temporarily relieving the demand.

But not enough—the need for more channels kept pressing. Through the cooperation of RCA associates in Britain, Germany, and France who control the overseas portions of the transatlantic coaxial cables, and the A.T.&T. Co., the owner of the North American portions, RCA Communications was permitted access to the cables for telegraph service. By using new techniques the number of cable channels can be extended, but only up to a limit which may be too restricting in a few years. In 1959, a congressional report[2] showed that there were approximately $1\frac{1}{2}$ million transoceanic telephone messages in 1950 and predicted 3 million in 1960 and 21 million in 1970. Actually, the A.T.&T. Co. handled 3,700,000 transoceanic telephone messages in 1960 and now estimates that they will handle 100,000,000 by 1980.

"It does not appear feasible to meet this rapidly expanding demand for communication services through conventional cable means," said the congressional report. The gross predicted for voice communications appeared to RCA Communications management to hold correspondingly true for telegraph services. Such belief was supported by the rapid increase in demands for Telex and leased channel services.

Consequently in 1959, RCA Communications, Inc. queried the Astro-Electronics Division about their activity in the field of satellite communication relays. AED told of its participation in the SCORE project and its activity in development of other projects for the military and the National Aeronautics and Space Administration (NASA). AED asked RCA Communications, Inc. to join in a study of the commercial aspects of satellite communication relays. AED knew RCA Communications' practical knowledge of long-distance communications gained from many years of successful operations in this field would add considerably to AED's theoretical and experimental research to bring about the ultimate development of a practicable system.

THE SATELLITE RELAY CONCEPT

The main reason for a satellite communication system is that a satellite at an altitude of thousands, or even hundreds, of miles above the earth can provide line-of-sight paths between cities separated by thousands of miles. These

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paths permit using microwave frequencies (1,000 to 10,000 Mc), with their wide bandwidths capable of handling a television program, or a thousand speech circuits, or a high speed facsimile signal which can be converted into printed pages at a rate of 600 pages per minute. The ionosphere has negligible effects on these frequencies. By comparison, present high-frequency circuits (3 to 30 Mc), which cover distances of thousands of miles over non-line-of-sight paths by reflections from the ionosphere, are limited to bandwidths about one thousandth of those needed for transmission of the aforementioned services.

A satellite at an altitude of 1,000 miles has a line-of-sight range of about 3,000 miles. Thus, a satellite 1,000 miles above New York City would be in view of both Los Angeles and Paris simultaneously, and could thus act as a repeater between these two cities. Unfortunately, it is not practical to keep a repeater so positioned in space at this altitude. A satellite stays in orbit by a balance between its outwardly directed centrifugal force and the gravitational force directed toward the center of the earth. Its orbital plane must always pass through the center of the earth. Therefore, its position in space is always moving with respect to a point on the earth, except for the special case of the so-called stationary, or *synchronous* orbit. For the synchronous orbit, the satellite in an equatorial orbit at a distance of 22,300 miles above the earth has a period of 24 hours, and its position in space is fixed with respect to a point on the earth. The possibilities of using this synchronous satellite for communications has been described in the *RCA Review*,[3] and will be briefly discussed later in this article.

For the moment, let us consider the use of satellites at altitudes of a few hundred or a few thousand miles, and consider the effect of the orbital angle of the satellite on its utility. Fig. 1 shows the orbital paths for three possible satellites: an equatorial orbit, an inclined orbit, and a polar orbit. For a low-altitude equatorial-orbit satellite, the stations visible to this satellite are rather restricted. For example, a satellite at a 300-mile altitude would see only stations within 1500 miles north and south of the equator, but these would be seen for every pass of the satellite. At this altitude the satellite period is 1½ hours. A polar orbit with the same altitude has the same satellite period, but the satellite would pass over all cities of the world. The daily frequency of these passes would depend on the latitude of the particular city. For example, a city located within 1,500 miles of the pole would see the satellite every pass. At the

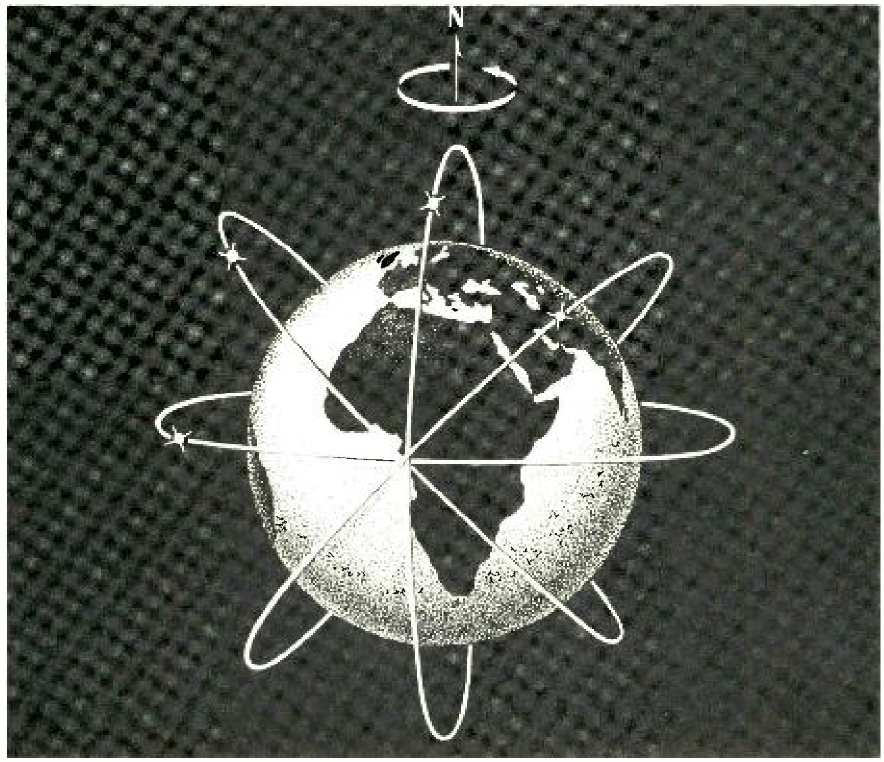
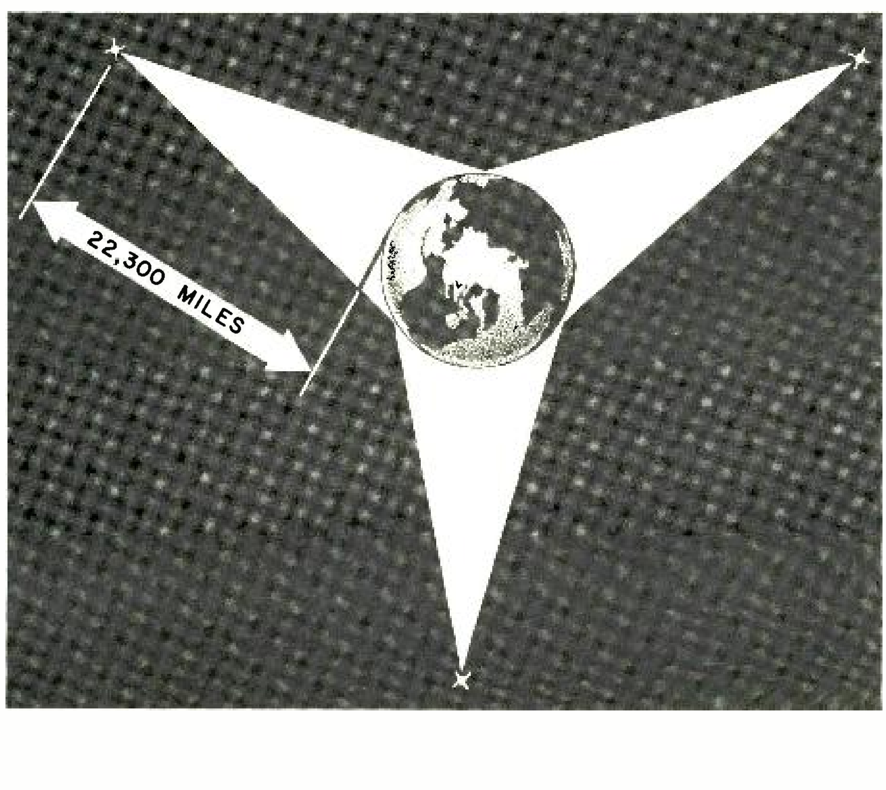


Fig. 1—Orbital paths for a system of nonsynchronous communications satellites.

Fig. 2—A synchronous satellite system.



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other extreme, a city at the equator would see the satellite a couple of times in succession, and then not see it again until about 12 hours later. At intermediate latitudes, the viewing time per day would be intermediate to these two extremes. Similarly, a satellite in an inclined orbit would pass over all cities below the latitude of its inclination angle. The exact number of passes per day would also depend on the latitude of the city.

ACTIVE AND PASSIVE REPEATERS

So far we have discussed satellites by considering their time in view with respect to ground stations, but we have not mentioned the nature of these satellites. For communication purposes, satellites are classified as *active* or *passive* repeaters.

An active repeater is similar to that used in a microwave relay station, where the received signal is amplified, shifted in frequency, and retransmitted back to the ground station. Such satellites can be unstabilized, or spin-stabilized; both cases requiring an omnidirectional antenna. The satellites might also be attitude-stabilized to permit using directional antenna or antennas for communicating between the ground stations.

The passive satellites receive energy from one ground station and reradiate to another distant ground station. Such a passive satellite might be a metallic-coated sphere, a flat plate or parabolic reflector, or a cloud of dipoles.

There are advantages and disadvantages to both the active and passive repeater classes, and to the various types within each class. For example, in the active repeater a directive antenna would decrease the transmitter power needed in the satellite, but only at the expense of requiring a stabilization system. With the present technology, it is simpler to have a higher-power transmitter with an omnidirectional antenna, rather than to use a stabilization system; however, this may change in the future.

The use of passive repeaters appears very attractive because no power is needed in the satellites. But this advantage is diminished because extremely large ground antennas and extremely high powered transmitters are required. The transmitter power needed in an active satellite is proportional to the square of the distance from the satellite to its ground station; on the other hand, the passive satellite requires ground-based transmitter power times antenna gain which is proportional to the fourth power of the distance, as in radar. Because we are talking of hundreds, or even thousands of miles, the path attenuation is very large.

Active repeater communication satellites may also be classified as *delayed repeaters* or *real-time repeaters.*

A delayed repeater satellite comes in view of a given city, receives messages from that city destined for another place, and records these messages for later play back when the satellite comes in view of the other cities. Such a delayed type of repeater is advantageous in that only one satellite can provide coverage for many cities. It cannot be used for speech or Telex communications, however, but could be used for deferred telegraph or data transmission.

A real-time repeater satellite is in view of both ground stations simultaneously. Except for the case of the synchronous satellite, many satellites must be used if one satellite is to be in view of a ground station 24 hours a day.

SYNCHRONOUS SATELLITES

A satellite with an altitude of 22,300 miles above the earth has a period of 24 hours. Such a satellite, when placed in an equatorial orbit, will be fixed with respect to points on the earth (Fig. 2). From such a satellite, almost half of the earth's surface is visible, including all areas up to $\pm 81°$ latitude. With three such satellites located 120° apart, it is possible to cover all of the civilized areas of the world, including overlap regions, as shown in Fig. 2.

The transmitter power needed for the satellite repeater to provide a 5-Mc transmission bandwith is in the range of 1 to 10 watts (depending on the ground antenna size and receiver performance). This power requirement might permit using most of our commercial radio repeaters, except for one important restriction, *reliability.* Note that we need about the same power for a 25,000-mile satellite circuit as for a 25-mile circuit used in a typical ground relay system. However, ground radio relay equipment must have sufficient power to overcome the noise of 100 repeaters in tandem (20 db): and also a fading margin of 30 db for multipath effects caused by transmission through a 25-mile layer of air. In transmitting to a synchronous satellite, we go through only one repeater (two links) rather than 100. With a powerful ground transmitter, the upward path to the satellite may be designed to contribute a negligible amount of noise to the system. Also, the amount of fading should be substantially less than in our earth-bound links because the radio signals pass through less of the atmosphere. If we were to increase from 25 miles to 25,000 miles on the ground, we would need a million times more power, or 60 db. For the satellite case, 50 db of this amount is recovered by virtue of the two factors mentioned above, and another 10 db or so can be obtained by using modern low-noise receivers such as the parametric amplifier, or the maser. Thus, our satellite repeater need have a very modest power output.

Reliability, as mentioned before, prevents us from using a commercial microwave relay repeater equipment. Reliability is the most important consideration for satellite communications, and applies not only to the repeater electronics, but also to stabilization equipment needed to keep the satellite in orbit and pointed towards the earth. The reason for the stress on reliability is obvious because it is impossible to maintain equipment once it is in orbit. The first approach to satellite equipment reliability has been to use duplicate equipment. This is not a completely satisfying answer, so work will continue for developing components and circuits with even greater reliability.

CONCLUSIONS

RCA's experience with satellites to date indicates that propagation from and to satellites is truly free-space propagation. No unknown effects have appeared, and received field strengths check closely with those calculated.

From an economic viewpoint, one might think of a transatlantic satellite repeater in the following terms: In 1956, A.T.&T. installed a transatlantic cable with a capacity of 150 kc at a cost of about $35 million. A 5-Mc circuit should cost considerably more. With some more development, now underway, it is accepted that a satellite system can be built for considerably less than a 5-Mc transatlantic cable. The question may be raised as to whether there is sufficient need for this channel capacity. All present studies indicate that this is indeed the case, considering future needs for television, telephony, telegraphy, and data transmission.

CCIR (Committee Consultative International Radio, an international communications organization) working groups are presently studying some of the complex problems incumbent with international utilization of satellite relays. RCA has been and will continue to be actively interested in these groups.

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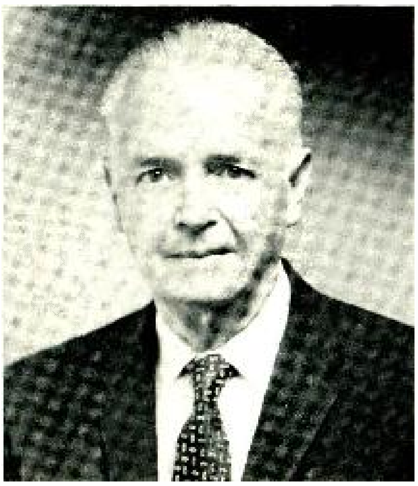

H. H. EDWARDS, after serving three years in the British Colonial Telegraph Engineering Civil Service, joined the American Marconi Company (later to become RCA) as marine operator. Two years later, in 1921, he transferred to the High Power International Service (now RCA Communications, Inc.) Traffic Division and later into the technical divisions. In 1938, Mr. Edwards transferred to the Management Group and during World War II held the position of Controller of Traffic Facilities. During this period and in postwar years he has served as Industry Advisor on the Radio Technical Planning Board and as Member of the Geneva Provisional Frequency Board Engineering Principles Committee and at National and International CCIR Conferences dealing chiefly with Ionosphere studies. In recent years he has been engaged in systems planning on the Traffic Engineering Staff and was Satellite Communications Systems Engineer, until his retirement on November 1, 1961.

The development of space vehicles for long-distance telecommunication links will in large degree be dictated by and must conform to those standards, practices, and procedures developed for other media over many decades. Discussed here are some of the problems of the Plant and Traffic Operations groups in making use of space vehicles for communications and of the problems of the groups developing space communications in conforming to present procedures. Cooperation will also be necessary among the many nations of the world in developing this new communications medium.

SATELLITES FOR INTERNATIONAL COMMUNICATIONS

. . . Operational Considerations

by **H. H. EDWARDS**
RCA Communications, Inc.
New York, N.Y.

DURING THE PAST DECADE, the domestic and international communications common-carriers have seen a vast expansion in their volume of traffic and in the types of services offered. During the next ten years, a still larger growth can be anticipated, even if only the present methods of communications are considered.

The existing media of h-f radio, long-distance land lines, and microwave equipment, submarine cables, scatter, etc., will be supplemented by a new medium, that of communications via space-relays.

This new method using microwaves will serve not only to supplement and expand existing services, but also will permit long distance and international development of other services not now fully exploited and in some cases unavailable, because of the wider bandwidth required.

FOUR MAJOR COMMUNICATIONS ASPECTS

In examining the scope and operations of present international communications, several major aspects must be considered in the development of a space system. Among these are: *policies, economics, practices,* and *procedures.*

Under *policies* one would find the desire of all countries to have a number of communication links to other countries without having these links pass through neighboring territories. Some of these countries have large traffic volumes and have developed or are developing large capacity links. Others, with less volume, find it difficult to keep up with increasing traffic demands. For both groups, space-communications will provide the means of expanding the scope and types of traffic handling. For the new and developing countries, this medium can be used as the principal method of providing the desired international linkage from within their own borders.

Many of the countries of the world maintain their international communications system as a government agency; and it can be assumed that the ground apparatus of a space system would be owned by such governments and would be afforded equal right of access to the space-vehicle relay functions.

Of pertinent interest under *economics* is the cost of the ground station. The space system must be of large capacity to make it economically feasible. In the early stages, it is likely that the users will be communications centers with large traffic volume, but that very soon there would be users whose individual requirements may be the equivalent of twelve, twenty-four or thirty-six "voice-frequency" channels. It is equally possible that eventually these "low-capacity" installations may be the majority of the users. Costs of these "low-capacity" installations must, therefore, be comparable to radio or submarine cable channel costs.

Countries cooperating in the International Telecommunications Union (ITU) have developed plant and operating standards resulting in a very high degree of compatibility among installations which vary at different places and among peoples of many different languages. The ITU develops its *practices* through member recommendations and from international engineering groups, such as the International Consultative Committees on Radio (CCIR) and on Telegraphs and Telephones (CCITT).

Even when fully developed, space communications will still be a subsystem of international traffic transfer, and in a very large proportion of circuit linkage will be one of several media used to complete the circuit, i.e., land lines, submarine cables, and space relays may be used in succession to relay a message. Under these conditions, satellite communications must conform to ITU practices.

Similarly, the operating *procedures,* also administered by ITU, have been cooperatively developed. In spite of language barriers, these procedures function smoothly and again, the space medium must conform to these operating procedures.

Accordingly, the established practices and procedures can be used as guides to develop the more technical aspects of engineering the space subsystem with due consideration to economics and to the desire of each country to communicate long distances from within its borders with a minimum of transfer over connecting media of other countries. The majority of ITU members fall into this category and of these, a large number

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would satisfy their international communications demands with operating spectrum space equivalent to less than twenty-four v-f (voice-frequency) channels for the near future.

The chief U.S. Government groups active in international satellite communications are listed in Table I.

SPACE COMMUNICATIONS OPERATIONS

Among the many phases of space communications, problems will exist in frequency assignment methods, natural phenomena and the practical engineering field. Each has some bearing upon operational considerations (Table II).

A study of these problems can be made by listing the probable services which may find space communications useful, the probable users and the fields in which this new medium can serve to develop new services.

Other services are envisioned in which information or intelligence is to be disseminated within a narrow bandwidth. These services can be regarded as similar to the possible use of point-to-point communications services by a terminal point with light traffic loading.

A third category would be services such as point-to-point communications with a substantial traffic loading but without a wide bandwidth requirement.

The fourth category would be the wide-bandwidth type of terminals to provide a large number of telecommunications channels or TV services.

SPACE COMMUNICATIONS SYSTEM PARAMETERS

The parameters of a telecommunication industry system, with particular reference to space communications, fall in a few general areas of interest.

1) *Area Classification:*
   - Domestic, e.g., USA traffic
   - Regional, e.g., Alaska, Canada, Mexico, USA
   - Inter-regional, e.g., North, South and Central Americas
   - International

2) *Terminal Distance Classification:*
   - Short, less than 250 miles
   - Intermediate, 250 to 750 miles
   - Medium, 750 to 2500 miles
   - Long, over 2500 miles

3) *Traffic Loading:*
   - Light load, total public telephone, telegraph and other supplementary services could all be handled on 12 to 24 v-f (voice-frequency) channels
   - Medium load, 24 to 72 v-f channels
   - Heavy load, 72 to 180 v-f channels

4) *Types of Traffic:*
   - Narrow band keying, teletype services at 50 baud rate
   - Public telephone and other v-f services at 3-kc bandwidth
   - Wide band services, Facsimile data processing, etc., 2500 bauds or higher

5) *Economic Considerations:*
   - Economics requires that space communications systems be comparable to other media in both installation and operation cost. Major cost items are the ground station installation, maintenance and operation, and the prorated share of the cost of the satellite family of vehicles.

6) *System Reliability:*
   - Anticipated life of satellite components
   - Maintenance of operational continuity on long term and day-to-day basis and during satellite "handover" period.

7) *Timing and Phasing Problems:*
   - Delay due to length of over-all circuit path
   - Doppler effects
   - Phasing of signals during satellite "handover"

To discuss the operational problems, certain assumptions must be made and some arbitrary values for the parameters of the system must be chosen. One of these arbitrary values could be that the average ground station would operate apparatus consisting of one or more groups of twelve v-f channels as v-f channels or with wider-band transmission equivalent to two or more v-f channels or with v-f channels divided into teleprinter subchannels or combinations of all three into a space system capable of accepting signals from many such ground stations. Other parameters could be selected which would permit the use of economical equipment such as medium-sized transmitting antennas.

Most of the circuits to be considered (terminal to terminal) will have an earth surface separation of 2400 to 3600 miles and it would be desirable to have as long a period of simultaneous visibility of each vehicle at the two terminals.

This distance factor makes a space system with the vehicle heights of less than 4000 miles relatively inefficient. Obviously, the 22,300-mile synchronous system would have many advantages (See Metzger and Rau, this issue). There seem to be no particular advantages in a space system operating at heights between 10,000 miles and 22,000 miles, which may not be obtained at heights between 4,000 and 10,000 miles, or by use of the synchronous vehicle.

By using Cape Canaveral as the firing point and without post-firing flight correction, a 30° inclined plane from the equator can be assumed. At this inclination the problems of computing and tracking are still relatively simple. Additionally this inclination provides adequate coverage for regions above 70° North or South Latitude where only a limited amount of communication is to be expected. This cannot be provided by an equatorial medium height system. The polar orbits provide maximum coverage in the regions where it is least required.

In broad terms, satellite relay systems

Table I — U. S. Government Groups Active in International Space Telecommunications

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Responsible in the space field for the many activities of which telecommunications is only one aspect. NASA also coordinates the civilian activities in this field.	FEDERAL COMMUNICATIONS COMMISSION Concerned chiefly with regulatory functions in connection with the establishment, operation and use of space communications systems. Relay via satellite is regarded as another subsystem of telecommunications along with h-f radio, land lines, submarine cables, etc., within the U.S.A. which are now regulated by the FCC.
DEPARTMENT OF STATE Establishes policy and handles many international coordination problems.	USA COMMITTEE OF THE CCIR Aids the ITU in the development and international utilization of the space medium by preparing the framework of basic scientific data and other information concerning the use of "space" for telecommunication.

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Table II — Operational Space Communications Problems

Frequency Assignment Factors

Freqency spectrum assigned to Space Communications

Bandwidth of each transmission assignment

Frequency tolerances

Frequency sharing between space systems and ground services

Type of modulation and frequency characteristics

Doppler effects between transmitter frequencies and apparent speed of space vehicle

Natural Phenomena Considerations

Laws of gravity related to rocketry and vehicle placement

Faraday effects

Signal propagation parameters

Atmospheric and ionospheric effects

Line-of-sight functions

Practical Engineering Aspects

Height and eccentricity of orbits

Location of orbit (polar, equatorial, inclined, etc.)

Earth motion relative to orbital planes

Number of orbital planes required

Number of vehicles required for continuous service

Field of view of vehicles at different heights

Ground range of vehicles at different heights

Avoidance or elimination of atmospheric effects

Thermal noise

Long distance circuit problems such as may exist between semi- and full-antipodean locations

Doppler compensation techniques

Speech circuit time delays and echo suppression

Maintenance of signal phasing in satellite handover in non-synchronous orbital systems

can be polar, equatorial or inclined in plane with circular or elliptical orbits and at low (under 4,000 miles), medium (4,000 to 12,000 miles), or synchronous (22,300 miles) in height.

Arbitrarily selecting values from these broad categories, a space system in a circular orbit, inclined 30° from the equator at 6400 miles (4-hour revolution period) has been chosen to develop further considerations.

An inclined (30° from equator) circular orbital system at a height of 6400 miles would have a field of view of approximately 135° and a ground range of approximately 9700 miles. Reducing these values to correct for a minimum elevation angle of 7½° for the antenna the figures then become 120° and 8400 miles, respectively. The period of revolution is 6 hours, or 360 minutes. The earth advances 90° in this time; therefore, the apparent period of revolution is 8 hours, or 480 minutes. (Three apparent passes per day.)

Time of visibility can be derived as follows:

$$\frac{\textit{Field of view}}{\textit{Circum. of earth}} \times \frac{\textit{Rev. period}}{1} = \textit{Visible time, or}$$

$$\frac{120°}{360°} \times \frac{480 \text{ mins.}}{1} = 160 \text{ mins. per pass}$$

For times of mutual visibility at two locations, terminals of an east-west circuit, on the same line of latitude:

$$\frac{\textit{Field of view} - \textit{Lat. separation in degrees}}{\textit{Circum. of earth}} \times \textit{Rev. period} = \textit{Time of use per pass}$$

Taking a practical example of a circuit between Belem, Brazil, and Quito Ecuador, both very close to the equator and separated by about 2800 miles and approximately 40° in latitude:

$$\frac{120 - 40}{360} \times \frac{480}{1}$$

$$= 106 \text{ minutes circuit time per pass}$$

Also using Quito, 79° W. longitude, as one terminal but selecting Valdivia, Chile, at approximately 74° W. longitude as the second terminal with only a 5° separation:

$$\frac{120 - 5}{360} \times \frac{480}{1} = \frac{115}{360} \times \frac{480}{1}$$

$$= 153 \text{ minutes of use per pass}$$

The two circuit examples above bring out an important fact. To Belem from Quito the time period is 106 minutes, to Valdivia 153 minutes. If large world centers such as London and New York, with very many circuits instead of only two are considered, the problem of keeping full continuity on each circuit becomes a large one even though the orbital patterns are easily computed and each vehicle easily found and tracked, since the number of handovers will vary widely.

The following examples are arranged in geographical groupings (Table III) to show one possible method of arranging ground equipment to obtain the longest common usage, without handover, for each grouping.

To depict the passage of time, it is assumed that the satellite passing over the 180° time-line will be at *0* time and in the column (Table III) headed *acquired*, the figures indicate the number of minutes after the passing over the time-line at which the eastern-most station acquires the satellite. Similarly, the column headed *relinquished,* indicates the number of minutes above zero at which one of the two stations (paired) loses the satellite. The last column gives the usable time per pass for the circuit.

Expanding the times given in Table III, the following "around-the-earth" ground siting would provide a good pattern of usable time (shown in minutes):

San Francisco—New York, 93
New York—Sao Vicente, 95
Sao Vicente—Johannesburg, 90
Johannesburg—Bombay, 100
Bombay—Malaya, 96
Malaya—Sydney, 116
Sydney—Honolulu, 93
Honolulu—San Francisco, 113

Two seemingly minor problems have generated a great deal of discussion: the time delay of a voice signal traveling over long space circuits, along with the associated problems of echo suppression, and the difference in the phasing of signals when repeated from two satellites to the same ground station. Only the latter is important in telegraph transmission.

When the two vehicles are equidistant from the ground station, there will be matched phases. For each 186 miles difference in distance, there will be a phase difference of 1-msec. Present h-f radio operation of a four-channel time-division multiplex (200-baud keying rate) regards multipath of greater amount than 1-msec as a potential source of circuit degradation.

Thus, for orbiting systems with no channel keying at more than 200 bauds, the change from the departing to the upcoming satellite (*handover*) should be made only when the signals are within a phase difference of some value equivalent to the 1-msec multipath tolerance;

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otherwise each teleprinter or other coded transmission channel, possibly several thousand, will be put out of phase. If high-speed computer-type keying is considered, this handover must be made when there is much less of a difference.

This handover problem limits the overall time-per-pass of each vehicle, since there is a very low probability that both satellites would be at the lower horizontal angles simultaneously; therefore, the concept of using each satellite as low as approximately 7½° elevation above the horizon requires reconsideration. It is more probable that elevations of 15° to 20° would be the lower limits of use.

The very complex handover problem in a multiprocess, multicircuit system increases the number of satellites required, or alternatively necessitates more equipment at each ground station, compared with a system where handover is not a problem. Furthermore, it makes the problem of scheduling the times of use at multiple circuit points still greater.

An additional handover problem will exist during those periods when the path of the vehicle crosses the area of thermal noise from the sun. (This transit problem will also be present several days of the year when the synchronous satellite is in the same area as the sun. At each ground station the periods of this type of interruption will not coincide with similar periods at each distant terminal with which it communicates; therefore, these total interruptions would be the number of interruptions at all the interlinked stations.)

Computing the vehicle's path and tracking for equatorial orbits is relatively simple. Semiequatorially inclined orbits are not much more complex. The handover problem for these two orbital patterns, serious as it is, becomes much more difficult when considering semipolar and polar orbits with their very complex apparent motions.

SPACE SYSTEM RELIABILITY

Reliability in its technical sense is an engineering aspect. From the operations viewpoint, the reliability of a space system would be its continuity of circuit maintenance and stability. Because each vehicle will be equipped for large capacity and will be relaying hundreds of voice channels and thousands of teleprinter or other code transmission channels, the required continuity over a long period, e.g., one year, must be better than 99.9 percent (approximately 525 minutes outage per year) and preferably in the order of 99.98 percent (105 minutes outage per year). Of equal importance, is the quantity of outages. No matter how brief an interruption may be (even 20 msec) each recording unit of apparatus must be rephased, or some similar action must be taken, to restore each channel; otherwise the mutilation on all signals must be regarded as a normal condition, thereby accepting a degraded transmission service.

MESSAGE ROUTING

Another item of importance in the operational area is the routing of signals or channels and the use of switching facilities at an intermediate ground station between two circuit terminals. In preceding paragraphs, it was mentioned that most countries prefer to operate their own circuits without depending upon use of connecting links through neighboring countries. However, economics and other factors make it desirable to consider the use of a distant point as a distribution center for small-volume collections of traffic to several other places. For example, an African country would, in the early stages of space communications, find it more efficient to operate into a European center and at that point obtain connecting links outward to North or South America, or may make use of European and North American relay points. Space communications would make it possible for an operating center to expand its direct circuits or to change relay points, if desired, as traffic volume increases.

Planning a pattern of routing and switching for the initiation of a space telecommunications system and for subsequent changes in, and additions to, the initial pattern poses quite an operational problem. Antipodean and almost-antipodean circuits provide an excellent example of routing and of operational problems over the multiple relay path. The projected ITU Inter-American Telecommunications Network[4] can be used to develop an example of an operation pattern for one area of a world-wide "space" network.

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Table III — Contact Times Between Major Cities

Group	Cities	Acquired	Relinquish	Minutes
1	New York—San Francisco (USA)	63	156	93
2	New York—Santiago (Chile)	65	222	157
2	New York—Buenos Aires (Argentina)	82	222	140
2	New York—Rio de Janeiro (Brazil)	101	222	121
3	New York—Sao Vicente (Cape Verde Islands)	127	222	95
4*	New York—Tangier (Morocco)	157	222	71
4	New York—London (Great Britain)	160	222	62
4	New York—Frankfurt (Germany)	177	222	45
4	New York—Johannesburg (U of SA)	197	222	25
5	New York—Rio de Janeiro (Brazil)	101	222	121
5	Rio de Janeiro—Tangier	151	261	110
5	Rio de Janeiro—London	160	261	101
5	Rio de Janeiro—Frankfurt	177	261	84
5	Rio de Janeiro—Johannesburg	197	261	64
6	New York—Sao Vicente	127	222	95
6	Sao Vicente—Tangier	151	287	127
6	Sao Vicente—London	160	287	136
6	Sao Vicente—Frankfurt	177	287	110
6	Sao Vicente—Johannesburg	197	287	90

* If it is desired to limit the number of handovers on the circuits in Group 4, a ground relay station can be established. For example, using either Rio de Janeiro or Sao Vicente the time shown under Groups 5 and 6 would be obtained.

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HOWARD R. HAWKINS joined RCA Communications, Inc. in 1946 as Assistant General Attorney. He became General Attorney in 1949 and Vice President in 1951. He serves as legal counsel for the Company and its subsidiaries, and also is in charge of its regulatory relations. He is a director of the Marconi Telegraph-Cable Company, Inc. Mr. Hawkins was graduated from the University of Indiana with degrees of Bachelor of Science in Public Business Administration in 1938 and Doctor of Jurisprudence with honors in 1941. He was Editor-In-Chief of the Indiana Law Journal in 1940 to 1941 and was elected to Order of Coif. He served with the U.S. Department of Justice, Federal Bureau of Investigation, in Washington, D.C., Connecticut and New York from 1941 to 1946 on assignments, among others, to communications and major security cases. Mr. Hawkins is a member of the bar of the U.S. Supreme Court, State of New York, State of Indiana, U.S. Court of Appeals for New York and District of Columbia, and the FCC. He is on the International Communications Committee of the International Law Section, American Bar Association, and a member of the Association of the Bar of the City of New York and the Federal Communications Bar Association. He served on the Ad Hoc Carrier Committee established by the FCC to formulate plans for commercial satellite communications.

Establishing, operating, and utilizing satellite systems for international communications have novel and complex legal aspects. Even so, these can be resolved largely by reasoned application of basic principles of national and international law. International agreements on frequencies and related matters will be needed. The regulation of these operations will be of common interest to all nations—as with conventional systems—and seems likely to be comprehensive. The legal matters inherent in such regulation will be of continual interest and significance.

SATELLITES FOR INTERNATIONAL COMMUNICATIONS

... Legal Aspects

by **H. R. HAWKINS, Vice President**

RCA Communications, Inc.

New York City, N. Y.

INTERNATIONAL COMMUNICATIONS by satellite systems offer bright promise for future expansion and improvement of global communications. The achievements of science and technology in this field are now being implemented through programs for the establishment of world-wide operational communications satellites. The legal aspects will be significant in such a practical application and use of the new technology.

Satellite relays will provide the long-distance transmission at microwave frequencies essential for greatly increased communications capacity and for television services. As space relays, they will not be through-systems to serve customer to customer needs, nor will they replace submarine cables and conventional radio systems. Hence, these satellites must be integrated with earth stations and also with other national and international communications systems.

These facts bear importantly upon the legal aspects of satellite communications. Present cable and radio communications are already substantially regulated and involve established national and international legal aspects. Many of these legal requirements will be applicable as well to the use of satellites. However, new problems will arise—problems that can be resolved in some instances by the reasoned application of existing statutory law and precedents to the novel factual situation that satellites create, but in other instances will require new international law or agreements.

NATIONAL LAW ASPECTS

United States policy has historically provided for ownership and operation of international communications facilities under government regulation in the public interest. Today, ten United States international carriers furnish international communications services jointly with their counterparts abroad — the foreign government administrations and authorized communications agencies.

Communications Act and the FCC

International communications carriers are regulated in the United States by the Communications Act of 1934, as amended.[1] The Congress set forth a basic policy in §1 of this Act for regulation by the Federal Communications Commission (FCC):

> "so as to make available, so far as possible, to all the people of the United States a rapid, efficient, nation-wide and world-wire wire and radio communication service with adequate facilities at reasonable charges."

The Act provides that no person shall use or operate apparatus for the transmission of energy, communications, or signals by radio within the jurisdiction of the United States, except in accordance with this Act and a license granted by the FCC. Therefore, a person desiring to engage in satellite communications will need a construction permit and a radio license from the FCC. These may be granted upon proper applications showing technical, legal, and financial qualifications, and that the public interest, convenience, and necessity will be served.

The exact nature and form of licenses and frequencies for future earth and space stations may be determined in the light of further international agreements, as will be discussed. Apart from such matters, appropriate terms and conditions reasonably related to satellite communications may be incorporated in station licenses and FCC rules to safeguard the public interest and to effectuate the purposes set forth in §1 of the Communications Act.[2,3]

Present common carrier regulation under Title II of the Communications

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Act will be equally applicable to common-carrier satellite communications, including requirements for just, reasonable and nondiscriminatory charges, practices, regulations, and services.

Antitrust Laws

The antitrust laws of the United States relating to unlawful restraints and monopolies, and to combinations, contracts and agreements in restraint of trade will be relevant. These laws apply to all areas of interstate and foreign commerce except those specifically exempted by the Congress. No general immunity has been granted in the international communications field. The Congress expressly declared in §313 of the Communications Act that the antitrust laws are applicable to:

> "the manufacture and sale of and to trade in radio apparatus and devices entering into or affecting interstate or foreign commerce and to interstate or foreign radio communications."

The Department of Justice is responsible for the enforcement of the antitrust laws. In carrying out the national policy and provisions of the Communications Act, the FCC must give appropriate consideration to the antitrust laws.[5,6]

The related §314 of the Communications Act prohibits the acquisition, ownership, control, or operation by a radio carrier of a cable system, or by a cable carrier of a radio system, in international communications if "the purpose is and/or the effect thereof may be to substantially lessen competition or to restrain commerce" between any place in the United States and any foreign country, "or unlawfully to create monopoly in any line of commerce." The Supreme Court has held that the FCC is entitled "to look at the entire competitive scene and not confine itself to one aspect of it" in applying such provision.[5] The introduction of satellite communications on a basis that would preserve such competition in international communications appears to be consistent with this section.

In the authorization, establishment, and operation of a communications satellite system, the FCC is empowered to act as public interest, convenience, or necessity require in furtherance of the purposes of the Communications Act. Pursuant to §301 of this Act, the FCC may assign bands of frequencies consistent with international allocations, study new uses of radio, and generally encourage the larger and more effective use of radio in the public interest.

In granting licenses for international communications, the FCC is authorized by §308(c) of the Communications Act to impose any terms, conditions, or restrictions authorized to be imposed with respect to submarine cable licenses by §2 of the statute entitled "An Act Relating to the Landing and the Operation of Submarine Cables in the United States." This statute authorizes the granting of a cable landing license "upon such terms as shall be necessary to assure just and reasonable rates and service in the operation and use of cables so licensed."[7]

The basic principles of communications law which will be applicable to commercial communications satellite systems thus have been promulgated by the Congress. The Supreme Court has set forth the proper considerations in applying the criterion of "public interest, convenience or necessity" to international communications. The Supreme Court has held[5] that, among relevant factors in weighing the public interest, is competition which is "reasonably feasible" and "beneficial"—such as for the purpose of "maintaining good service and improving it."

Historically, international communications carriers have generally provided their own radio transmission facilities. However, with respect to communications satellites, this is neither practicable nor possible for economic and other reasons, including the high cost of satellite relays, insufficient traffic among certain of the carriers, inadequate frequency spectrum, and the international implications of orbiting satellites. There is likely to be only one such system for commercial use, at least during the early period of satellite communications. Some joint use is therefore a practical requirement.

Two formal proceedings by the FCC have been focal points for the consideration of legal and similar aspects of satellite communications: *Docket No. 13522*, involving primarily the allocation of frequencies, in preparation for the Extraordinary Administrative Radio Conference of the International Telecommunication Union tentatively scheduled in the latter part of 1963; and *Docket No. 14024*, concerning administrative and regulatory problems looking toward the establishment of a commercially operable satellite communications system.

Communications Carriers and Satellite Suppliers

The legal aspects may affect the international communications carriers which are presently engaged in furnishing international communications services and which intend to provide such services via satellites, other carriers and media of communications which may use satellites, and enterprises which have an interest in or are engaged in satellite research and development or in furnishing equipment for the construction, operation and maintenance of the satellites.

President Kennedy, on July 24, 1961, issued a statement on communications satellite policy, after studies and policy recommendations by the National Aeronautics and Space Council, for the optimum development and operation of communications satellites. The Space Council is composed of the Vice President, Secretary of State, Secretary of Defense, Administrator of NASA, Chairman of the AEC, and certain other members as appointed by the President. It is their function to advise the President on aeronautical and space policies, plans, programs, and accomplishments of all agencies of the U. S. engaged in such activities, and to develop a comprehensive space program.

The President's statement favored private ownership and operation of the United States portion of the satellite system, provided that such ownership and operation meet specified policy requirements. These requirements contemplate that new and expanded international communications services will be made available at the earliest practicable time and that the satellite system will be made global in coverage as soon as technically feasible.

The President's statement also pointed out that: opportunities must be provided for foreign participation through ownership or otherwise in the communications satellite system; present and future authorized communications carriers must have nondiscriminatory use of and equitable access to the satellite system; effective competition, such as competitive bidding, will be required in the acquisition of equipment used in the satellite system; the structure of ownership or control must assure maximum possible competition; there must be full compliance with antitrust legislation and with the regulatory controls of the Government; and an economical system must be developed, the benefits of which will be reflected in overseas communications rates.

The FCC, on July 25, 1961, issued a Supplemental Notice of Inquiry in

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Docket No. 14024 on matters within its jurisdiction, which set forth procedures to govern discussions by international common carriers, through an Ad Hoc Carrier Committee, looking toward joint formulation of a plan of organization or joint venture for the development, construction, ownership, operation, management, and use of commercial communications satellites. The Supplemental Notice specified public interest objectives which any plan of organization and operation or joint venture must accommodate. These objectives are considered factors in the public interest and requirements of applicable communications and antitrust laws.

The FCC specified that a communications satellite system will be expected to provide the potential means for global coverage, ownership of the satellites must be shared with interested foreign governments or communications agencies, and regardless of whether such organizations participate in ownership, they will be entitled to access to the satellites on equitable and reasonable terms.

The FCC also specified that any joint venture of international common carriers must be arranged or structured to prevent any single participating carrier from being in a position "to dominate or control" the development, construction, management, operation, or use of the communications satellite system to the detriment of other carriers whether or not they participate in the joint venture as owners; it must permit future ownership participation by any present or future international common carrier desiring such ownership.

The FCC added that clear and definite provision must be made to ensure that present and future international common carriers, whether or not they participate through ownership in the joint venture, will have equitable access to, and nondiscriminatory use of, the satellite system on fair and reasonable terms for the purpose of obtaining satellite communications facilities to serve overseas points with the types of service for which they are or may be licensed or authorized by the FCC. Further, the FCC stated that adqeuate and effective provisions must be included in any joint venture plan, such as competitive bidding, to ensure against favoritism in the procurement of communications equipment required for the construction, operation and maintenance of the satellite system, and to foster opportunity for continued research and development by all enterprises seeking to compete in furnishing equipment for the satellite system. Finally, adequate accounting and records must be maintained to comply with all applicable laws and governmental regulations.

Pursuant to the FCC action, an *Ad Hoc* Carrier Committee recommended, in a report to the FCC on October 13, 1961, that each U. S. carrier authorized by the FCC to provide communications services via satellites should be allowed to participate in joint ownership of satellites and to establish and operate its own ground stations, participate in joint ownership of ground stations with other carriers, or lease capacity in such ground stations as authorized by the FCC. The Committee recommended also that a nonprofit satellite corporation should be created to develop, construct, operate, manage, and promote the use of communications satellites for the United States interests. It proposed that the satellite corporation have three directors appointed by the President of the United States or by whomsoever he shall designate to make the appointments, two directors designated by each authorized participant in ownership of the satellites and a director designated by the carriers which do not own but may lease satellite facilities.

The FCC has indicated that this report was to serve as a basis, together with other views and information, for further administrative action looking toward the establishment of a communications satellite system.

Several other approaches to satellite ownership and operation have been suggested. These approaches range from government ownership of the satellites, with authorized use by U. S. and foreign carriers through their own ground stations, to various combinations for ownership of satellites and ground stations by communications carriers, aerospace manufacturing entities, and the public.[8]

It appears that alternate approaches to satellite ownership and operation are under consideration and time may be required to resolve in the best manner the complex administrative and regulatory problems that are involved. The international political implications appear to warrant particular consideration.

In the meanwhile, the most important activity with respect to satellite communications should be to speed research and development of techniques, systems and apparatus so that the establishment of an operational system will not be delayed. Substantial research and development projects are being carried forward by government and industry looking toward the launching of experimental active communications satellites in 1962 and 1963.

The Committee on Science and Astronautics, U. S. House of Representatives, has concluded, in a *Report on Commercial Applications of Space Communications Systems,* as follows:

> "The committee advises the encouragement of private enterprise to participate in this development to the limit of its resources, talent, and capacity. However, it is also the view of the committee that because of the many significant questions of public policy raised, and the absence of precedents on which to rely, the Government must retain maximum flexibility regarding the central question of ownership and operation of the system. No final decision should be made during the early stages of development which might prejudice the public interest or U.S. international relations."[9]

As in other regulated public services, the legal aspects which are applicable to the normal conduct of the international communications business will continue to be applicable upon the integration of satellites into international communications operational systems. Satellite communications seem likely to be closely regulated in the public interest after the system becomes operational. Particularly if one or a limited number of satellite systems are established, substantial regulation of operations and use of the satellites is likely to become the primary reliance for the protection of the public interest.

INTERNATIONAL LAW ASPECTS

Legal problems of space exploration have been matters of extensive study and consideration.[10] The United Nations has been the forum for much of such activity as the agency through which general space law could be established to govern the conduct of nations. Principles in other fields which may be relevant include freedom of the high seas, sovereignty of air space, and the suspension of these principles in the doctrine of *res nullius*.

Though international law of space appears in the process of emergence, such law may not crystallize for an indefinite future period.[11]

The Congress has declared that "it is the policy of the United States that activities in space should be devoted to

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peaceful purposes for the benefit of all mankind."[12] On September 22, 1960. President Eisenhower proposed to the General Assembly of the United Nations that nations agree "celestial bodies are not subject to national appropriation by any claims of sovereignty" and that we press forward with "a program of international cooperation for constructive peaceful uses of outer space under the United Nations." Improved world-wide communications was cited as one of the benefits of such cooperation.[13]

Existing international agreements and concepts of international communications indicate that the establishment of world-wide communications satellites need not await the ultimate disposition of the larger legal problems of space exploration. The International Telecommunication Union (ITU), nearly a century old and now a subsidiary organ of the United Nations. has long been the basic organization for the establishment of international communications law and agreements among nations. Through the ITU, international agreements on the use of frequencies, on standards and operating procedures, and on various other telecommunications matters have been formulated and accepted by governments and communications agencies throughout the world.

The Ordinary Administrative Radio Conference of the ITU, Geneva. 1959. recognized satellite communications and allocated frequencies to be used on an experimental basis for such communications. Article 1 of the *Radio Regulations* adopted at this Conference defined space services. earth-space service, space station, and earth station. Such agreement among many nations relating to radio communications constitutes the basis of a treaty. (The U.S.S.R. is a member of the ITU and signed the Geneva, 1959. *Radio Regulations.*)

Preparatory work and further studies of satellite communications are being carried on by organs of the ITU in preparation for the next Extraordinary Administrative Radio Conference. Recommendation No. 35 of the Geneva Conference proposes that such a Radio Conference be convened. in principle, during the latter part of 1963. The Administrative Council of the ITU is to review the situation during its 1962 and 1963 ordinary sessions on the basis of information received from members and associated members of the ITU, the International Radio Consultative Committee, and other interested organizations. Should the Administrative Council decide that there is sufficient justification for the convening of the Extraordinary Administrative Radio Conference in 1963, it will so recommend to members and associate members. Preliminary views of the United States for frequency allocations for space radio communications in preparation for the proposed 1963 space conference have been released.[14]

International law of radio use in outer space can be based upon activities of the ITU. The ITU agreements appear to establish the principle of international law that the operation of satellites for communications purposes constitutes a proper use of outer space.

Though further agreements will be needed to allocate actual frequencies for operational satellite communications on an international basis, the allocation of such frequencies and the appropriate assignment of them to earth and space stations should establish legal rights to engage in satellite communications in accordance with prescribed technical and other provisions of the International Telecommunications Convention and *Radio Regulations.*

President Kennedy's statement of July 24, 1961. indicated that the Government, in addition to its regulatory responsibilities, will conduct or maintain supervision of international agreements or negotiations relating to satellite communications; and it will examine with other countries the most constructive role for the United Nations, including the ITU, in international space communications. The ITU can be an effective forum for the resolution of international legal aspects associated with the establishment and operation of communications satellites.

It is noteworthy that world-wide concepts and patterns of international communications are well established. Those matters not dealt with through the ITU have been largely resolved by separate international agreements entered into directly by United States international carriers and their counterparts abroad. International carrier agreements with government administrations and authorized communications agencies normally cover operating terms and conditions. compensation usually by divisions of revenues and similar matters relating to communications operations. Agreements like these often reflect pertinent provisions of agreements reached through the ITU, which may or may not have treaty status, as applicable terms and conditions of providing international communications. Separate agreements may be entered into as common undertakings by two or more administrations or agencies for the construction and maintenance of communications facilities.

International communications agreements which are developed through the ITU and separately by the communications agencies are generally scrupulously followed, because of the common interests of nations in the maintenance of world-wide communications. These concepts and patterns of international law and cooperation seem likely to continue with the introduction of satellite communications.

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7. 47 U.S.C., §35.
8. See Hearings on *Communications Satellites* before the Committee on Science and Astronautics, U.S. House of Representatives, 87th Congress, 1st Session (1961); and Hearings on *Space Satellite Communications* before the Subcommittee on Monopoly of the Select Committee on Small Business, U.S. Senate, 87th Congress, 1st Session (1961).
9. House Report No. 1279, 87th Congress, 1st Session (1961) p. 28.
10. "Legal Problems of Space Exploration," Senate Doc. No. 26, 87th Congress, 1st Session, prepared for Senate Committee on Aeronautical and Space Sciences (1961).
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12. National Aeronautics and Space Act of 1958, as amended, 42 U.S.C., §2451.
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SYSTEMS SUPPORT ENGINEERING

In modern weapon and space systems, the sophistication of checkout and maintenance problems can approach those of the primary system. Solving such problems is the business of Systems Support Engineering, an activity of the DEP Aerospace Communications and Controls Division in both Camden, N.J. and Burlington, Mass. Their efforts range from study and development of support concepts to the design of hardware—for RCA-produced weapon systems and on direct contract to other companies and the government. [Editor's Note: Credit is due D. B. Dobson, RCA ENGINEER Editorial Representative, for supplying this material.]

SYSTEMS SUPPORT ENGINEERING performs complete support programs for underseas warfare systems, ground-based systems, manned aircraft, strategic and tactical missiles, and spacecraft. An additional capability is the design and construction of personnel training simulators; a life sciences group working with the RCA Laboratories, studies and designs of biomedical monitoring devices and life-support equipment for future use by astronauts. Typical hardware programs presently underway are shown in the table. A selection of current papers that have emanated from Systems Support Engineering is presented in the *Bibliography*.

RESEARCH AND DEVELOPMENT PROGRAM

Research and development programs are also being conducted, oriented toward the development of new support concepts, devices, and techniques that can be applied to systems now under consideration by the military and NASA. The increasing complexity of new systems will demand constant attention to changing requirements and corresponding rapid new development of support techniques.

Extensive study programs are in progress to predict the support requirements of typical future spacecraft and weapon systems. In life-sciences, comprehensive investigations are being conducted for biomedical equipments, life support devices, in-flight monitoring of astronaut performance and physiological behavior, and the simulation and training devices which are necessary to assure human safety and survival.

GREATER RELIABILITY

In achieving an ever greater reliability, new techniques are being developed to predict failures and to "heal" malfunctions before they cause system degradation. Advanced methods are being studied and established which increase the ratio of useful service time to training time for short-term military personnel, and remote control devices are being developed to replace the human element wherever possible.

ADVANCED TEST TECHNIQUES

An advanced test-techniques program continues to assure RCA's lead in the automatic test systems. More-sophisticated computational capabilities and computer-controlled machines are already in the design and fabrication stage. The DEE family of automatic evaluation equipment will continue to satisfy the test demands from the most moderate requirement to the most complex computer-controlled systems.

Continuing emphasis is given to standardization of equipment and the use of the "Erector-set" or "brick-and-cinder-block" concept. The successful implementation of this concept has made it possible to instrument an electronic test system with only those stimulus, measurement, and control building blocks actually required for the intended test application. Electronic building blocks (available designs), can quickly be added, substituted, or removed, so that each system can be updated at low cost and incrementally expanded to meet additional test tasks or increased work-flow rates by the interchange of building blocks. Such test systems avoid a high rate of obsolescence.

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SYSTEMS SUPPORT PROGRAMS

Dynamic Accuracy Test System, (DATS) • A checkout system for the MC-10/F-102A Interceptor

The Digital Evaluation Equipment (DEE Family). Applied to industrial test equipment for the Camden Defense Plant and Letterkenny Ordnance Depot • 5th echelon support for Army Missile Systems • Signal Corps Depot at Tobyhanna.

Automatic Programmer and Test System (APATS) • Instrumentation and checkout of DISCOVERER and MIDAS as operated in Lockheed's Space Chamber.

Data Link Test Systems • Checkout Equipment for the Air Force and Navy time-division data link (TDDL)

Homing All the Way to Kill (HAWK) • Missile test system and field maintenance equipment.

Underseas Warfare (USW Support Systems) • Integrated ship electronic checkout systems.

Spacecraft Support • SATELLITE INSPECTOR, MIDAS missile detection and alarm system, Advanced Trainer, DYNASOAR, APOLLO, SLOMAR, BOSS-WEDGE.

Life Sciences • Automatic hypodermic injection device, automatic blood pressure monitor, mechanization of microscopic studies of the Mars surface, study of bio-electronic measurements during space travel.

Communications Satellite Checkout Equipment • (RELAY).

Surround • Study of a spherical (360°) trainer using optical techniques with 90° vertical field of view.

Automatic Programmed Checkout Equipment (APCHE) • A part of the ATLAS launch complex.

Teaching Machines • for training maintenance personnel.

Adapters for North American Basic Automatic Checkout Equipment (BACE) • Used with the Navy A3J.

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Dr. Elmer W. Engstrom

President, Radio Corporation of America

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Dr. Elmer W. Engstrom Elected President of RCA

The RCA engineering and research community can be justifiably proud that one of its pioneer members is now President. The review of his career presented below is of interest to every RCA engineer and scientist; speaking for them, the RCA ENGINEER extends sincere congratulations.

Dr. Elmer W. Engstrom, who joined RCA in 1930, was born in Minneapolis, Minnesota, on August 25, 1901. He received a BSEE at the University of Minnesota in 1923 and then became associated with the General Electric Co., where he was assigned to engineering development work in the Radio Engineering Department. His early responsibilities included work on high-power radio transmitters and development of broadcast receivers. When commercial activity was initiated in sound motion pictures, he was placed in charge of the engineering development and apparatus design.

When the radio engineering and manufacturing activities of General Electric were transferred to RCA in 1930, Dr. Engstrom continued as Division Engineer in Charge of *Photophone* sound-motion-picture apparatus for the RCA Manufacturing Company at Camden, New Jersey. He then took over the engineering responsibilities for RCA's broadcast receivers and continued in this field until he began the organization of a research department, first in the fields of apparatus and systems. Later he was responsible for radio tube research and coordinated this with the apparatus and systems work.

Beginning in the early thirties, Dr. Engstrom participated in the evaluation of television, directing the research toward a practical service. In this, he was responsible for development and construction of apparatus used in field tests and in the planning and coordination which led to the reality of black-and-white television service. Following this, he and his associates conducted research on color television. This resulted in the development of the compatible color television system which RCA pioneered.

Dr. Engstrom was a member of the National Television Systems Committee at the time television standards for broadcasting were established, and was a member of the Radio Technical Planning Board. He was a member of the National Television Systems Committee which developed technical signal specifications for color-television transmission, adopted by the Federal Communications Commission on December 17, 1953.

In 1942, when all the research activities of RCA were brought together at Princeton, New Jersey, Dr. Engstrom became Director of General Research, and in 1943, Director of Research of RCA Laboratories. On December 7, 1945, he was elected Vice President in Charge of Research of the RCA Laboratories Division; on September 7, 1951, he was elected Vice President in Charge of RCA Laboratories Division; on January 11, 1954, he was elected Executive Vice President, RCA Laboratories Division; and, on June 4, 1954, he was also elected Executive Vice President, Research and Engineering. On October 21, 1955, he was appointed Senior Executive Vice President of RCA.

During World War II, Dr. Engstrom was responsible for research in the fields of radar, radio, air-borne television, electronics, and acoustics.

The honorary degree of Doctor of Science was conferred on him in June 1949 by New York University. On March 23, 1960, Dr. Engstrom was awarded an honorary Doctor of Laws degree from Findlay College, Findlay, Ohio. An honorary Doctor of Laws degree was also awarded to him from Rider College, Trenton, New Jersey, on June 4, 1961.

In August, 1949, Dr. Engstrom received the *Silver Plaquette* of the Royal Swedish Academy of Engineering Sciences. In October, 1950, he received the *Outstanding Achievement Award* gold medal from the University of Minnesota for "pioneering in television research." He received the *Fall Meeting Award* for 1952 of the Institute of Radio Engineers and the Radio and Television Manufacturers Association. The *Progress Medal Award* was presented to him by the Society of Motion Picture and Television Engineers on October 4, 1955; and, in November, 1955, he was elected a foreign member of the Royal Swedish Academy of Engineering Sciences. On February 11, 1956, he received the *John Ericsson Medal* from the American Society of Swedish Engineers. On May 20, 1958, he was awarded the *Industrial Research Institute Medal* for "distinguished leadership in industrial research." On October 12, 1959, he was a recipient along with Brigadier General David Sarnoff, Chairman of the Board of RCA, and Dr. V. K. Zworykin, Honorary Vice President of RCA, of the *Christopher Columbus International Prize in Communications* for "outstanding leadership in the development and introduction of television." On March 21, 1960, the President of the Republic of Italy conferred on Dr. Engstrom the rank of *Commander in the Order of Merit* of the Italian Republic. On October 20, 1960, Dr. Engstrom received the *Medal for the Advancement of Research* from the American Society of Metals.

The election of **Dr. Elmer W. Engstrom** as President of RCA was announced on Dec. 1, 1961 by Chairman of the Board **David Sarnoff,** following the regular monthly meeting of the RCA Board of Directors. Dr. Engstrom, who has been Senior Executive Vice President of RCA since 1955, succeeds **John L. Burns,** whose resignation as President and a Director of RCA and a Director of subsidiary companies was accepted by the Board on Dec. 1. Mr. Burns, President of RCA since March 1, 1957, will continue to serve the company on special assignments from Chairman Sarnoff.

General Sarnoff will continue as Chairman of the Board and Chief Executive Officer of RCA, the position he now holds. Dr. Engstrom will have supervision of all company operations and will report to the Chairman.

Dr. Engstrom is a member of the Board of Directors of RCA and of its subsidiaries, the National Broadcasting Company, Inc., and RCA Communications, Inc.

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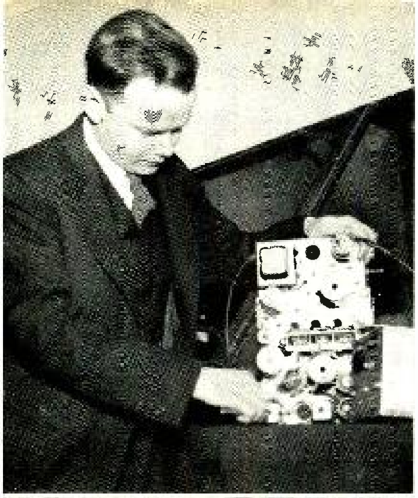

. . . 1934

Dr. Engstrom and a radio receiver in a Camden Laboratory.

. . . 1950

Dr. Engstrom with an early developmental color kinescope.

. . . 1961

Dr. Engstrom and a model of a synchronous satellite of the type proposed by RCA for global communications.

Dr. Engstrom is a member of the Defense Science Board, Office of the Secretary of Defense, Washington, D.C., and a member of its Executive Committee. He is a member of the Advisory Committee of the Research Division of the College of Engineering at New York University. He is Vice Chairman of the Hoover Medal Board of Award for 1962. He is a *Fellow* of the Institute of Radio Engineers, of which he was a Director in 1949, and he has served as a member and as Chairman of the IRE Awards Committee and as a member of its Research Committee. He is also a *Fellow* of the American Institute of Electrical Engineers and has served as a member of the Lamme Medal Award Committee. He is a member of the Board of Governors of the American Swedish Historical Foundation. He is a member and past President of the Princeton Chapter of Sigma Xi, science honor society.

Dr. Engstrom was for several years Chairman of the Research and Engineering Advisory Panel on Electronics in the Office of the Secretary of Defense. He was a member of the Research and Development Committee of the National Security Industrial Association and was Chairman of its Visiting Committee to the Naval Research Laboratory. He was a member of the AIEE Technical Advisory Committee to the National Bureau of Standards and a member of the Advisory Council to the Department of Electrical Engineering at Princeton University. Dr. Engstrom has also been a representative to and a past President of the Industrial Research Institute. He has served as a member of the National Association of Manufacturers Committee on Research.

Among many civic activities, he has served as a member of the Department of Radio and Television, Presbyterian Church, U.S.A. Dr. Engstrom resides in Princeton, N.J.

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A REPORT ON TIROS II AND III

by **G. H. CORRINGTON, Ldr.**
Engineering Project Systems
Astro-Electronics Div.
DEP, Princeton, N. J.

Fig. 1—Upper right: TIROS III. Arrow: magnetic attitude control wound around base. Note omnidirectional infrared sensors at sides, and TV cameras (RCA trademark)—Background is Hurricane Anna photographed by TIROS III during its 117th orbit. This photograph was stored on magnetic tape and transmitted to the Pt. Mugu, Calif. TIROS Station during the 113th orbit. Hurricane Anna was 200 miles north of Caracas, Venezuela in this photo.

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The noteworthy success of the TIROS satellites is an important achievement of RCA engineering at the Astro-Electronics Division, as well as for the nation's over-all space effort. TIROS I, described in detail in the Feb.-Mar. 1961 RCA ENGINEER[1,2] initiated this series of successes, which now includes TIROS II and III. While the three are basically similar 260-pound-plus payloads placed in near-circular, 400-mile-high orbits by Thor-Delta vehicles. TIROS II and III have involved operational refinements and additional instrumentation. Additional TIROS launches are planned, all as prelude to more-sophisticated, second-generation meteorological satellites such as NIMBUS, components of which are now under development at AED.

SHORTLY AFTER the successful launch of TIROS I on April 1, 1960, AED was awarded a contract by NASA to modify and test the TIROS satellites fabricated as back-up models for the TIROS I launch. One modified version of TIROS I thus was orbited as TIROS II on November 23, 1960. Then, under another NASA contract (No. NAS5-936) AED modified the remaining TIROS II back-up models to create TIROS III, which was orbited on July 12, 1961. Although TIROS I met the great majority of its primary and secondary objectives[1,2], as did TIROS II and III, the modifications in each program refined and improved performance.

TIROS II

TIROS II was orbited with the following refinements: electromagnetic control of the spin axis orientation; the addition of NASA infrared equipment; and improved position-reference and telemetry subsystems.

Electromagnetic Attitude Control

One of the major additions to TIROS II (and III) was a 250-turn torquing coil wrapped around the periphery of the satellite (Fig. 1). This provided limited control in changing orientation of the spin axis to obtain optimum performance of the infrared subsystem, the TV cameras, and the power supply.

The torquing coil controls attitude by generating a magnetic dipole within the satellite which interacts with the earth's magnetic field to develop a predictable torque which causes a precession of its spin axis. TIROS I, with its residual dipole, provided some of the data used in designing the attitude control, and further extensive analysis and tests using a magnetic test fixture (Fig. 2) provided the remaining information. The resulting design provided magnetic fields of variable polarity and varying strengths to a maximum of about 3 amp-turns/m^2. The programming of the magnitude, direction, and duration of the current through the coil was controlled from the ground through attitude calculations made from position reference data.

NASA Infrared Equipment

To provide data on the radiations reflected and emitted by the earth and its atmosphere throughout the complete orbit, the TV equipment on the satellite was complemented by an infrared subsystem added to TIROS II to provide heat maps. Heat data was computer-processed and then either tabulated or automatically plotted on isothermal maps.

The NASA infrared experiment consisted primarily of two radiometers, a tape recorder, a transmitter, and the associated electronics and controls (Fig. 3). Timing information and correlation between the NASA package and the TV subsystem was provided in the following manner:

1) A revolution counter pulse from a sensor mounted on the periphery of the satellite was triggered by the sun to provide spin-rate data.
2) A shutter pulse from each camera provided a reference for infrared and TV data correlation.
3) A real-time pulse sent from the ground station just prior to infrared playback provided a correlation of all data.

One of the two radiometers used in the experiment was a five-channel scanning radiometer with a 5° field of view at an angle of 45° with the spin axis. The five sensors (controlled by a chopper arrangement) alternatively looked through the baseplate and then through the side of the satellite, and therefore always had a reference temperature of outer space as a calibration. The ranges (in microns) of the five channels were:

6.39±5%	radiation from the earth's water vapor
0.55—0.75	visible spectrum for reference purposes
0.2— 5.0	earth's albedo or reflected sunshine
7.0—30	earth's total emitted radiation
8.0—12.0	atmospheric window; emission from the surface or

The second radiometer was a nonscanning infrared instrument that sees a wide field (approximately 30°) through the satellite base parallel to the spin axis. It contained two detectors covering the following ranges: *black cone*, 0.2—50 microns (the earth's total reflected and thermal radiation); *white cone*, 5—30 microns (the earth's thermal radiation). Using sum-and-difference techniques, the earth's heat balance could thus be studied.

The radiometer data then frequency-modulated subcarrier oscillators whose output was continuously recorded on endless-loop magnetic tape during the complete orbit, along with telemetry and timing information (Fig. 3). During the ground-station contact, the information was played back at a 30:1 accelerated rate and relayed to the ground by FM transmitter. The information recovered was from the previous 100 minutes of orbit. The temperature resolution of the subsystem was approximately 2° C.

Position Reference Improvements

Attitude information from TIROS I was received in digital form. However, extraneous triggering of the subsystems was occasionally caused by cloud transitions, thereby blocking the signal from the earth-sky or sky-earth transition. For TIROS II and III, this problem was removed by changing the digital system to an analog system. The analog output allowed the ground station to select the desirable pulses by gating techniques, thereby providing a much more stable and accurate attitude signal.

Telemetry Subsystem Improvements

Telemetered information received from TIROS I contributed much data concerning the operating conditions aboard the satellite. However, a review of this data indicated that more useful information could be obtained by replacing some data points of limited value with more important information, by using a more precise calibration technique and by providing for emergency restarting of the telemetry.

Additional, more-accurate temperature measurements were made possible by using some of the limited value points and by using selected 30°C range capabilities in place of the 130°C ranges used previously. Since temperatures were quite stable on some portions of the satellite while it was in orbit, the limited-range sensors provided much more accurate data.

A more precise calibration of telemetry parameters was provided by using five calibrated voltages to replace the single point previously used. This gave a continuous linearity check of the entire system. The provision for telemetry restart was included as a method to measure parameters in the satellite in case of failure of the normal automatic readout. This telemetry method also allowed more precise evaluation of the power supply. Voltages were now measured at the end of a pass without additional programming, in addition to normal first-contact voltage measurements.

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Fig. 2—Magnetic Tests of TIROS II.

TIROS III

The mission of TIROS III is to obtain meteorological observations over much of the EARTH, as in TIROS II; but during the period August to October 1961, when hurricanes and tropical storms are most prevalent, emphasis was placed on securing maximum data from such storms. The observations are used, operationally that is, on a real-time basis to locate and track hurricanes, just as TIROS I and II data was used operationally for other types of storm systems. As important as the operational application of the data is the research application of the data to improve and extend the knowledge of the atmosphere and to develop better methods of forecasting the formation, development, and movement of hurricanes and other types of storms.

Since long life was desired for TIROS III, two complete, redundant TV systems were used. Two wide-angle cameras were installed and used rather than the one wide and one narrow angle camera used in TIROS I and II. Other refinements were improved camera circuits, electronic clocks with complete isolation of clock-set systems, plus an additional infrared experiment developed by the University of Wisconsin under a NASA contract.

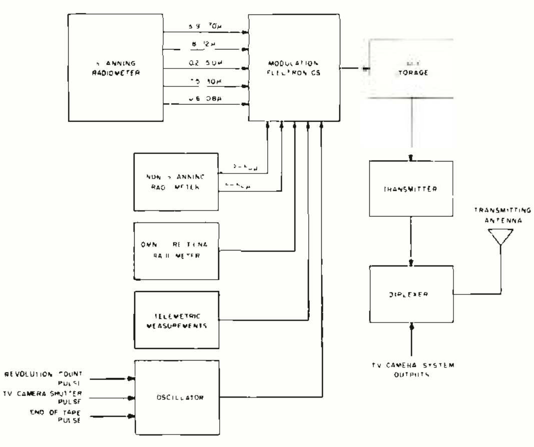

Fig. 3—Infrared equipment.

The desire for a long life justified installation of two identical wide-angle systems in TIROS III. Improved circuits provided a much more stable and reliable operation, such as addition of a dark-current regulator for the vidicon, an improved shutter, and replacement of some transistors with later models. New calibration techniques for intensity levels and spectral response also contributed to the precision of the measurements taken by the cameras.

Improved Clocks for Remote Sequencing

A major improvement in the clocks used for remote sequencing of pictures was made on TIROS III. Mechanical sequencers were replaced by all-electronic sequencers, eliminating the possibility of failure from mechanical wear. This increased the reliability of the timer by more than 100 times.

Additional flexibility and reliability of the two satellite clock systems was achieved by changes in both the satellite and ground stations that permitted setting each clock only during the playback of its previous remote pictures.

The TIROS III ground stations were also changed to provide two sequential, remote, 32-picture, 16-minute cycles—or a total coverage of 32 minutes of remote coverage by the satellite during a nominal 100-minute orbit. This mode of ground-station operation was not previously possible without special programming.

Omnidirectional Infrared Subsystem

In addition to the two NASA infrared sensors carried over from TIROS II, the University of Wisconsin experiment added four sensors to the TIROS III infrared equipment. The very-wideband black and white sensors (two of each were used) of this infrared equipment had a hemispheric shape to provide omnidirectional coverage. Fig. 1 shows the pairs of sensor extended from the payload. Each consists of a bolometer mounted at the top of a 1-inch hemisphere of highly conductive material. The hemisphere is then mounted in the center of a highly polished, flat, 4-inch circular mirror, but thermally isolated from it.

For omnidirectional coverage, a pair of sensors, one black and one white, was mounted at diametrically opposed points on the periphery of the satellite. The extended mounting arms prevented the sensors from seeing the satellite and registering incorrect temperatures. The information obtained from the four sensors was recorded continuously on the NASA tape recorder on a time-shared basis (Fig. 3). Timing information used on the NASA experiment also was used for this experiment. The black sensors measure the sun's radiation, the earth's reflected shortwave radiation, and the earth's longwave reradiation in the infrared (a very wide band). The white sensors measure primarily only the longwave re-radiation from the earth. The combined measurements from the black and white sensors permit deduction of the earth's thermal-radiation characteristics.

CONCLUSION

The success of the TIROS weather observation system has created considerable interest in this method for gathering meteorological data. Because of TIROS success, foreign countries are now participating by gathering more standard supporting types of data, and by making limited operational use of cloud analyses derived from the TV pictures. The data handling processes organized during the TIROS I, II and III will be continued and refined by further TIROS launches during 1961 and 1962, in preparation for a second generation of weather-observation satellites.

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GLENN H. CORRINGTON received his BEE from the University of Minnesota in 1953 and has since pursued graduate work. From 1953 to 1958 he was with RCA-DEP in Camden, first assigned to the Airborne Fire Control Section as Production Engineer on the APS-57 Radar Fire Control System. In addition, he worked on automatic frequency control and i-f amplifiers for radar. He also conducted work in systems engineering on MA-10 Fire Control Radar for the F104 aircraft. Other work involved systems integration and evaluation for Aero-11B Fire Control System and ASTRA Fire Control, navigation and communications systems for the CF 105 Aircraft. In 1958, he joined the Astro-Electronics Division in the Electro-Mechanical Design and Reliability group, responsible for system integration and evaluation for the TIROS I, II, and III Satellites. At present, he is Project Leader for the TIROS IV, V, and VI series. He has performed various aspects of space systems work, including the payload tests for the TIROS launch at Cape Canaveral.

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SYSTEMS, PRODUCTS, AND CREATIVITY

PURSUE A NUMBER of parallel paths of engineering simultaneously. tie them together at appropriate points, and a unified end result is achieved. This approach is characteristic of the design plan frequently applied to Aerospace Communications products.

The framework of such a plan does not preclude engineering innovation and originality — rather, it provides for innovation and originality. In fact, the plan itself *is* the means by which new concepts, new components, and even flights of fancy are reconciled with existing engineering practices and, thus can qualify for use in the end product. *Result:* the state of the art is furthered.

The design plan serves as a stimulus to *creative engineering*. The very term suggests that one of the steps in the creative process is to transform expressed ideas into practical engineering terms and eventually, perhaps immediately, to relate them to the total body of engineering knowledge.

When pursuing the parallel engineering paths and tie-points, both product and system-design planning have much in common. For example, the modern black box is often a microsystem. and the system subassemblies of today may well become the micromodules of tomorrow. These similarities stimulate a free interchange of design planning and project control techniques between the two areas. Under the circumstances, it is no mere coincidence that the plans of the systems engineer bear such a striking resemblance to the product design evolution of the *flight display* described in this article.

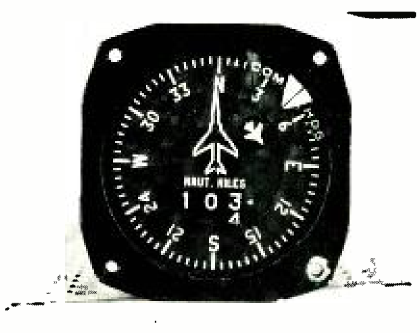
EXAMPLE OF A PLANNED PRODUCT: THE BEARING-HEADING INDICATOR

To emphasize the structure of the plan, technical detail and complexity are omitted in this paper in favor of simple sketches showing an engineering product-design program of modest proportions. The brief product description below introduces the photos and charts and shows that even in a modest program there is room for innovation.

The *bearing-heading indicator* (Fig. 1) is an air-borne display developed for use with the RCA time-division data-link (TDDL) digital-communications system. Prior to high-speed digital communications, military intercept missions were directed by voice over the ground-air command radio link. Today, in an air-defense system such as SAGE, or eventually in a civil air-traffic-control communications system such as AGACS,

by **M. HOLBREICH**
Aerospace Communications & Controls Div.
DEP, Camden, N.J.

Fig. 1—The bearing-heading indicator.



digital outputs of ground-based flight-path computers are transmitted directly to large numbers of flying aircraft via TDDL and displayed on such devices as the bearing-heading indicator.

Military versions of the indicator accept outputs of the airborne digital receivers and the magnetic compass and display them as 1) *aircraft heading*, 2) *command heading*, 3) *target bearing* and, 4) *range*. By "flying" the command-heading pointer on the indicator, the pilot of an interceptor guides the aircraft to the target area where the fire-control system takes over to complete the mission.

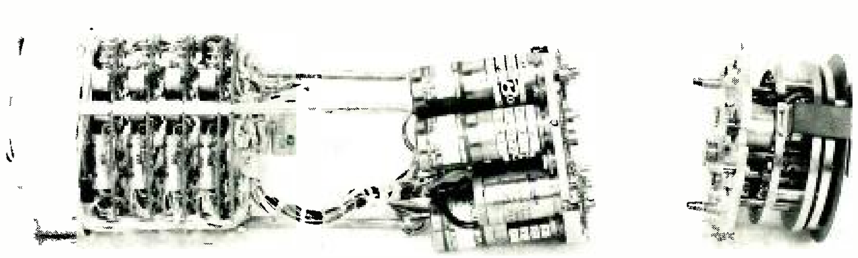
The bearing-heading indicator is housed in a standard 3-inch aircraft instrument case, hermetically sealed for protection against extreme environments. It contains four electromechanical servomechanisms which position visual displays in response to analog signals. Economy of manufacture and ease of maintenance are provided by a separable construction based on three subassemblies (Fig. 2): one completely electronic, the second with all electromechanical components, and the third a mechanical display head.

The electronic portion is represented principally by the servo amplifiers and associated circuit elements. An example of innovation in this area is a new concept related to servo operation wherein a single resistor replaces an earlier circuit consisting of three transistors, four capacitors, seven resistors, and a transformer.

In the electromechanical area, utilization of a new servo motor is one noteworthy innovation. With the application of this small device (1 inch long by ¾ inch in diameter), a stable servo loop without rate-feedback was developed and tachometers found in earlier instruments were eliminated. Through similar innovation, the whole electromechanical complex of servo motors, gearing, resolvers, synchros, and multiturn potentiometer was significantly simplified.

In the mechanical area, both wrought and cast-metal parts are used; components include ball bearings, internal and external spur gears, bevel gears, intermittent-motion mechanisms and a miniature differential small enough to fit in a thimble. Utilization of a new differential and development of an over-all hermetically sealed instrument enclosure are examples of innovation. In addition,

Fig. 2—Subassemblies: (l. to r.) electronic, electromechanical, and mechanical.



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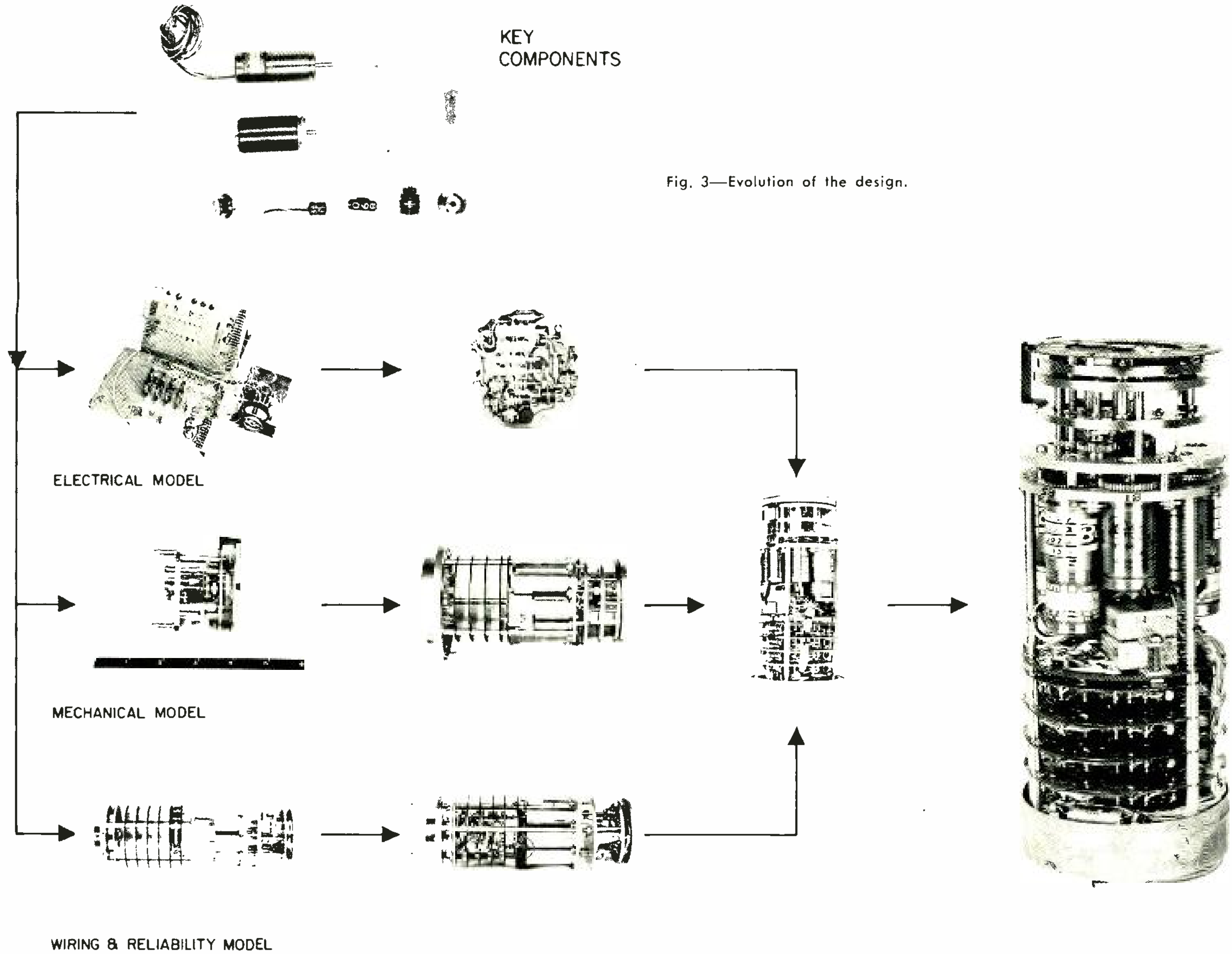

Fig. 3—Evolution of the design.

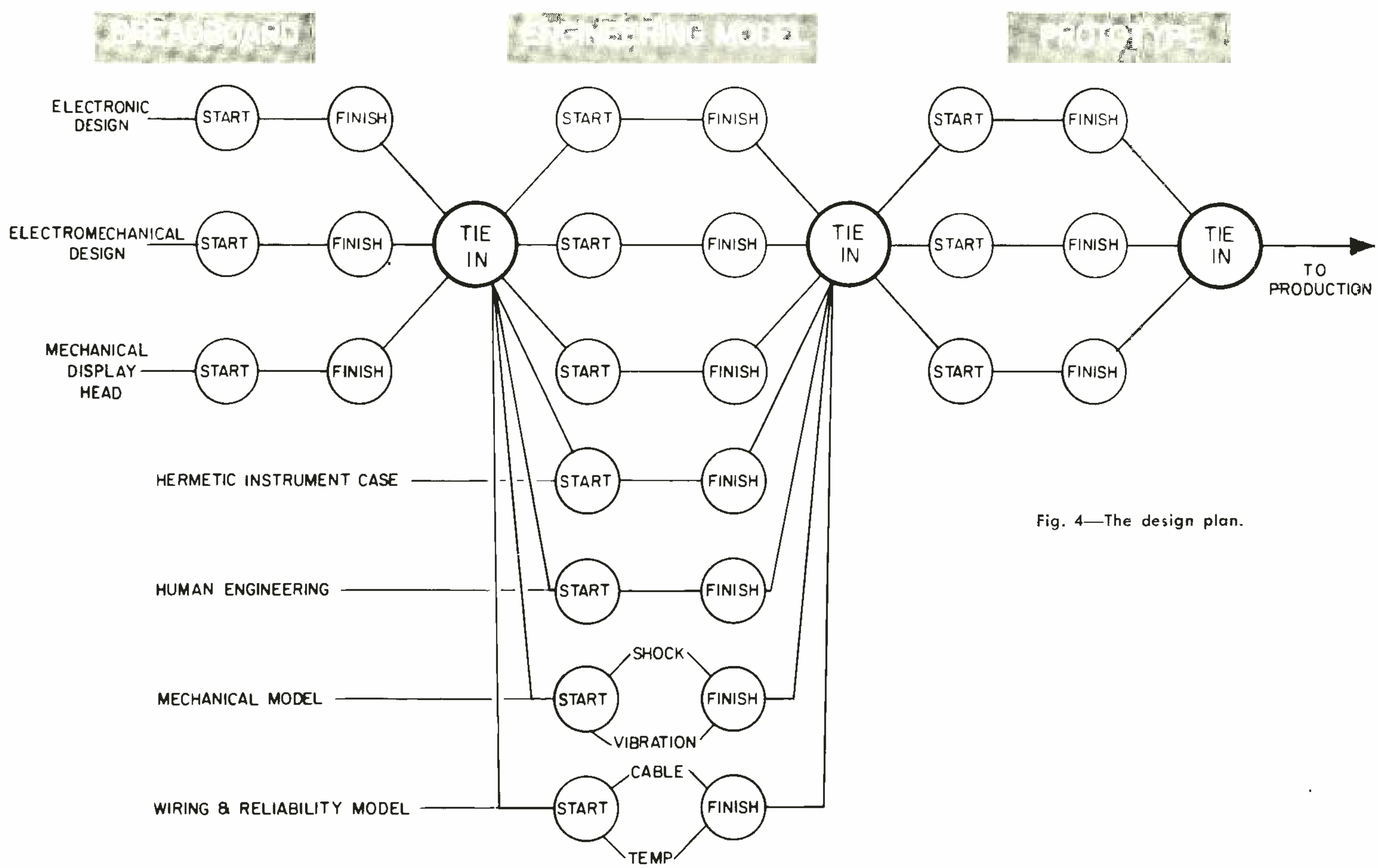

Fig. 4—The design plan.

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the display presentation was made something more than a carry-over from the past by enlisting the services of a human-engineering group and an industrial designer in developing an easier-to-read visual indicator for the pilot, thus lessening chances of reading errors and improving operating reliability.

The sum effect of many integrated innovations such as these is an improved, more reliable product — the result of carefully planned work to reconcile engineering originality with established design discipline.

DESIGN EVOLUTION

Evolution of the bearing-heading display is shown in Fig. 3, illustrating the progress from breadboard to engineering model, and thence to production prototype.

Design progress is based on the parallel flow of three types of study representation: an electrical unit, a mechanical unit, and a wiring and reliability unit. To conclude the engineering model stage, the three parallel paths were drawn together in a single operating unit. Refinement of the design was then completed in the production prototype to demonstrate the adequacy of the manufacturing drawings and verify the reproducibility of the design.

In addition to the three main paths of activity, many subordinate paths were followed in parallel and scheduled for completion at appropriate times. Examples of these parallel pursuits are the development of the hermetically sealed instrument case and the human-engineering evaluation of the display presentation.

To achieve the design goals in the specified time, the various areas of design were pursued simultaneously. The electrical model was used by the electronic engineers to develop the servo loop in conjunction with its mechanical load; the mechanical model was used by the mechanical engineers to develop the display mechanism and verify details of construction; the wiring and reliability model was used cooperatively by both electronic and mechanical engineers to evolve the packaging configuration, arrange cabling, anticipate assembly problems, and with the addition of dummy resistive heat loads, predict temperature distribution within the assembly. Thus, independent parallel activities, drawn toward a common goal by realistic models, made it possible to concentrate all the necessary engineering effort within a short calendar period.

A DESIGN PLAN

The approach to a new product presents an engineering problem; the design plan is simply the program to solve that problem. Thus, a design plan motivates the evolution of a design. The resemblance between Fig. 4 and a logic diagram is striking (one can hardly look at a "tie point" without thinking of an *and* gate). Computers will play ever greater roles in both conception and execution of design plans of the future. (See Nupp article on PERT, this issue.)

A much abbreviated version of the bearing-heading indicator design plan is represented by Fig. 4. With time for a reference, the plan is related to schedules, financial controls, manpower loadings and system commitments. The number of parallel paths and secondary tie-points might be expanded indefinitely to include such items as special engineering test equipment, component development, reliability and value analysis. Steps can be subdivided and events added at either end. For example, the breadboard might be preceded by preliminary design and advanced development. However, the lines drawn here represent the typical case since from the standpoint of progress and control, the breadboard with its preliminary components and schematics is the first concrete step in the direction of a product design. The final prototype with its accompanying documentation signifies the conclusion of the product design.

INNOVATION

The design plan is precisely a program of anticipated or planned events; the most significant are in the nature of experiments intended either to verify analytical predictions or to reveal previously unexplored relationships. *By this definition it is a program for purposeful, planned team activity and at the same time a means to creative engineering in product design.*

The element of discipline in the plan is obvious; the element of creativity requires some explanation. An ideal product, like an ideal formulation, consists of known things combined in known ways to obtain a predictable result; the more complete the knowing, the more certain is the prediction of behavior. Experiments that verify the characteristics of new design elements, or reveal the behavior of "dreamed-up" or analytically determined configurations, are a means of *making known*—hence, an avenue to creative engineering and originality in product design.

The originality in a highly articulate pinball machine is superficially apparent. Like a circus sideshow, teeming with motion, flashing lights, noise, color, and promise of treasure, its very purpose is to attract and enthrall. By contrast, the unpretentious engineering accomplishments in a highly refined electron microscope or solid-state device are recognized only with painstaking study. Even more subtle, perhaps hidden forever, are the thought and the planned experiments behind the integrity of the product, its simplicity, reliability, and maintainability, its manufacturability, and its value in terms of function versus cost. Yet these very things are the substance of the design plan, the schedule, and the engineering cost estimate.

CONCLUSION

It is frequently said that "science makes it known; engineers make it work" (by combining known things in known ways to obtain predictable results). Therefore, engineering creativity must consist of participating in the business of *making known*. A planned combination of analytical and experimental engineering techniques overcomes obstacles, introduces originality, and stimulates innovation.

ACKNOWLEDGEMENTS

The author wishes to acknowledge L. Pessin, D. S. Hall and B. Atkins whose engineering accomplishments are described in this article.

MILTON HOLBREICH attended Columbia University, where he completed the six-year engineering program consisting of three-years pre-engineering in Columbia College and three years in Columbia Engineering School. He received the degrees of BA in 1939, BS in 1940, and MS in 1941 in Industrial Engineering. His occupational experience has been entirely with RCA: Six months in the engineering training program, starting in June 1941, a year and a half in manufacturing administration, then mechanical engineering design and development to the present, interrupted by a leave of absence, 1943-46, for military duty in the Signal Corps. Mr. Holbreich has worked on commercial equipment as well as military communications systems for both the Navy and the Air Force. Recently, he was Project Engineer for the equipment described in this article.

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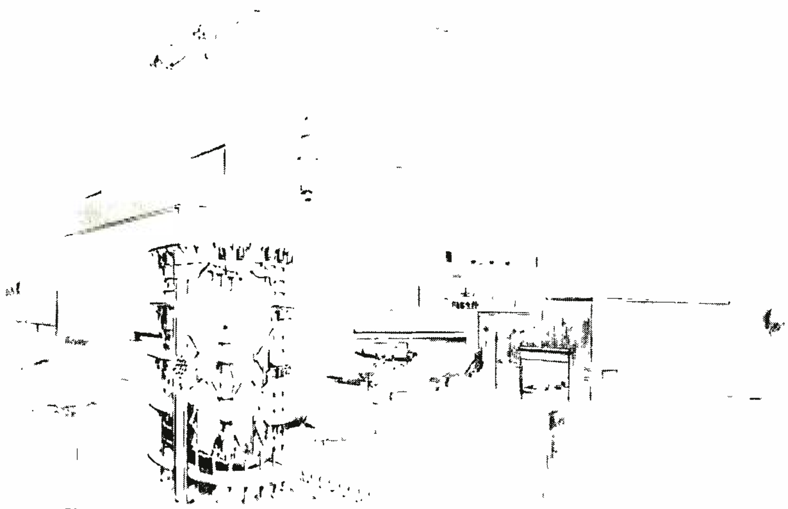

Fig. 1—The USAF Mark I Aerospace Environmental Test Facility.

The Mark I Aerospace Environment Simulator was conceived by the U. S. Air Force[1] to test full-scale space vehicles at the USAF Arnold Engineering and Development Center, Tullahoma, Tenn. The RCA Service Co. was prime contractor for the design and construction of the entire facility, which uses state-of-the-art techniques to simulate space-flight conditions.

THE USAF MARK I

by **H. REESE Jr., Mgr.**
Nuclear and Scientific Services
Government Services
RCA Service Co.
Cherry Hill, N.J.

The Mark I Aerospace Environment Simulator has been designed to simulate space-flight environments of vibration, temperature, pressure, solar radiation (ultraviolet, visible, and infrared), earth radiance, and earth albedo. While these are not the only conditions encountered by space vehicles in ascent and in orbit, they do represent conditions of prime importance which can be simulated at reasonable cost. The Mark I is intended primarily for military satellites such as Midas, Samos, Advent, and Satellite Inspector.

The simulation of space conditions of high vacuum and temperature by the Mark I will allow study of these two prominent causes of satellite failure. High vacuum can cause adverse overheating from lack of convective cooling, bearing failure due to the vaporization of lubricant, and decomposition of materials caused by outgassing. The temperature of a satellite can vary over extremely wide limits, since it both radiates to space, which acts as a thermal sink at about 4°K, and receives heat from the sun, which represents a black body in the visible and infrared range at 6000°K. It is thus quite easy to have equilibrium temperatures far out of the more normal temperature range of military standards for components, for example 220 to 340°K.

In addition, conditions for which there is now little quantitative information will be simulated: real-time variation in atmospheric pressure due to ascent from sea level to an altitude equivalent to a pressure of 30 mm-Hg; vibration from the booster coupled through adapters; buffeting at Mach I; vibration from last-stage ignition (little air damping because of altitude); and degradation of surfaces due to solar radiation (primarily ultraviolet).

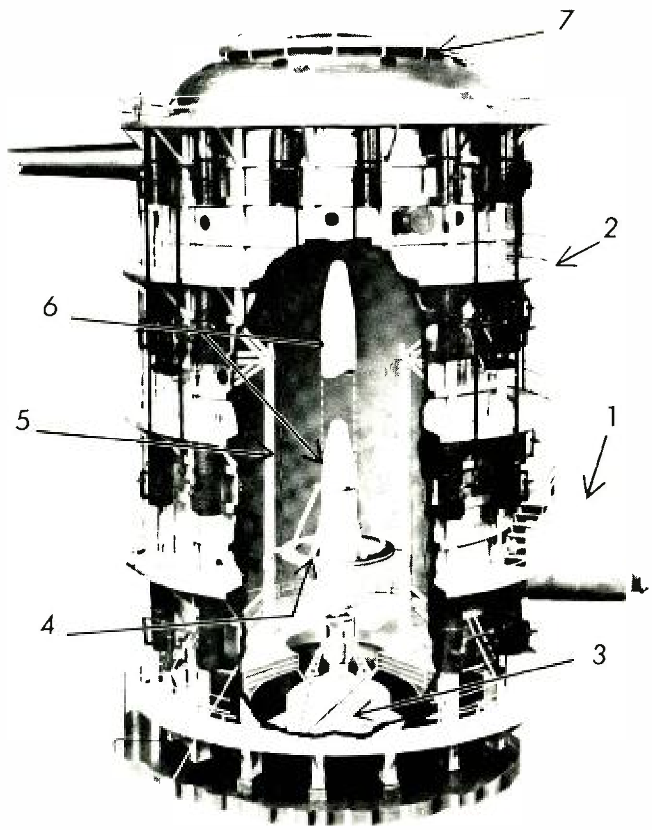

Fig. 2—Cutaway view of the vacuum chamber, which is 42 feet in diameter and 82 feet high. Some of its features are (see text for details): 1) air lock for future personnel access to the evacuated chamber; 2) walkways; 3) vibration system; 4) test-vehicle support ring, which includes gear for simultaneous rolling and pitching of the vehicle during tests; 5) screw-jocks for raising vehicle; 6) test vehicle attached to the vibrator (bottom position) for ascent simulation, and shown in phantom raised into the orbital simulation position; 7) 20-foot-diameter lid, removable for insertion of test vehicle.

THE HIGH-VACUUM SPACE CHAMBER

The building to house the Mark I facility will be 170 feet high, including 48 feet below ground (Fig. 1). Of its total volume of 1.5 million cubic feet, about half is open space to accommodate the

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large vacuum chamber (Fig. 2), 42 feet in diameter and 82 feet high. Construction is fairly standard, except that the basement concrete slab is 7 feet thick. This unusually thick floor must withstand buckling forces caused by edge loading from the building walls, and hydrostatic uplift in the center with virtually no center counterbalancing loads because of the open space required for the vacuum chamber.

Nine floor levels with rooms at the side accommodate mechanical equipment, instrumentation, offices, preparation rooms, calibration facilities, and the control room. A large "clean room," located above the vacuum chamber, will be used to clean vehicles before putting

AEROSPACE SIMULATOR

them inside the chamber so that outgassing of foreign materials is kept to a minimum.

The vacuum chamber will be constructed of 304L stainless steel, ⅞ inch thick. This stainless steel was chosen for low outgassing characteristics, oxidation resistance, and good weldability. *T*-shaped ribs of ordinary steel were placed on the outside of the tank for reinforcement, permitting economies by reducing the wall thickness by more than half.

Although at present there is no plan for access by humans to the evacuated chamber, an 8-foot-diameter air lock, shown in the lower right-hand corner of Fig. 2, has been provided for future use. The air lock will have its own high-vacuum pumping system so that the chamber can be entered when it is operating at 10^{-8} mm-Hg. Test vehicles will be inserted through a 20-foot-diameter lid at the top.

Forty-eight 32-inch-diameter high-vacuum oil-diffusion pumps will be hung on the side of the chamber; mechanical roughing and booster pumps will be mounted on the lowest basement floor. Also shown in Fig. 2 are the six walkways around the tank for maintenance and operating access. Viewing ports are provided for direct visual examination of the vehicle under test. Remotely operated television cameras will also be used to monitor the test vehicle and the inside of the tank. The total weight of the chamber is approximately 350 tons, half of which is stainless steel.

The vibration system is located at the bottom of the chamber, and consists of four 50,000-pound hydraulic shakers and one 5,000-pound electrodynamic shaker mounted on a 200,000-pound reaction block isolated from the building by a spring mount.

Provisions have been made on the side of the chamber opposite the air lock for 77 carbon-arc lamps to simulate the radiation of the sun. These lamps will beam light through sapphire windows to a cassegrainian optical system, transmitting a collimated beam to the test vehicle.

Proper test-vehicle orientation with respect to the "sun" can be obtained by the vehicle handling equipment (Fig. 2). The center support ring has a 12-foot-diameter bearing for rolling the vehicle. Trunnions at the sides permit simultaneous pitch so that most orbital conditions can be simulated. In Fig. 2, a test vehicle is attached to the vibrator. After ascent simulation, the vehicle is raised to the orbital position (shown in phantom) by four stainless steel screwjacks. Attached to this ring, but not shown in Fig. 2, is a bird-cage-like arrangement which contains tungsten filaments and extends the full length of the vehicle. These filaments and their associated reflectors simulate the lower-intensity albedo radiation, as well as the earth's radiance.

The chamber walls will be maintained at approximately 72°K by a pumped-liquid-nitrogen system. Adjacent to the cold wall is a condensing system, or cryogenic pump, consisting of a closed-cycle gaseous-helium system operating at 17°K. The cryogenic pump will consist of 29 arrays (Fig. 6).

Master controls are in the control room at the fifth-floor level, near the top of the vacuum chamber and overlooking the chamber room. Local controls are located throughout the building, but the master control panel can override all local controls. A three-dimensional model in the control room will indicate vehicle attitude at all times. Input tapes to control vehicle attitude and solar lamps will be fed into a tape reader located in the control room, so that a particular predetermined orbit can be simulated.

Monitors for all important parameters, including television for the vehicle, will be included in the control room. Automatic controls are used wherever possible.

VIBRATION

The vibration transmitted to the payload from the rocket engines during ascent is usually greatest at first-stage ignition, primarily from nonuniform burning of the fuel. Most of the ignition vibration at frequencies above 100 cps is acoustically coupled through the atmosphere to the payload, rather than mechanically coupled through the rocket structure. A typical resonant frequency for an adapter (transition structure) between a booster and second stage might be of the order of 50 or 60 cps or less, so that the mechanical transmission of vibration above this frequency would be extremely small. Yet, experiments show that vibration over 1000 cps is present in payloads during first-stage ignition, therefore from acoustical coupling. In simulating such vibration, it is easier and equally effective to mechanically couple the payload to the vibrator, rather than to reproduce extremely high sound levels.

Another period of intense vibration occurs just prior to the time the vehicle passes through Mach 1.0, usually at an altitude of 20,000 to 40,000 feet and caused by atmospheric buffeting. This is very difficult to simulate exactly, but again, effective simulation is achieved by mounting the payload directly on the vibrator. At last-stage burnout, some vibration is usually imparted to the payload which although generally small could be important, since the vehicle is out of the atmosphere and there is no air-damping of the vibration.

To simulate the very large vibration of forces first-stage ignition, the Mark I utilizes four 50,000-pound hydraulically actuated shakers operating over a frequency range of 10 to 700 cps with a total load of 40,000 pounds. Hydraulic vibrators were chosen primarily because of their compactness and economy, since comparable-capacity electrodynamic shakers could occupy inordinate space and would be extremely expensive. The hydraulic vibrator, however, is not useful at high frequencies, since its output drops very rapidly (Fig. 3).

Since last-stage ignition tends to transmit higher frequencies to the payloads because of the tighter coupling between the rocket and payload, an electrodynamic vibrator will provide a force of 5000 pounds over a frequency range of 10 to 2000 cps (Fig. 4). The mechanical coupling between this vibrator and the test vehicle must be kept as tight as possible, with the transition piece between vibrator and test vehicle having as high a resonant frequency as possible. The transition piece will be made of beryllium, to obtain a high modulus of elasticity with a minimum weight.

SPACE TEMPERATURE

It is generally accepted that outer space appears as a heat sink at a temperature of about 4°K. Since most vehicles in orbit operate near room temperature, they will be radiating energy to this heat sink.

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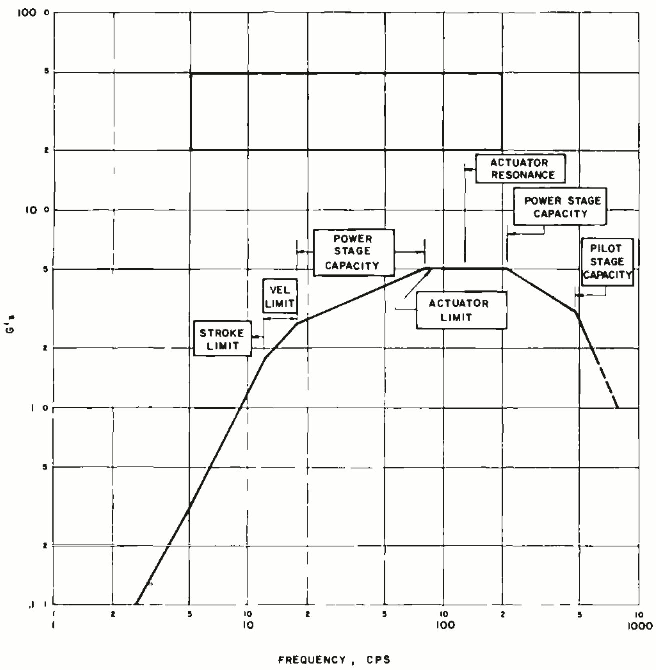

Fig. 3—Factors limiting performance of hydraulic vibrator.

One way to simulate this sink would be to have the entire inside of the space chamber appear as a black body and operate it at a temperature of about 4°K. It would then only be necessary to place a test vehicle in the chamber and observe the effect on thermal balance. However, the cost of such a system would be extremely high: Fig. 5 shows a plot of the approximate cost per kilowatt of a refrigeration plant operating at various temperatures. It can be seen that there is a sharp increase in cost between 50 and 100°K, so that it would be economically advisable to use a chamber wall temperature of approximately 100°K if proper simulation can be obtained. If one calculates the energy radiated from a 300°K body to a 100° surface and compares this to the radiation between 300°K and 4°K, it is found that the difference in radiation is only slightly more than 1 per cent, since the radiation varies as the fourth power of temperature.

The above calculations assume that the cold wall has a uniform temperature and an emissivity of 1.0. If this is not true, the error could be greater. To maintain conditions as nearly as possible to the above, the cold wall will be constructed out of Revere copper *tube-in-strip* (Fig. 6), blackened on one side so that the emissivity is as high as possible. It is expected than an emissivity of at least 0.9 can be obtained. This would not change the validity of the above considerations. The tubes through which liquid nitrogen flows in the tube-in-strip are only 2 inches apart. The high flow rate of approximately 170 gpm will maintain a uniform temperature throughout the wall with little possibility of hot spots.

The actual chamber-wall temperature in the Mark I design is 72°K, since this temperature was easily obtained utilizing a pumped-liquid-nitrogen system. The lower temperature is also very helpful in maintaining low pressures in the chamber.

Fig. 6 shows the cold-wall construction in relationship to the chamber wall. The purpose of the radiation baffle is to lower the thermal loading of the cold wall by reducing the thermal radiation from the chamber wall to the cold wall. By use of the baffle, the radiation heat load is reduced by a factor of three. A cryo pump shield operating at the same temperature as the main cold wall can also be seen in Fig. 6. The purpose of this shield is to prevent direct radiation from the test vehicle and other warm objects in the chamber to the cryogenic pump, which is operating at 17°K. The heat-removing capacity of the system at 17°K is 7.5 kw, and at 72°K is 90 kw. The liquid-nitrogen system will be the recirculating type and will remove heat directly from the chamber, as well as cooling the gaseous helium before expansion for the 17°K system. The low temperatures encountered in the chamber will be measured by a diode temperature-sensing element[3].

SPACE PRESSURE

At pressures encountered by orbital vehicles (10^{-7} mm-Hg and lower), convective cooling disappears, and equipment which operates normally at atmospheric pressure may overheat. In addition, after a prolonged period in orbit, lubricants tend to boil away, leaving surfaces very clean and causing them to cold-weld together. In the case of a bearing, failure would occur.

To simulate these low pressures in the Mark I, the 304L stainless-steel tank will be evacuated by forty-eight 32-inch-diameter oil-diffusion pumps and 8000 square feet of cryogenic pumping surface. The net pumping speed of the diffusion pumps is approximately 1,000,000 liters/sec for hydrogen at 10^{-7} mm-Hg. The pumping speed of the cryogenic system for nitrogen with a chamber wall temperature of 72°K is approximately 25,000,000 liters/sec. The pumping speed will vary depending on molecular weight and temperature of the molecules being pumped. In spite of this high speed for condensibles, the large number of diffusion pumps are required for non-condensibles at 17°K, such as hydrogen and helium. It is expected that the hydrogen outgassing rate of a typical missile may be as high as 700,000 liters/sec at 10^{-7} mm-Hg.

Under normal conditions, the vacuum chamber contains almost four tons of air and will be pumped down from 760 to 30 mm-Hg pressure in approximately 80 seconds to simulate the real-time pressure curve that a satellite would experi-

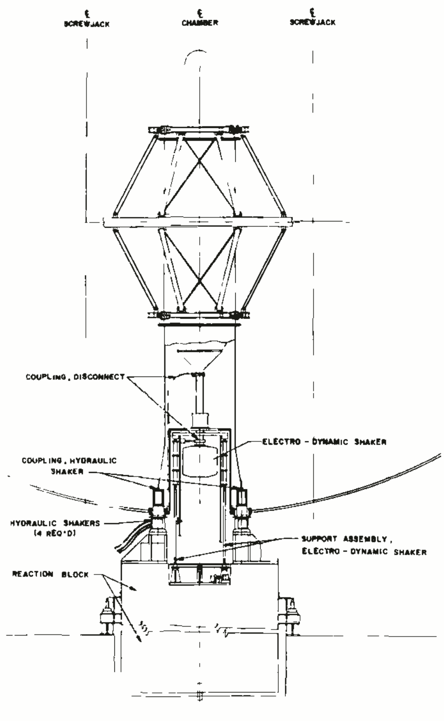

Fig. 4—Vibrator assembly.

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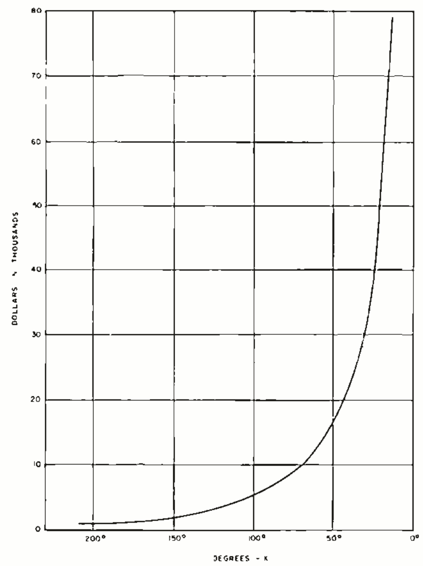

Fig. 5—Refrigeration cost per kilowatt versus temperature.

ence in accelerating through the earth's lower atmosphere. The plenum evacuation system at the Arnold Engineering and Development Center will be utilized as a pump for this purpose. The Mark I chamber will be approximately 800 feet from the plenum evacuation system and will be connected to it through a 7-foot-diameter duct. This duct is then connected to the main roughing lines of the

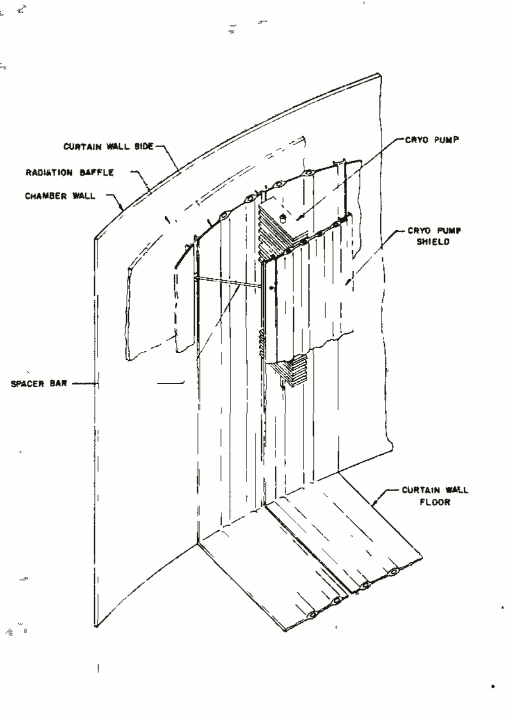

Fig. 6—Vacuum-chamber cold-wall details.

chamber and separated from the chamber by vacuum valves.

Pressure vs. time will be controlled by a large butterfly valve to follow the curve shown in Fig. 7. When the pressure reaches 30 mm-Hg, conventional booster pumps of the Roots type are used, backed up by conventional oil-sealed mechanical roughing pumps. When the system pressure is down to 10^{-3} mm-Hg, the 32-inch oil-diffusion pumps will be energized. When the pressure reaches 10^{-5} mm-Hg, the cryogenic pumping system can then be energized to reduce the pressure to 10^{-8} mm-Hg. It is expected that this entire procedure will take about fifteen to twenty hours.

DIRECT SOLAR RADIATION

The direct solar-radiation power level just above the earth's atmosphere is approximately 1400 w/m^2. Most of the power is included in a spectrum from 0.4 to 3.5 microns. The spectral distribution is represented by Johnson's curve[4] (Fig. 8), which represents the radiation from a black body at approximately 6000°K in the visible and infrared range. The decollimation of the radiation is approximately ½° because of the finite size of the sun.

In a space simulator, it is necessary to simulate the solar spectrum as well as the intensity. The reason for this is that the absorbtivity-to-emissivity ratio is a function of spectrum and, since one of the more important tests is to measure the thermal balance of a satellite, the correct power density should be used at each frequency. The collimation should also be simulated as nearly as possible so that many solar power devices which are dependent on imaging the sum will be capable of operation. The ultraviolet portion of the spectrum between 0.2 and 0.4 microns has a very small percentage of the total power included in it, but the radiation damage effects in this frequency range are sometimes severe and frequently cause changes in the absorptivity-to-emissivity ratio at other frequencies. For these reasons it is necessary to include a source of ultraviolet, although it need not be collimated as well as the spectrum from 0.4 to 3.5 microns. This is fortunate, since the index of refraction of quartz, one of the few known optical materials capable of passing ultraviolet, has an index of refraction which increases rapidly below 0.4 microns and would defocus the ultraviolet portion of a single source for the complete spectrum.

There are two light sources capable of producing the very intense light for solar simulation: the carbon arc and the xenon lamp.

The carbon arc produces the highest intensity of any source (a radiance of 2800 w/cm^2) and consumes about ⅓ inch of carbon rod per minute. Thus, operating costs for long-term tests are fairly high. However, it closely simulates the Johnson curve (Fig. 8) with the exception of the ultraviolet range, where the output is somewhat lower than that of the sun. The carbon arc has a slight flicker, which is usually not objectionable. The image of the carbon arc is approximately circular and fairly constant in all regions of the image. This makes the optics less complicated for imaging the arc in the shape of a hexagon, which will permit packing many arcs together to make a uniformly irradiated surface. It is also necessary to provide fairly elaborate cooling ducts to cool the arc mechanism and remove the carbon dust from the arc.

The xenon lamp appears to be fairly simple in that it is contained in a closed envelope and needs only the necessary electrical connections. However, in presently available lamps, the light source is not as large as the carbon arc nor as intense. This would require several times as many individual lamps and optical modules to illuminate the same area as a carbon arc system. The xenon lamp image is rectangular and requires unsymmetrical optics, or a more-complicated double-imaging set of optics, or the loss of part of the image to form a nearly circular or hexagonal beam. Also, the spectrum of the xenon lamp is considerably different than the solar spectrum so that considerable filtering would be necessary. This would reduce the intensity to about half the unfiltered level, thus requiring still more lamps. Also, the xenon lamp envelope begins to darken soon after it is put into operation, causing a reduction in output; e.g., after 500 to a 1000 hours of operation, the output is reduced to 50 percent. With the lower intensity of the xenon lamp, the smaller size of the image, and the darkening of the lamp envelope, approximately five times as many light sources would be required, using 2.5-kw xenon lamps as compared to 12-kw carbon-arc sources.

Because of these considerations, it was decided to use carbon arcs in the Mark I simulator. To irradiate an area 5 feet wide and 32 feet high, 77 light-source modules are required, each irradiating an hexagonal area of approximately two square feet (Fig. 9).

INDIRECT THERMAL RADIATION

In addition to the direct solar radiation, there are two indirect sources from the earth that are significant in determining

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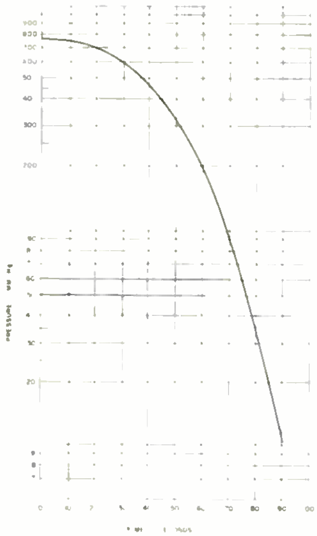


Fig. 7—Ascent pressure curve.

satellite temperatures: 1) *albedo*, the radiation from the sun reflected by the earth without absorption, and 2) *radiance*, simply the thermal radiation from the earth due to its own temperature.

The direct radiation is fairly constant from day to day, but the albedo and radiance vary considerably because of the large changes in absorption and emissivity brought about by changes in cloud cover and surface variations. Johnson[5] has indicated a power density range of albedo for different times of the year and at various latitudes of 17 to 224 w/m² and for radiance of 156 to 216 w/m². The spectrum of the albedo would be similar to the direct solar spectrum, while the radiance spectrum will be similar to that from a black body between the temperatures of 218°K and 288°K depending on surface and atmospheric conditions.[6]

Because of the low temperature of the earth, it would be very cumbersome to simulate the spectrum of the earth's radiance. It is much more practical to use a higher temperature source for simulation of the radiance. Also, since the albedo is only a small percentage of the direct solar radiation, it is not practical to go to considerable expense to simulate the spectrum of the albedo. However, they must be considered in the thermal balance. For these reasons, both the albedo and radiance are simulated by a bird-cage arrangement of tungsten filaments operating at 1900°K that encompasses a test vehicle inside the vacuum chamber. The filaments can be turned on or off and modulated individually to simulate the radiation received during any orbit. The total radiant power available with all filaments on is approximately 35 kw, which represents 400 w/m² of albedo radiation and 250 w/m² of earth radiance on the vehicle.

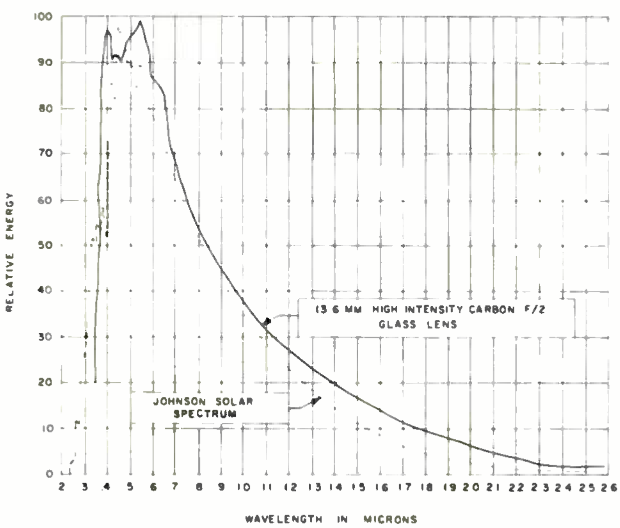
CONCLUSIONS

Facilities such as the Mark I will contribute very much to our knowledge of equipment performance in space. Although the ultimate test must always be actual performance in space, the flexibility and low cost of a simulator—relative to actual space flight—make it particularly attractive for both development work and quality-control pre-flight testing.

ACKNOWLEDGEMENTS

Although the RCA Service Company had prime responsibility for design of the Mark I, much of the work described in this article was performed by the Industrial Tube Products Department of the RCA Electron Tube Division and the DEP Astro-Electronics Division. John Mark was Project Engineer in charge of the Tube Division effort, and Carl Osgood was Project Engineer in charge of the AED effort.

Fig. 8—Relative spectral distribution of 13.6-mm high-intensity carbon arc and the Johnson solar spectrum.



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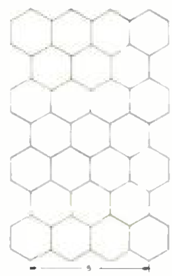

Fig. 9—Solar lamp illumination pattern.

HARRY REESE, JR. received his BS in EE from Carnegie Institute of Technology in 1944 and a Master's Degree from the same school in 1948. From 1944 until 1946, he served in the U. S. Navy, with the rank of Lt. (jg), as Radar Officer on the Aircraft Carrier *Croatan*. He was employed as a development engineer for the Brown Instrument Division of Minneapolis-Honeywell from 1946 until 1949. From 1949 to 1952 he was employed as a development engineer at the Oak Ridge National Laboratory where he worked on the Aircraft Reactor experiment and high-voltage accelerators. During this time, he was co-developer of a new-type r-f ion source. From 1952 to 1958, he was Assistant Manager, Nuclear Power Department, Curtiss-Wright Research Division, responsible for supervision of the Physics Section, including reactor physics, instrumentation, hot lab, research reactor, and health physics. In August 1958 he joined the RCA Service Company as Manager of Atomic Energy Services, where he has been responsible for all of the Service Company's atomic energy programs. In May 1960 he was made Manager of Nuclear and Scientific Services. In addition to those duties, he has been Project Manager of the Mark I Simulator Project.

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A NEW UHF CERAMIC PENCIL TRIODE FOR AEROSPACE APPLICATIONS

This new uhf triode was developed to cope with the operating environments of aerospace vehicles. It required investigation of basic structures and parameters of existing ceramic-metal pencil tubes, extensive test programs, and special attention to materials and production methods. This work is an example of the considerable engineering effort involved to revamp an existing component type into one that will meet the severe premiums of aerospace performance and reliability in quantity production.

S. BOGAENKO and O. JOHNK
Microwave Tube Operations
Electron Tube Division
Harrison, N.J.

THE INCREASINGLY adverse environments to which aircraft, missiles, and satellites are subjected place severe requirements on the reliability of their basic electronic components. Under AEC sponsorship, the Electron Tube Division has developed a new quick-heating, rugged uhf ceramic pencil triode particularly suited to such demands.

This development involved an extensive investigation into the grid and cathode structures of existing ceramic-metal pencil tubes because their concentric cylindrical structure is readily adaptable to coaxial line circuits. This type of construction (Figs. 1 and 2) has the additional advantages of low power drain and inherent freedom from fluctuations resulting from supply-voltage changes.

The parameters which control warm-up time and vibration-noise output in pencil tubes were experimentally determined and evaluated. An extremely rapid warm-up time resulted from a more efficient thermal design of the heater and cathode mass; the new tube becomes operational in less than 10 seconds after application of all voltages.

This paper includes graphs which show the effect of the heater-coating mass and cathode mass on warm-up time and the effect of the various grid parameters on the mechanical resonant frequency. The grid design evolved couples optimum electrical characteristics with excellent mechanical ruggedness; no resonant frequencies exist below 6000 cycles.

Extensive test and life-test programs were conducted to insure satisfactory amplifier and oscillator operation. In addition, special characteristics such as grid blackout, frequency drift with heater voltage and temperature, and mixer and oscillator life tests were also evaluated. Finally, changes were made in tube fabrication and parts processing to achieve the high degree of quality control needed for tube production.

QUICK-HEATING CONSIDERATION

A curve of typical warm-up time—the time required for plate current to reach 90 percent of its stable value—is shown in Fig. 3. The factors which affect warm-up time have been well defined by Hardin[1] and Schrader[2]; the empirical formulas developed by Schrader were used to determine the approach for the development program.

Fig. 4 shows the effect on warm-up time when heater-cathode structure materials are varied individually. These curves show that the greatest reduction in warm-up time is achieved by reducing the mass of both the cathode and the heater coating. A 35-percent reduction in cathode mass was obtained by reducing both the length and the wall thickness of the cathode sleeve. Although the mass of the heater coating has been reduced by 40 percent, the coating thickness is still sufficient to meet the heater-to-cathode insulation requirements.

The desired warm-up time was obtained without an increase in cathode temperature. Throughout the development program a conservative cathode design temperature of 780°C was maintained to ensure good life performance.

VIBRATION CONSIDERATIONS

The design objective of the program was the development of a tube able to withstand 6 hours of continuous vibration at 10-g acceleration from 50 to 500 cycles and at 5-g from 500 to 2000 cycles. The maximum allowable noise at any point within this range was 150 mv measured across a 10,000-ohm load resistor.

The source of vibration noise was traced to mechanical movement of the grid structure. All other elements are very stable and do not contribute to the noise output. The amplitude of the vibration noise is determined by the displacement of the grid structure during vibration. Under a constant acceleration, this displacement is inversely proportional to the square of the mechanical resonant frequency. Therefore, one of the first design tasks was the development of a grid structure (Fig. 5) having a resonant frequency in excess of 5000 cycles (Fig. 5). The resonant frequency f_r is inversely related to the grid-structure's mass m and compliance c:

$$f_r \propto \frac{1}{\sqrt{mc}}$$

Compliance is the amount of deflection of a member per unit of applied force.

Resonance studies on numerous grid-structure variations are graphed in Fig. 6. Fig. 6a shows that the resonant frequency is inversely proportional to the square of the grid length. Fig. 6b shows that the resonant frequency is only slightly affected by a change in the winding rate of the helix. A change in winding rate from 200 to 550 turns/inch increases the resonant frequency only 200 cycles because the strengthening effect of a higher helix pitch is almost completely counter-balanced by the increased helix mass. Fig. 6c shows that the resonant frequency varies directly with the diameter of the helix wire. The

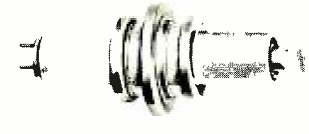

Fig. 1—A typical RCA ceramic-metal pencil tube, about actual size.

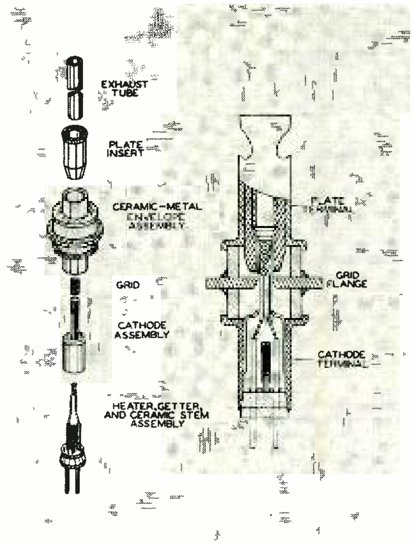

Fig. 2—Basic pencil-tube construction.

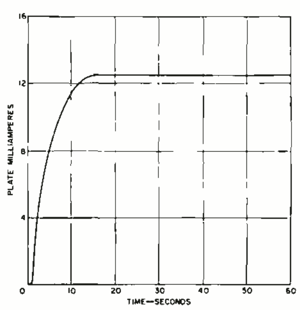

Fig. 3—Typical curve of plate current as a function of time.

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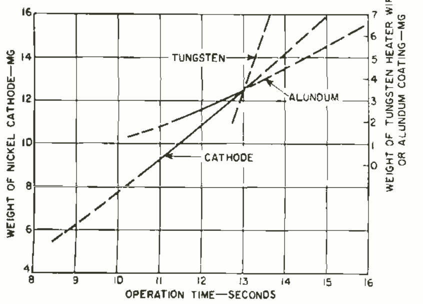


Fig. 4—Warm-up time for various heater cathode materials.

compliance of an individual helix-wire span is inversely proportional to the fourth power of its diameter, whereas the mass varies directly as the square of the diameter. Fig. 6d shows the almost linear relationship between the resonant frequency and the number of side rods. The compliance of an individual helix-wire span is inversely proportional to the cube of the span length (or to the cube of the number of side rods). If the change in the mass of the individual spans is neglected, the mass of the entire grid structure is then directly proportional to the number of side rods.

Thus, the three factors having the most effect on resonant frequency are grid length, helix wire diameter, and number of side rods. The final grid structure was designed with a grid length of 4.75 mm, a helix-wire diameter of 0.8 mil, and 18 side rods. The helix pitch, which has a relatively minor effect on the resonant frequency, was set at 315 turns/inch for electrical-performance considerations. With these parameters, the resonant frequency of the grid structure was raised to well above 6000 cycles.

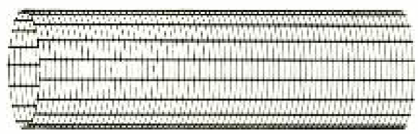
Fig. 7 shows a comparison between the vibration characteristics of the newly designed grid structure and those of a conventional ceramic-metal pencil tube. The grid structures of both tubes were shocked into resonance by a single impact applied at their grid disks. A Tektronix 531 oscilloscope, adjusted so that its trace started at the time of the shock impulse, was used to display the vibration-noise output. A slow trace was used to compare the damping characteristics as shown in Fig. 7a, and a fast trace was used to indicate the resonant frequencies of the two grid structures as shown in Fig. 7b.

The final design was subjected to extensive vibration studies. It has been confirmed that the mechanical resonant frequency of the tube is above 6000 cycles. Noise voltage caused by mechanical excitation of the tubes is well below the objective limit and below 10 millivolts in almost all tubes. Many tubes show no increase in noise voltage above the background level as excitation is applied.

This design was also subjected to shock tests at 500 g for 1 msec and at 150 g for 11 msec. During shock and vibration the tubes were continuously monitored for intermittent shorts of less than 50,000 ohms. Although major electrical characteristics were checked before and after these tests, no significant changes were noted. Performance has been so good that it has become practice to perform shock and vibration tests in sequence on the same tube samples.

Extensive testing was performed during and after the design phase to assure compliance with the objective test specification. Special tests had to be performed in addition to the standard triode tests. One of these tests, for grid blackout,[3] is essentially a method used to determine tube recovery time after a positive pulse has been applied to the grid. Two signals are applied to the grid, one a low-level r-f signal and the other a 5-volt positive pulse of 0.25-µsec duration. The r-f signal voltage across the load resistance is compared just prior to the

Fig. 5—Newly developed grid structure.



leading edge of the pulse E_1 and 0.8 µsec after the leading edge of the pulse E_2. Fig. 8 shows the signal across the load resistance. The db loss in signal L_x can be evaluated from:

$$L_x = 20 \log \frac{E_1}{E_2}$$

Additional tests involved a complete evaluation of the tube in an L-band oscillator cavity. Tests were performed at −62 and at +125°C ambient temperature. No deterioration in performance due to the tube was observed. Thermal stability to changes in heater voltage was very good. Fig. 9 shows the change in power output and frequency over a range of heater voltages. The change in frequency during the first 60 seconds after heater voltage is applied is less than 0.2 Mc.

A pulse life test was performed in which the tube was operated at zero bias with continuous plate current flowing. A positive 25-volt pulse at a duty cycle of 0.6 percent was then applied to the grid; tubes consistently met this severe requirement.

Because of widely varying voltages encountered in airborne equipment, heater-cycling life tests were also performed. During these tests the heater was operated at 8.0 volts; no failures were allowed at 10 cycles. As a result of these tests the heater demonstrated that it is capable of withstanding prolonged high voltage.

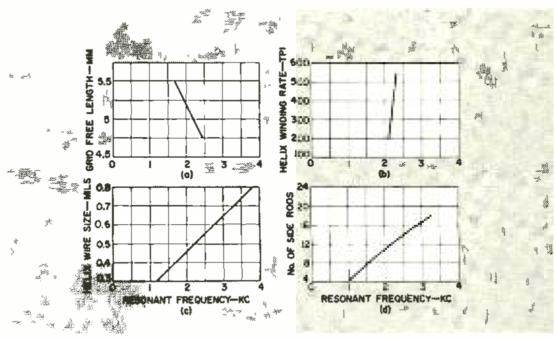
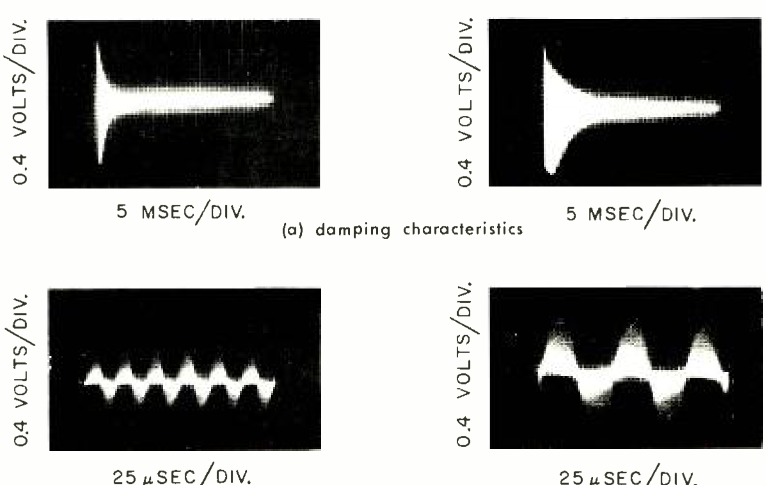


Fig. 6—Resonance curves for various grid structures.

QUALITY ASSURANCE CONSIDERATIONS

Because of the high degree of quality necessary for the production of this tube, an improvement program for the areas of materials, methods, and controls has

Fig. 7—Comparison of the vibration characteristics of the newly developed grid structure (left), and conventional pencil-tube grid (right).



(a) damping characteristics

(b) resonant frequency

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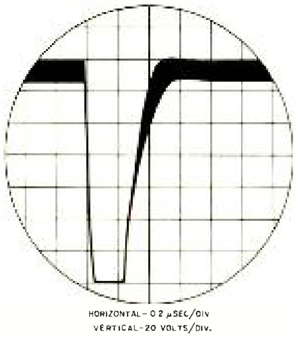

Fig. 8—The r-f signal voltage across the load resistance.

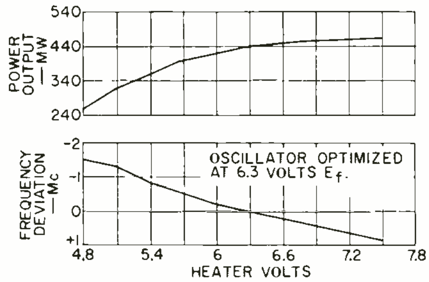

Fig. 9—Changes in power output and frequency with heater voltage.

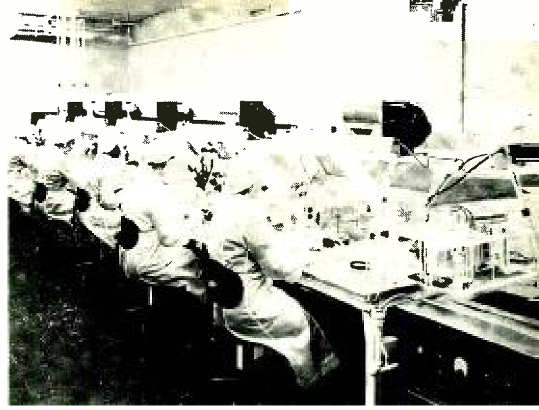

Fig. 10—Hooded mounting tables used in final tube assembly.

been instituted. Cathodes are fabricated from an RCA vacuum-melted alloy to ensure control of activators and impurities. Oxygen-free high-conductivity copper is used for the plate insert because of its high thermal conductivity and ease of outgassing, and gold plating of the grid helix wire is used to eliminate grid emission.

Throughout the parts-fabrication and assembly areas, the latest cleaning and processing techniques are used. Internal parts are vacuum-fired, and all parts are washed ultrasonically before final assembly. Emission coating is applied to cathodes mounted on a rotating fixture to ensure uniform coating. The entire cathode-spray operation is performed in a mechanized spray booth having a closely controlled atmosphere. The spray booth is equipped with a rotating fixture, mechanized traverse rods, drying lamps, and hooded enclosures. Final assembly is made in special controlled-atmosphere mounting rooms.

The tube parts are assembled on dust- and lint-free hooded mounting tables to further reduce the possibility of contamination (Fig. 10). These tables are interconnected so that parts never leave the hoods until final assembly has been completed. Exhaust of the final assemblies is performed on a stationary ultra-high-vacuum system with a high-temperature bakeout of the entire tube for thorough outgassing.

Statistical quality controls are used throughout manufacture, and process averages are established for every stage of fabrication and assembly. Continuous lot identification is maintained, beginning with the inspection of incoming raw materials and vendor parts and culminating with the testing of tubes for all electrical characteristics.

The improvement program for quality assurance, which has been highly successful in producing uniform tubes at a good yield, is being continued so that tubes of even higher quality and greater uniformity of characteristics will be produced.

CONCLUSIONS

This comprehensive development program has produced a tube which meets the design-objective environmental, electrical, and performance characteristics, as shown in Table I. In addition, the complete evaluation of each design modification has evolved a high-volume design which fulfills all objective specifications.

TABLE I—Tube Characteristics

Heater Voltage, 6.3 +19% −8% volts
Heater Current, 225 ma
Direct Interelectrode Capacitances:
- Grid to plate, 2.4 pf
- Grid to cathode, 4.3 pf
- Plate to cathode, 0.03 max. pf

Maximum Ratings:
- D-C Plate Voltage, 250 volts
- D-C Cathode Current, 25 ma
- Peak Cathode Current, 1.5 amperes
- D-C Grid Current, 6 ma
- Plate Dissipation, 2.5 watts
- Seal Temperature, 225°C
- Altitude, 100,000 feet

Typical Operation Characteristics:
- D-C Plate Voltage, 125 volts
- Cathode-Bias Resistor, 50 ohms
- D-C Plate Current, 13.5 ma
- Transconductance, 13,000 μmhos
- Amplification Factor, 80

ACKNOWLEDGMENTS

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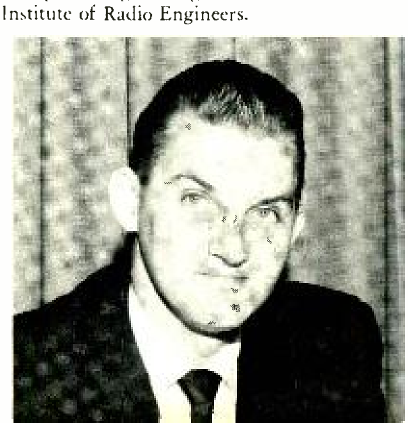
SERGEI W. BOGAENKO received his BSEE from Newark College of Engineering in 1959. He joined the RCA Electron Tube Division in 1956 and is currently a Design Engineer in the Microwave Tube Design and Development Activity. His major work has been in the design and development of uhf pencil tubes and S- and C-band traveling-wave tubes. He is responsible for much of the early design work on the RCA line of ruggedized ceramic-metal pencil tubes and served as project engineer in the development of several of them. He has also done work on the use of depressed collector potentials to improve the efficiency of traveling-wave tubes. At present, he is the project engineer responsible for the development of a 6-KMC, 10-watt communications traveling-wave amplifier. Mr. Bogaenko is a member of the Institute of Radio Engineers.

OTTO JOHNK joined RCA as a specialized engineering trainee in 1955 and subsequently was assigned to the Electron Tube Division as a Test Engineer in the Industrial Receiving Tube Activity. He later transferred to the Microwave Tube Applications and Systems Engineering Activity where he has been responsible for the electrical and environmental testing and the engineering refinements of a variety of developmental uhf pencil tubes. He is currently a Design Engineer in the Microwave Tube Design and Development Activity. Mr. Johnk completed the Advanced Electronics Technology Course at the RCA Institutes in 1955 and is now working toward his BSEE degree at Newark College of Engineering. He is a member of the Institute of Radio Engineers.



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IMPROVED SOLAR CELLS FROM GALLIUM ARSENIDE

Silicon solar cells have been used exclusively in space vehicles, but have been developed to almost their full potential. Further solar-cell improvements must come from other materials. Now, new gallium arsenide cells with high conversion efficiences (over 11 percent) provide advantages over silicon in improving temperature characteristics and radiation resistance. Presented here are gallium arsenide cell design considerations and typical cell characteristics compared with silicon.

by **Dr. A. R. GOBAT, M. F. LAMORTE, and G. W. McIVER**

Semiconductor and Materials Division

Somerville, N. J.

THE ACCELERATED space-exploration program has also accelerated development of an improved solar cell to provide increased power, improved temperature characteristics, and greater resistance to bombardment by high-energy particles.

Silicon solar cells have been used almost to their full potential. A theoretical analysis of other semiconductors as possible improved photovoltaic materials[1] showed that gallium arsenide (GaAs) has one of the highest conversion-efficiency values at both room temperature and elevated temperatures. This analysis was based on only two physical facts besides the p-n junction: 1) the highest voltage that can be generated by the solar cell is limited to the bandgap voltage; 2) only a certain portion of the sun's spectrum is potentially useful for energy conversion. Other crystalline properties make GaAs even more attractive as a solar-cell material and superior to silicon, cadmium telluride, cadmium sulfide, or the graded-bandgap gallium-phosphide–gallium-arsenide materials.[2-5]

This paper describes the characteristics of GaAs solar cells having conversion efficiencies greater than 11 percent. The cells are fabricated from monocrystalline n-type material with an impurity concentration of $10^{17}/cm^3$. Zinc diffusion is used in the construction of the junction to provide a penetration of 1 to 3 microns, a surface concentration of $10^{20}/cm^3$, and a sheet resistance ranging from 20 to 60 ohms per square. The 10-ohm total resistance of the cell results in a small internal power dissipation. If either the contact resistance or the diffused-layer sheet resistance is high, internal power dissipation appreciably reduces conversion efficiency; the grid structure minimizes dissipation in the diffused layer. An antireflection coating on the top surface of the cell reduces reflectance from 31 to 9 percent.

CELL CHARACTERISTICS

Although GaAs solar cells are similar to silicon cells in general construction details, their characteristics are quite different, as shown in Table I. The GaAs cells have a larger open-circuit voltage because of the larger bandgap. Because a correspondingly smaller portion of the solar spectrum is used, however, the short-circuit current density is smaller, the matched load resistance is higher, and the number of cells required in a series-parallel circuit design is different than for silicon cells. Typical voltage-current characteristics of high-efficiency GaAs cells are shown in Fig. 1.

Conversion efficiency for these cells is calculated on the basis of active area; i.e., total area minus grid-contact area. The area of the stripes, however, is not more than 15 percent. Efficiency values for the GaAs cells were greater than 11 percent in all cases and reached as high as 13 percent in normal sunlight.

The open-circuit voltage for GaAs cells is usually greater than 0.85 volt, although values as high as 0.96 volt have been observed with an incident energy of 100 mw/cm². The open-circuit voltage of high-efficiency cells is within 0.05 volt of the p-n junction built-in voltage, which is typically greater than 0.92 volt.

Values of short-circuit current density for GaAs cells are more than half the theoretical values. The useful portion of the solar spectrum at sea level for GaAs provides a current density of 32 ma/cm², provided the reflectance at the surface is zero. However, the reflectance at the GaAs surface of approximately 31 percent reduces the current density to 22 ma/cm². A properly deposited antireflection coating reduces the reflectance over the useful portion of the solar spectrum to an average value of 9 percent and restores the short-circuit current density to 29 ma/cm². If a collection efficiency of 100 percent is assumed, the coating must have an index of refraction of 1.8 ± 0.2 and a zero-order thickness equal to a one-quarter-wavelength match to minimize reflectance in the wavelength range from 0.6 to 0.7 micron. The coating used is silicon oxide, which has an index of refraction of approximately 1.8 when properly applied; the calculated thickness is 925 ± 175 angstroms. Experimental data show an improvement attributable to the coating as high as 22 percent. Multiple coatings might be used to reduce the reflectance below 9 percent, but it is questionable whether the increased cost is economically feasible.

The rectangular shape of the voltage-current curves in Fig. 1 indicates that the internal power dissipation attributed to the series resistance of GaAs cells is small, or even negligible. This dissipation, which reduces conversion efficiency, may also determine to a large extent the steps which must be taken to maintain the temperature of the space vehicle to a manageable level. The method used to determine internal power dissipation is described briefly below.

The voltage-current relationship for a solar cell is given by[6]:

$$J = J_{sc} - J_{ro} \exp\left[\beta(V - IR_s)\right] \qquad (1)$$

Where: J is the current density for a given voltage V, J_{sc} is the short-circuit current density, and J_{ro} is the space-charge recombination current density (all in ma/cm²).[7] The Term V in the exponent is load voltage (volts), I is the

Fig. 1—Typical voltage-current energy-conversion characteristics for high-efficiency GaAs solar cells (incident energy is 100 mw/cm²).

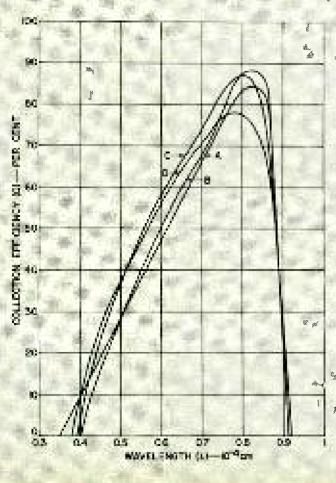
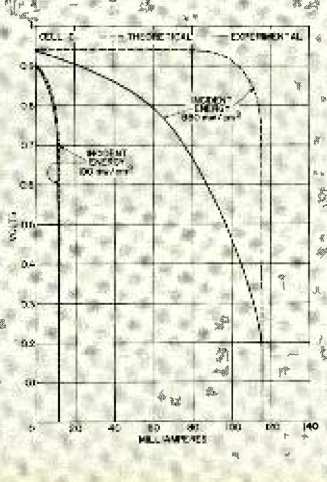


Fig. 2—Comparison of experimental and theoretical energy-conversion curves for GaAs cells (zero resistance assumed).



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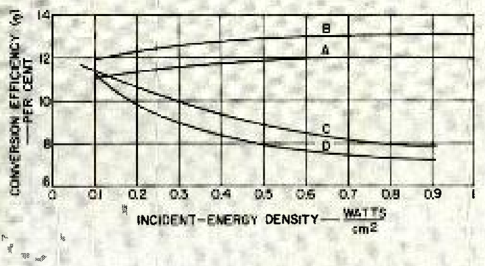


Fig. 3—Conversion efficiency as a function of incident energy for two values of stripe separation.

load current (ma), and R_s is the cell series resistance (ohms). The value of β is given by $\beta = q/AkT$ (volt^{-1}). The constant A is included to describe the nonideal diode behavior of the cell. The term J_{ro} accounts for the deviation from the saturation-current value. The value of A may be determined as follows:

$$A = \frac{q}{KT} \; \frac{dV_{oc}}{d(\ln J_{sc})} \qquad (2)$$

Where: V_{oc} is the open-circuit voltage (volts). If the value of A calculated from Equation 2 is substituted in Equation 1 and R_s is set to zero, all the constants are known and the curve for zero internal power dissipation can be plotted.

Fig. 2 shows both theoretical and experimental curves for a typical GaAs solar cell for incident energies of 100 and 880 mw/cm^2. These curves show that the power dissipation is negligible for an incident energy of 100 mw/cm^2. The grid-structure contact of the cell is designed to provide maximum power output for incident solar energies ranging from 100 to 140 mw/cm^2, the latter value being equal to that encountered just beyond the earth's atmosphere.[5]

The optimum stripe separation for the grid-structure contact is given by:

$$2w = 2\left[t \, \frac{}{E_o + 2R_cL\,(J_{sc} - J_{ro}\,[\exp \beta V_o]\,[1 - \beta E_o t])} \right]^{1/2} - 2t \qquad (3)$$

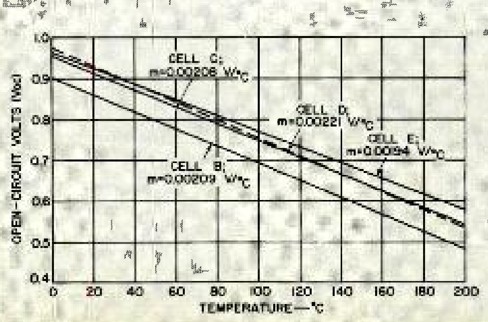
Where: $2w$ is the stripe separation (cm), $2t$ is the stripe thickness (cm), V_o is a constant voltage midway between stripes (volts), E_o is the electric field on the cell surface (volts/cm), R_c is the contact resistance (ohms), and L is the stripe length (cm). When the short-circuit current density J_{sc} increases with increasing incident energy, the optimum stripe separation must be decreased to minimize power dissipation in the diffused layer. As shown in the second set of curves in Fig. 2, the power dissipation increases for incident energies greater than those for which the grid structure is designed, and the power output shows a corresponding decrease. Efficiency at one value of incident energy is not necessarily a measure of efficiency at any other value. Solar cells designed for space applications should be designed specifically for the range of energy values the vehicle is to encounter.

Fig. 3 shows curves of efficiency as a function of incident energy for GaAs solar cells using different grid structures. For cells A and B, which have stripe separations of 0.67 cm, the efficiency decreases as the incident energy increases. For cells C and D, which have a stripe separation of 0.05 cm, the efficiency is highest between 0.7 and 0.8 w/cm^2.

If the short-circuit current density J_{sc} becomes sufficiently high, the open-circuit voltage V_{oc} attains a saturation value called the junction built-in voltage ϕ_o. In high-efficiency cells this voltage approaches one volt, as shown in Table II. Values of ϕ_o lower than 0.9 usually indicate that both the open-circuit voltage and the short-circuit current density are poor, and usually result in poor efficiency values. It can be shown that for V_{oc} to approach ϕ_o the excess-minority-carrier concentration must be equal to the majority-carrier concentration in both the p and n regions. Materials with high absorption coefficients, such as GaAs, generate a higher excess-carrier concentration and more nearly approach the junction built-in voltage under normal values of illumination.

The calculated values of J_{ro} for these cells are orders of magnitude greater than the saturation current density, which is of the order of 10^{-15} ma/cm^2. The typical values shown in Table II indicate that a recombination component in the space-charge region contributes to the forward current. The values of A deviate sufficiently from unity to suggest that the large J_{ro} values are caused by a recombination phenomenon in the space-charge region.

Fig. 4—Open-circuit voltage of four GaAs cells vs. temperature.



TEMPERATURE CHARACTERISTICS

As stated previously, the temperature coefficient of GaAs cells is approximately one-half that of silicon cells because of the larger bandgap. This feature permits greater flexibility in the design of space-vehicle equipment and also eliminates the need for special precautions required with silicon cells. Under certain conditions, it may be advantageous to use reflectors to increase the incident energy on the GaAs cells; because of the improved temperature coefficient, the power output may increase appreciably.

Table I—Typical Characteristics for GaAs and Silicon High-Efficiency Solar Cells.

	Si	*GaAs*
Open-Circuit Voltage V_{oc}, volts	0.6	0.9
Short-Circuit Current Density J_{sc}, ma/cm^2	27	17
Matched Load Resistance, R_{Lmp}, ohms	10	30

Incident solar energy 100 mw/cm^2; cell area 2 cm^2.

The degradation of conversion efficiency with increasing temperature results primarily from a decrease in open-circuit voltage. Fig. 4 shows the open-circuit voltage of typical GaAs cells as a function of temperature; the voltage-temperature coefficient for these four cells ranges from 1.94 to 2.21 mv/°C. Open-circuit voltage of the GaAs cell at 200 °C is equal to that of the silicon cell at 25 °C. The drop in open-circuit voltage of the GaAs cells from 0 to 200 °C is approximately 50 percent.

Approximately the same variation exists for conversion efficiency of GaAs cells (Fig. 5). The temperature coefficient of conversion efficiency for the four cells ranges from 0.021 to 0.034 percent/°C. The measured temperature coefficient of 0.025 percent/°C is approximately half the measured value for commercially available silicon cells, which ranges between 0.04 and 0.06 percent/°C.

In Fig. 5, two slopes are distinguishable for the curve of cell C, i.e., the temperature coefficient is lower below 107 °C than above this point. This change in slope has been observed on several cells, although usually only one slope is present. Where the change occurs, it is attributed to the temperature variation of the short-circuit current of the cell.

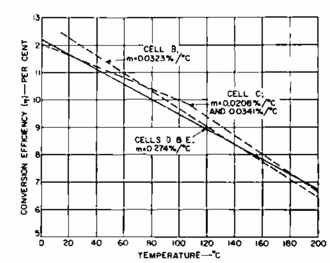


Fig. 5—Conversion efficiency of four GaAs cells vs. temperature.

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Table II—Typical Cell Parameters for High-Efficiency GaAs Solar Cells.

Cell	η (%)	V_{oc} (Volts)	J_{sc} (ma/cm²)	R_{Lmp} (ohms)	A	J_{ro} (ma/cm²)	ϕ_o (volts)
A	11.1	0.86	16.9	23	2.1	9.05×10^{-5}	0.935
B	11.6	0.84	18.4	21	2.0	1.30×10^{-8}	0.93
C	11.5	0.90	17.2	24	2.1	8.64×10^{-5}	0.94
D	11.2	0.90	17.2	23	1.6	3.12×10^{-9}	0.94
E	11.3	0.91	17.4	23	—	—	—

Although the short-circuit current of both GaAs and silicon cells usually increases with increasing temperature, the increment is small compared to the decrease in open-circuit voltage. The break in the curve may be caused by a nonlinearity in the current-temperature relationship. An increase in minority-carrier diffusion length due to the filling of traps and/or recombination centers and the decrease in the bandgap at elevated temperatures could cause such nonlinearity.

The rate of change of short-circuit current with reciprocal temperature is normally linear, as shown in Fig. 6, and ranges from 2.9 to 3.94 $\times$ 10^{-3} ma-°K/cm². The increase in current from 0 to 200 °C is approximately 15 percent, considerably smaller than the decrease of open-circuit voltage. If the short-circuit current could be made to increase even more rapidly with increasing temperature, the efficiency-temperature coefficient could be reduced by an amount related to the current increment.

SPECTRAL RESPONSE

Evaluation of cells in artificial light is not satisfactory, because its spectral distribution differs significantly from that of the sun. Discrepancies often result when cells are evaluated both indoors beneath an artificial light and outdoors in natural sunlight, because the conversion efficiency is an integrated function of the spectral response characteristic, which may differ from cell to cell in both shape and magnitude. Although evaluation of solar cells beneath a tungsten lamp or solar simulator is standard practice, such evaluation can serve only as a guide. In many respects, the collection efficiency determined from the spectral distribution of short-circuit current is a better measure of the cell efficiency.

The collection efficiency is the ratio of the number of minority carriers separated by the p-n junction per unit time per unit wavelength[5] to the photon flux per unit wavelength. This ratio is influenced by the photon absorption in the semiconductor material, the ratio of minority-carrier diffusion length to junction penetration, the surface recombination velocity, and the built-in drift field in the diffused layer. Some of these parameters can be controlled by appropriate control of the fabrication process.

Because the drift field is negligible in the GaAs cells discussed in this paper, efforts were concentrated on optimizing the other parameters for optimum design. Investigations are now under way to obtain a sufficiently high drift field to provide negligible recombination in the diffused layer. For the lifetime values encountered in the diffused layer, the junction penetration should be about 0.5 micron, with a surface concentration of 10^{20} cm³.

The use of the collection-efficiency ratio permits the calculation of the short-circuit current density under any conditions of solar illumination. As a result, this ratio may also serve as a relative measure of conversion efficiency. In addition, it can be used to determine surface losses.[8] It has been suggested, therefore, that the collection-efficiency characteristic be specified for the evaluation of solar cells. Unfortunately, this characteristic is not easily measured because of the difficulty of calibrating the spectral light source. For the measurements given in this paper, a model No. 112 Perkin-Elmer spectrometer was used, and an Eppley thermopile in conjunction with a Liston Becker d-c amplifier was used to calibrate the spectral distribution of the photon density of the spectrometer over the useful portion of the spectrum.

Typical collection-efficiency characteristics for four GaAs cells are shown in Fig. 7. The drift field in these cells is not sufficiently high to minimize both recombination in the diffused layer and surface recombination losses. As a result, collection efficiency decreases fairly rapidly at short wavelengths. New fabrication techniques under investigation should increase the drift field substantially and provide a slower decrease in collection efficiency.

The maximum collection efficiency occurs close to the edge of the bandwidth, where the absorption coefficient is approximately 10^4/cm. For this value, an appreciable fraction of the hole-electron pairs are generated in the junction region, where most are collected and separated by the junction built-in field. At shorter wavelengths, the absorption coefficient approaches 10^5/cm; at this value, most of the hole-electron pairs are generated in the surface region.[3] Some of the electrons recombine in the surface region and in the diffused layer, and a smaller fraction of these carriers are collected by the junction. As a result, the collection efficiency is lower.

Although some experiments have indicated that these losses in GaAs may be reduced appreciably,[4] more recent work shows relatively high values.[10] If the usual light sources were employed in the latter work, the rate of decrease of collection efficiency at short wavelengths is even greater than that shown in Fig. 7. These results indicate that the fabrication technique determines the losses in the surface region and the diffused layer. In particular, the built-in drift field is important, as are the surface recombination velocity and the electron diffusion length.

Fig. 7 shows a maximum possible increase in collection efficiency of approximately 60 percent in the wavelength range from 0.4 to 0.8 micron. When this figure is combined with the solar photon spectrum, the short-circuit current density of a cell will show a maximum increment of approximately 50 percent. This calculation will result in the theoretical value of short-circuit current density.

RADIATION-DAMAGE EFFECTS

Table III illustrates the results of electron and proton bombardment on gallium arsenide cells. Although these

Fig. 6—Short-circuit current density of four GaAs cells vs. reciprocal of temperature.

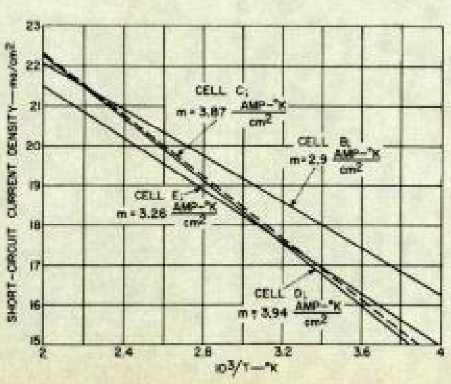

Fig. 7—Spectral-response characteristics of GaAs cells.

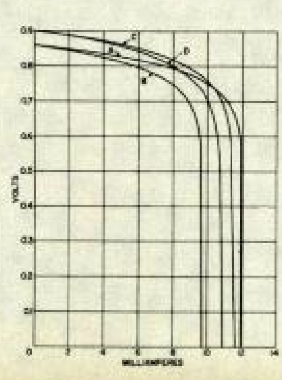

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Table III—Results of Irradiating GaAs Cells with 0.8-Mev Electrons and 19-Mev Protons.

Cell	Initial Conversion Efficiency η_i (%)		Total Flux		Degradation After Total Flux (%)			
	Out-doors	Artificial sun after Mounting	Electron ($10^{16}/cm^2$)	Proton ($10^{13}/cm^2$)	$\frac{\Delta\eta}{\eta_i}$	$\frac{\Delta J_{sc}}{J_{sci}}$	$\frac{\Delta V_{oc}}{V_{oci}}$	$\frac{\Delta R_L}{R_{Li}}$
E	—	6.6	6.9	—	58	50	13	74
F	—	4.8	4.3	—	54	42	10	58
G	5.3	4.8	7.2	—	54	46	11	65
H	—	3.8	8.7	—	63	54	8	100
I	6.5	4.0	8.0	—	63	61	14	123
X	7.5	5.7	—	1.2	48	43	25	30
Y	7.4	6.0	—	1.2	50	55	31	54

results are preliminary, they suggest that GaAs cells have superior resistance to both electron and proton irradiation than silicon cells.

Both the current and voltage characteristics of the cells decrease after bombardment with electrons of the order of 0.8 Mev. However, the change in short-circuit current is greater than the change in open-circuit voltage. These results suggest that a decrease in minority-carrier diffusion length and/or an increase in surface losses occurred. A decrease in diffusion length is probably caused by a reduction in the lifetime value; an increase in surface losses is probably caused by an increment of surface recombination velocity.

Unfortunately, the parameters J_{ro}, A, and ϕ_o were not measured prior to bombardment in these tests; therefore, no reason can be given for the decrease in open-circuit voltage V_o. However, past experience indicates that J_{ro} and A may have changed to produce the lower generated voltage.

The average degradation in efficiency was 56 percent after the cells were subjected to an average total flux of $7 \times 10^{16}/cm^2$. For silicon cells having comparable conversion efficiency (η_i of about 7 percent), a 44-percent decrease from the initial value resulted with a flux of $3 \times 10^{16}/cm^2$ on n-on-p cells and with an order-of-magnitude less flux on p-on-n cells. These data show that the radiation resistance of GaAs cells is approximately twice that of n-on-p cells and twenty times that of p-on-n cells.

The GaAs cells were degraded slightly in the mounting procedure; this fact is part of the reason for the discrepancy between the measurements outdoors and those in artificial light. In general, high-efficiency gallium arsenide and silicon cells degrade more easily than low-efficiency cells.

In the case of the results of bombardment with protons of the order of 19 Mev (Table III), the degradation in open-circuit voltage is comparable to the degradation in short-circuit current. These data suggest that a decrease in diffusion length occurred, but that there was also a substantial increase in space-charge recombination current. In addition, a change in carrier concentration may have reduced the value of ϕ_o and contributed to the decrease in open-circuit voltage.

The average cell degradation after proton bombardment was 49 percent for a total flux of $1.2 \times 10^{13}/cm^2$. The resistance of GaAs cells to proton irradiation is from ten to twenty times that of silicon cells having comparable efficiencies. As in the case of electron bombardment, higher-efficiency cells degrade more rapidly. Again, some of the degradation resulted from mounting the cells prior to bombardment; the actual degradation due to bombardment is probably less than the values reported in the tables.

CONCLUSIONS

Results on high-conversion-efficiency cells fabricated from GaAs crystal substantiate earlier predictions that this material is highly suitable for solar cells. Space-charge recombination current in GaAs cells is much larger than the calculated saturation current, as it is for a silicon junction. The grid-structure contact should be designed for a given solar-energy range to reduce internal power dissipation. The GaAs cells have improved temperature characteristics as compared with silicon cells, and are more resistant to electron and proton bombardment. Temperature degradation always occurs in the open-circuit voltage; radiation degradation occurs in the short-circuit current, and to a smaller degree in the open-circuit voltage.

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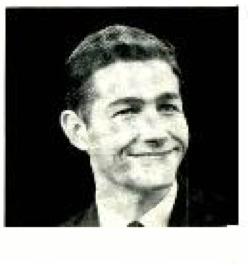
Dr. ANDRE R. GOBAT studied at the Universities of Zurich and Basel, and received the Ph.D. in Physical Chemistry from the University of Basel in 1940. He came to the U.S. to demonstrate a new process for the conversion of natural gas into liquid hydrocarbons. During W. W. II he served in the Army of the United States. He then worked for C. J. Tagliabue, a former Instrument Company. He joined the ITT Labs early in 1947, and was associated with development of semiconductor materials and devices, including improvement of selenium rectifiers, preparation of uniformly doped Ge or Si monocrystals, and development of diodes, power rectifiers, and transistors. In 1958, Dr. Gobat joined the Semiconductor and Materials Division at Somerville, N.J., Advanced Development. He is now concerned with development of Ga As solar converters. He is a member of the American Physical Society.

MICHAEL F. LAMORTE received the B.S. from Virginia Polytechnic Institute in 1950 and the M.E.E. from the Polytechnic Institute of Brooklyn in 1951. He held a Teaching Fellowship in 1950-51 and a Research Fellowship in 1951-52 at the latter institution. He was an Adjunct Professor in the E.E. Graduate School of University of Pittsburgh. From 1952 to 1955 he was at the Signal Corps Engineering Labs, Fort Monmouth, N.J., in study of fundamental properties of semiconductors. From 1955 to 1959 he was with the Westinghouse Electric Corp., investigating device theory and technology. Special contributions were made to high-power silicon devices, crystalline material and diffusion studies. In October 1959, he joined the RCA Semiconductor and Materials Division at Somerville, N.J. Now, as Project Leader of the New Devices Section, Advanced Development, he is responsible for R&D on varactor diodes and Ga As solar cells. Author of several papers, he is a member of the American Physical Society, the IRE and IRE-PGED, Phi Kappa Phi, Tau Beta Pi, and Eta Kappa Nu.

GEORGE W. McIVER graduated *cum laude* from the U. of Kansas in Feb. 1960, with a degree in Engineering Physics and is presently working toward an M.S. in Physics at Rutgers University. He joined the Semiconductor and Materials Div., Somerville, N.J. in March 1960, and is currently in the New Devices Group in Advanced Development. His work is in development of high-efficiency Ga As solar cells, including fabrication techniques, measurements of detailed phenomena, and Ga As diffusion techniques. He is a member of Sigma Pi Sigma.



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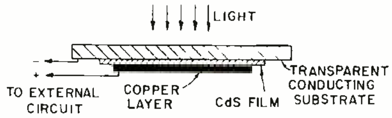

Fig. 1—Geometry of CdS evaporated-layer photovoltaic cell.

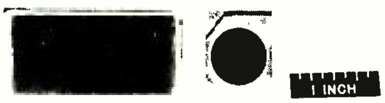

Fig. 2—CdS thin-film photovoltaic cell.

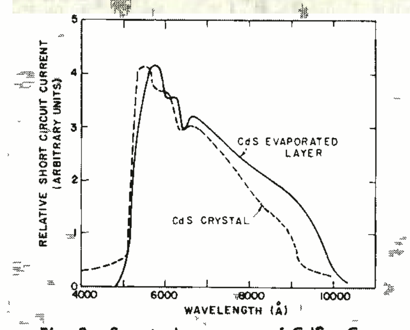

Fig. 3—Spectral response of CdS—Copper photovoltaic cell.

LOW-COST PHOTOVOLTAIC CONVERSION OF SOLAR ENERGY

The photovoltaic effect, through solar cells, has potential as a terrestrial energy source. Economics will rule in any practical application, and present-day devices are far too expensive for all but specialized cases — e.g., in satellites, where silicon solar-cell power at some $1000 per watt is the only long-term source and has been eminently successful. To overcome the high costs, present research is uncovering methods of fabricating cells that may allow for their terrestrial use at practical costs. Such cells may be of significant use to under-developed countries.

P. RAPPAPORT and Dr. H. I. MOSS

RCA Laboratories
Princeton, N. J.

PERHAPS THE ULTIMATE in terrestrial use of solar energy is the production of power for ordinary home use. Consider a 1000-ft^2 home in an area where 100 w/ft^2 of solar energy is available for an appreciable part of the year. If the sunlight striking such a roof were converted with 10-percent efficiency, 10 kw of electrical energy would be available. If suitably stored, this would provide sufficient electricity for typical home use, including air-conditioning when most needed. At present prices, the cost of the silicon solar cells alone for such an installation would be over $1 million. The high cost is due to the requirement to form silicon into single crystals before making the cells.

On the other hand, if solar cells could be made by evaporation, sputtering, settling, or some other deposition technique not requiring the single-crystal phase, there is no reason why the cell cost could not be reduced appreciably. Such techniques are inexpensive and have already yielded promising results for solar cells.[1,2]

If a large-area deposited cell were made at the cost of $1 to $10 per square foot, the cost of the roof described might be as low as $1,000. This would still be expensive for under-developed countries; but, from the viewpoint of the house cost and the cost of electricity, it would be quite reasonable even in parts of the U.S. At the rate of 2¢/kw-hr and assuming a continuous average daily sunshine of 33 watts/ft^2, this unit would pay for itself in two years with an 85-percent duty factor, and in ten years with a 15-percent duty factor. The duty factor involves the number of sun-less days and other losses that vary according to geographical location. Certainly, in areas where sunshine is plentiful such a device would be economically attractive. Other costs such as electrical power storage and installation are not included. Much work is going on in storage systems, and it is assumed here that advances will produce an economical device.[3]

STATE OF THE THIN-FILM ART

There have been a number of good review papers[4,5,6] on the subject of solar cells since the first paper in 1954 by Chapin, Fuller, and Pearson,[7] and no attempt will be made here to further review the subject except as applicable to the present discussion. Table I shows a comparison of experimentally achieved solar-energy conversion efficiencies of single-crystal cells versus nonsingle-crystal cells. Obviously, at the present time, single crystals are far superior. This is due to the fact that the great bulk of the past work has been applied to single crystals because of the past emphasis on high efficiency. Although only a small effort has been applied to polycrystalline films, some of the results have been quite promising. Such film devices, besides being lower in cost, should also be lighter in weight (important for space applications) and more reliable because of the reduced number of connections inherent in large-area panels, compared to present 1-by-2-cm cells.

The work on single-crystal cells gives an upper limit to the efficiency expected from a polycrystalline film. Thus, it is reasonable to expect 10-percent efficiency from a silicon deposition. The item in Table I corresponding to the silicon nonsingle-crystal cells was for a polycrystalline cell made by Elliot, et al.[8] In these cells, the grain size was about ½ mm. larger than in a truly inexpensive deposition process like vacuum deposition or sputtering.

TABLE I—SOLAR CONVERSION EFFICIENCY

Material	*Efficiency, Percent*			
	Single Crystal		*Nonsingle Crystal*	
Silicon	14	(5)	10	(8)
Gallium Arsenide	>11	(17)	—	
Cadmium Sulfide	8	(9)	5	(18)
Cadmium Telluride	4	(10)	< 1	(13)
Indium Phosphate	2	(4)	—	
Gallium Phosphide	1	(11)	—	
Selenium	—		1	(12)

Note: Parenthetical numbers indicate Source, see Bibliography.

The essential properties that a thin film of a polycrystalline semiconductor must possess to be applicable to photovoltaic-cell fabrication are as follows: In the case of a p-n junction cell, the thickness of the film must be great enough to absorb an appreciable amount of the photons having an energy greater than the band gap of the film material.[5,8,14] Also, the carrier diffusion lengths must equal or exceed the film thickness. In the case of a polycrystalline layer, the minimum grain size must be at least equivalent to the film thickness. This insures that a carrier diffusing towards the junction will not be intercepted by a grain boundary and thus given an opportunity to recombine. In the case of a metal-semiconductor-junction photovoltaic cell, the above requirements for a thin layer may not have to be as stringent as for a p-n junction device.

There have been a few reports in the literature before 1960 concerning the application of sintered or vacuum-evaporated polycrystalline semiconductor films to photovoltaic-cell fabrication. Some of the materials that have been investigated include cadmium sulfide,[15] cadmium telluride,[13] silicon,[14] selenium,[12] and certain organic semiconductors.[16] The conversion efficiencies of these cells amounted to 1 percent or less. Cast silicon cells have been made which are polycrystalline with grain sizes of 5 × 10^{-2} cm and show efficiencies of about 10 percent.[8] An evaporated cadmium-sulfide–film photovoltaic cell with efficiency of 3.5 percent has been reported.[2]

EXPERIMENTAL WORK ON CADMIUM SULFIDE FILM CELLS

Cadmium sulfide layers were vacuum deposited onto heated conducting pyrex substrates. The pressure during the evaporation was about 10^{-5} mm-Hg. These layers were about 5 to 10 microns thick and were hard and adherent. Microscopic and x-ray diffraction

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studies revealed the layers to be microcrystalline and free from pin holes. Their optical properties appeared to be very similar to cadmium-sulfide single crystals. The evaporated layers without additional treatment are relatively conducting because of the presence of excess cadmium. Resistivity of these films could be as low as 1 to 10 ohm-cm.

Fabrication of the photovoltaic cell was completed by applying an opaque layer of copper to the exposed surface of the cadmium sulfide layer, followed by a suitable heat treatment. The geometry of the finished cell is illustrated in Fig. 1. Electrical contacts to the cell were made on the copper layer and on the conducting substrate.

Back-wall illumination of these cells with an artificial light source equivalent to a sunlight radiation density of 92 mw/cm^2 can produce open-circuit voltages up to 0.5 volt and short-circuit current densities up to 5 ma/cm^2. Conversion efficiencies of over 1 percent are readily obtained. Cells with active areas up to 10 cm^2 have been fabricated; however, the highest efficiencies were obtained from cells with areas of about 1 cm^2.

Fig. 2 shows two typical experimental cadmium sulfide cells deposited on a glass substrate. Note that the glass is the top surface of the cell for protection and ease of cleaning.

Fig. 3 shows the spectral response of a typical cell when illuminated with a Bausch and Lomb grating monochromator. The cell response has been normalized to take into consideration differences in the spectral intensity transmitted by the monochromator. This curve is similar to curves obtained from single-crystal cadmium-sulfide–copper photovoltaic cells. The dashed curve in Fig. 3 is the spectral response of such a single-crystal cell, normalized so its maximum coincides with the maximum of the evaporated-layer cell.

SUMMARY

Present-day solar cells are much too expensive to provide electrical power for everyday terrestrial applications, but solar cells made by a deposition technique from a suitable raw material would be inherently inexpensive. A cost of $1 to $10 per square foot of a 10-percent-efficient solar cell would probably bring the cost into the range of economic feasibility for home use. A practical and inexpensive cadmium-sulfide solar cell that is 3.5-percent efficient has been achieved. Such cells may be perfected to yield 6 percent; however, with further research other materials, such as silicon, may yield an inexpensive film-type cell with efficiencies approaching 10 percent.

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PAUL RAPPAPORT studied chemistry for three years at Temple University before entering the U.S. Navy in 1944. In 1946 he entered the Carnegie Institute of Technology and received a BS in Physics in 1948 and an MS in physics in 1949. During 1948-1949 he worked part time on the C.I.T. synchrocyclotron. He joined RCA Laboratories in July 1949 in the Electronics Research Laboratory. He worked for two years on secondary electron emission, then on an investigation of possible uses of radioactive materials in electronics. This included development of a dielectric charger device, followed by work on the direct conversion of nuclear energy into electricity using semiconductors in conjunction with radioactive materials. It was this work that led to his invention of the Atomic Battery, the immediate predecessor of the Solar Battery. During the past six years, his activity has also included the fields of radiation damage to semiconductors, and research on the III-V compounds. Mr. Rappaport is the author or co-author of 25 publications; he has 15 patent applications and has received two *RCA Achievement Awards* for outstanding work in research. In April of 1960 he was appointed head of the Energy Conversion Research Group. He is a member of PiMu Epsilon, Sigma Xi, and the APS, and is listed in *American Men of Science* and *Who's Who in Atoms*. He is currently serving on several government research advisory committees on Electrical Energy and Space Power Systems. These include the National Aeronautics and Space Agency, and the National Academy of Sciences', Materials Advisory Board. He has also been appointed to the American Rocket Society's and the AIEE's Energy Conversion Committees for the current year.

DR. HERBERT I. MOSS received the BS in Chemistry from the University of Louisville, Louisville, Ky., in 1953, and the Ph.D. in Inorganic Chemistry from Indiana University in 1960. While at Indiana University, he held a graduate teaching assistantship from 1953 to 1956, and a research assistantship from 1956 to 1959. He joined the staff of RCA Laboratories, Princeton, in 1959, and is currently engaged in research on photovoltaic materials. Dr. Moss is a member of the American Chemical Society, American Institute of Chemists, Electrochemical Society, and Sigma Xi.

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ROTARY PLASMA GUN
Applied Research on Plasma Acceleration

In recent RCA ENGINEER articles[1-3], the field of plasma physics has been reviewed and some specific applications discussed. DEP Applied Research is now carrying out work on plasma acceleration, electron-beam–plasma interactions, Cerenkov generators, high-temperature gas dynamics, and magnetohydrodynamics. Described here is the work on plasma acceleration, some potential applications — which includes spacecraft propulsion — and the makeup of the plasma acceleration laboratory in Camden.

by **R. E. SKINNER**
Plasma Physics Group
Applied Research
DEP, Camden, N. J.

Plasma acceleration devices offer solution of a critical space propulsion problem—how to obtain high payload-to-total-vehicle weight ratios for spacecraft. This criterion implies low fuel consumption by the propulsion system, as well as low specific weight of the propulsion system. Plasma acceleration devices achieve this goal by giving directed energy to the propellant at high exhaust velocities. They, in turn, derive the energy required from an auxiliary power system instead of from the propellant, as in the case of a conventional rocket engine. The high-velocity directed energy is imparted to the propellant by ionizing it and, in turn, making use of one of a number of basic physical mechanisms for accelerating the ionized propellant (plasma) to high velocities (5×10^6 cm/sec and up).

The initial goals of the Plasma Acceleration Program in DEP Applied Research are to produce high-velocity plasmas, and to study the physics of devices for such production and of the plasma itself. Concurrent studies are being made of possible applications of plasma accelerators and high-velocity plasmas, which include space propulsion and injection into the entropy-trapping type of thermonuclear fusion machines.

THE ROTARY PLASMA GUN

DEP Applied Research effort has been concentrated on one particular device for producing high-velocity plasmas, the rotary plasma gun (Figs. 1-4). This concept was chosen because of its possible high efficiency, lack of obvious instabilities, and basic simplicity. Its essential elements are seen to be a pair of coaxial cylinders, an applied axial magnetic field, a toroid of plasma located between the electrodes, and a capacitor (bank) which is discharged across the electrodes.

The principle of operation is as follows: The discharge current from the capacitor flows up one cylinder, radially through the plasma, and back on the other cylinder. It is assumed that the temperature and density of the plasma are such that the plasma has a high conductivity, of the order of, or greater than, copper. The current flow does two things. First, the current flow on the coaxial cylinders produces the usual azimuthal magnetic field associated with a coaxial transmission line. This field, in combination with the externally applied field, leads to a resultant helical field geometry. Second, the radial current flow through the plasma toroid (or ring) produces a body force on the toroid analogous to the force on a current-carrying wire in a magnetic field. The force vector arising from the interaction of the radial current with the self-produced azimuthal field is directed away from the end of the gun connected to the capacitor bank and produces an axial acceleration a_z and hence gives an axial velocity v_z to the plasma toroid. The interaction of the current with the externally applied axial field produces an azimuthal force and therefore, acceleration a_θ and velocity v_θ. The resultant motion of the plasma is analogous to that of a screw, and at any point, its motion is normal to the resultant magnetic field. Finally, the rotational motion is converted to linear motion in the divergent axial magnetic field at the nozzle and beyond.

The conversion from rotational to linear energy in the divergent magnetic field is similar to the conversion of random thermal energy to directed energy that takes place in an ordinary rocket engine nozzle. Here, however, the divergent field forms a magnetic nozzle.

There are important differences between the magnetic and the mechanical nozzles, and it still remains to establish the conditions under which this conversion can take place as well as to experimentally demonstrate the mechanism.

The device described can be regarded as a cross between the homopolar motor (or hydromagnetic capacitor) under study at the University of California Radiation Laboratory[4] as a possible fusion machine and the linear coaxial rail gun being investigated at Los Alamos[5] as an injection device for entropy-trapping fusion machines. Which mode of operation dominates is determined by

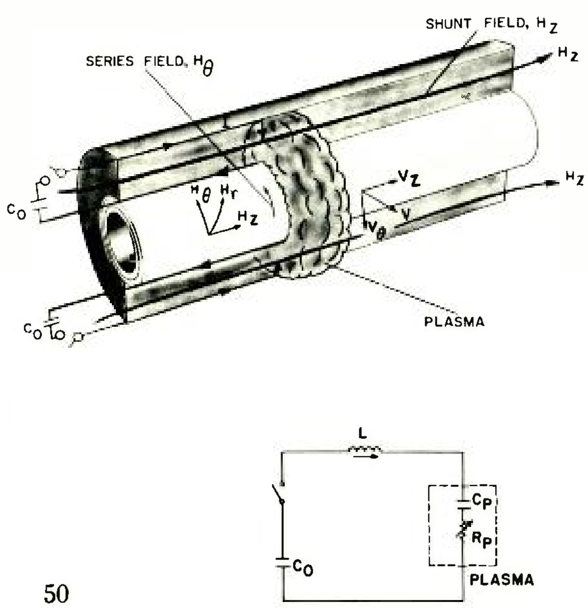

Fig. 1—Coaxial plasma gun and equivalent circuit.

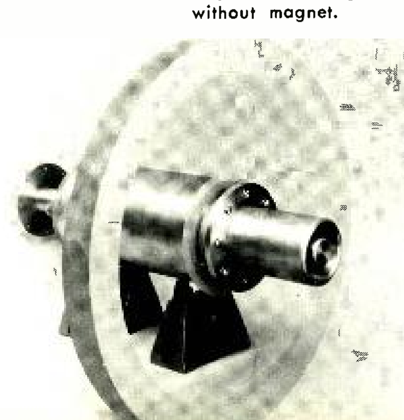

Fig. 2—First laboratory model of gun, without magnet.

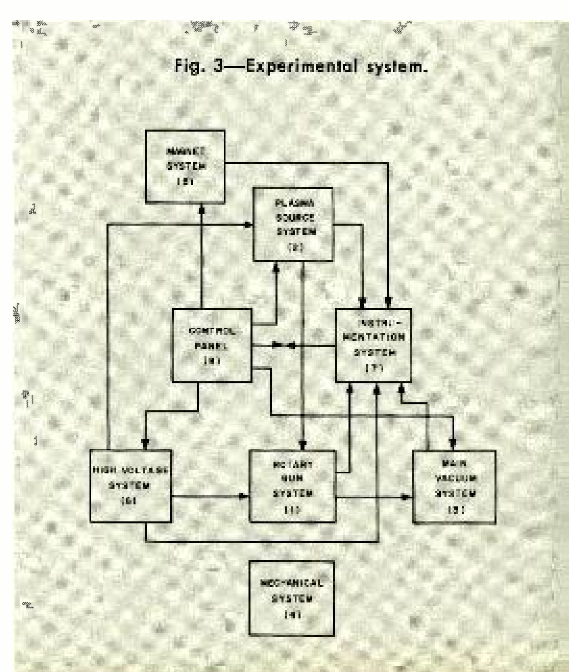

Fig. 3—Experimental system.

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the relationship between the azimuthal and applied fields and the toroid mass.

A complete mathematical analysis shows that the rotary gun may be represented in terms of the equivalent circuit shown in Fig. 1. Here, the energy stored in the capacitor C_p represents the energy of rotational motion, and the energy dissipated in the variable resistor R represents the energy of translation of the plasma. It is clear from the equivalent circuit that the current flow is oscillatory and damped in nature. It can be shown that the damping term increases with time. Further, if the conditions of operation are chosen such that the rotary mode of operation is dominant, then the equivalent circuit reduces to that of the capacitor C_0 charging capacitor C_p thru an inductor L_0. Under such conditions, it is possible to get all the energy initially stored in the capacitor C_0 into the capacitor C_p and, therefore, into rotational energy of the plasma. This condition occurs when $C_0 = C_p$ and at a time equal to the half period of the oscillatory frequency. This feature brings out a major advantage of this scheme for plasma acceleration over others that have been proposed: namely, it is theoretically possible to convert all the initial stored energy into kinetic energy of the plasma. This neglects dissipation in circuit resistances and the plasma. Furthermore, the matching conditions are well defined and known. The first laboratory model of the gun, without magnet, is shown in Fig. 2.

ACCELERATION LABORATORY

Experiments in plasma physics, no matter how simple in concept, are extremely difficult to perform. As is evident from the description of the C-Stellarator facility given in recent articles[3], a laboratory for investigating the properties of the device described can easily become quite complex.

In Fig. 3 is shown a block diagram of the experimental system. In Fig. 4 is shown a picture of the laboratory as it exists at this time.

From Fig. 3 it is seen that the experimental system is composed of eight subsystems: 1) rotary gun, 2) plasma source, 3) main vacuum, 4) magnet, 5) mechanical system, 6) high-voltage system, 7) control panel, and 8) instrumentation system.

Rotary Gun

The rotary gun system consists of the main capacitor bank, a transmission line, and the rotary plasma gun. The main capacitor bank is a 15-μf, 20-kv, low-inductance energy-storage capacitor. The inductance of the capacitor is 55 nh(10^{-9} henries). The transmission line is a specially constructed parallel plate assembly with a self-inductance of approximately 3 nh. The total estimated inductance of the system is 80 nh, the remaining 22 nh arising from the inductance of the coaxial electrodes up to the point of plasma injection. The ringing frequency of this system is 205 kc, giving an acceleration time of 2.4 μsec.

Plasma Source

The plasma source system generates the plasma and injects it into the region between the coaxial electrodes of the gun in as close an approximation of a toroid as possible. The initial plasma source for these experiments is a plasma button[6], i.e., two electrodes (currently copper) spaced a few thousandths of an inch apart across which a capacitor bank is discharged. The resultant arc vaporizes and ionizes some of the electrode material to form the plasma. The reasons for this particular choice of source are 1) long lifetime, 2) possibility of an injection time short as compared to main acceleration time, and 3) within limits, the amount of injected plasma can be varied in a controlled fashion. The second of these reasons is the most important; it allows a regime of behavior not investigated by others to be explored.

The plasma source system consists of 1) a source assembly which is located inside the center electrode, 2) a special flexible, low-inductance coaxial transmission line, 3) the capacitor bank, shunt, spark gap switch, and trigger assembly, 4) the spark-gap switch and vacuum system, and 5) the trigger (firing) circuitry. Special techniques had to be developed for the fabrication of each of these subassemblies. Of particular interest is the button and the graded-vacuum spark-gap switch. The particular button source used is made from two 40-mil copper wires spaced on 45-mil centers and potted in a low-temperature ceramic.

The requirements imposed upon the design of the switch are quite typical for pulsed circuitry involved in plasma physics, and are as follows: 1) ability to hold off high voltages (here 20 kv), 2) ability to handle currents ranging up to at least 0.5 megampere, 3) very low inductance (5 to 10 nh), 4) preferably low jitter, 5) quiet operation, and 6) compatibility with the geometry of the rest of the system (here coaxial). An examination of the literature showed that the graded-vacuum spark gap switch is still the best technique for satisfying the above requirements. A cross-sectional view of the final switch

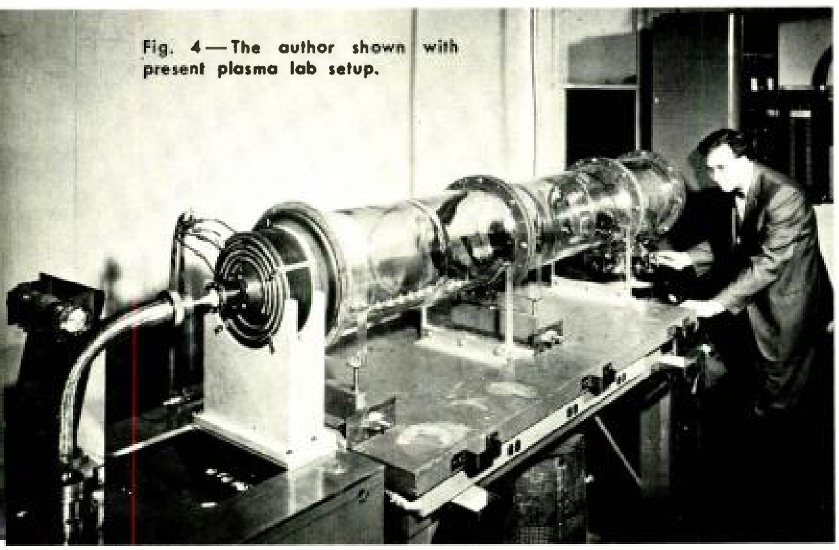
Fig. 4 — The author shown with present plasma lab setup.

R. E. SKINNER received his BA in Physics and Mathematics from Reed College in 1955. His Bachelor's thesis dealt with the interdependence of cosmic-ray stars in nuclear emulsions. In 1955-1956, he was a National Science Foundation pre-doctoral Fellow at the California Institute of Technology and received his MS degree in Physics from there in 1957. In 1959, he attended a special summer course on Plasma Dynamics at MIT. At Reed College, Mr. Skinner held teaching and research assistantships. In the summer of 1955 he worked with the theoretical Physics Group of the Atomics International Division, North America Aviation. In September 1955 to June 1956 he served as a consultant to Atomics International on reactor kinetics theory. In June 1956, Mr. Skinner joined the full-time theoretical-physics staff of Atomics International, where he performed research on reactor kinetics, reactor static theory, theory of light scattering, and the theory of bubble nucleation and growth. In March 1959, Mr. Skinner joined the staff of DEP Applied Research. Since that time he has performed theoretical work on the detection of weak magnetic fields, nuclear weapon effects, and has carried out experimental and theoretical work in plasma physics. His most recent investigations include theoretical and experimental studies of plasma acceleration and electron-beam–plasma interactions; he is Project Engineer for these two programs. Mr. Skinner has published numerous reports and articles. He is a member of the American Physical Society and its Plasma Physics Division, and the American Nuclear Society.

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design is shown in Fig. 5. The switch operates in the following fashion: The voltage from the source capacitor bank is divided between the plasma source and the switch. A high potential exists between the cathode and the anode of the switch. The center electrode floats at a potential roughly equal to one-half that between anode and cathode. Discharge initiation across the electrodes of the plasma button trigger located in the cathode causes a plasma to be generated and propelled downward across the evacuated gap. Injection of the plasma causes the gap to break down with a time delay of up to 10 μsec and with extremely low jitter. The value of the time delay is determined by the pressure in the evacuated region (0.1 to 20 microns of mercury). Properties of the switch such as time delay, jitter, and hold-off voltage are important. Experiments related to determining these properties and the effects of parameters, such as pressure on delay time, have been performed and further experiments are planned. The switch trigger button is triggered by a thyratron-type pulse generator which provides 30 kv peak pulses of the order of 20 nsec (10^{-9} seconds) wide. The circuit is typical of those used in plasma physics experiments. The particular circuit used is shown in Fig. 6. The 30-kv pulse is derived from the voltage doubling action at the effectively open end of the pulse-forming cable.

The source capacitor bank is composed of two special 0.05 μf, 20-kv, energy-storage capacitors. The over-all inductance of the source system is estimated to be 29 nh, and the measured ringing frequency is 2.24 Mc, giving an injection time of the order of 4×10^{-7} μsec. Measured velocities of the plasma produced by the source alone are 3×10^{6} cm/sec for 4 kv on the source capacitor bank, and 6×10^{6} cm/sec for 8 kv on the source capacitor bank.

Main Vacuum

The main vacuum system consists of two 3-foot lengths of 13-inch-outside-diameter Pyrex tubing and a Pyrex tee with a 1.5-foot cross length. This arrangement gives an over-all length of 7.5 feet to the system and a volume of 187 liters. All vacuum-tight glass-to-glass joints are ground-glass-to-ground-glass using Dow Corning silicone high-vacuum grease. All glass-to-metal joints are neoprene *O*-rings or gaskets and silicone high-vacuum grease. The end opposite the gun is sealed by a metal plate which contains provisions for bringing out coaxial transmission lines, a controlled leak, and other instrumentation leads. The system is pumped down by a 4-inch oil diffusion pump. Vacuums of 3×10^{-6} mm-Hg are readily obtained with no nitrogen in the cold trap, and vacuums as high as 5×10^{-7} mm-Hg have been obtained on occasion without nitrogen in the cold trap. The gun is sealed to a flat 1.5-inch-thick Pyrex disk by *O*-ring seals. This disk, in turn, is sealed to the vacuum system by the usual ground-glass-to-ground-glass seal.

Magnet

The present magnet system consists of an air-core solenoid magnet capable of producing 800 gauss at its edge together with a special three-phase, 20-kw, 300-volt silicon-diode-rectifier power supply. Air-core magnets capable of producing fields up to 10 kilogauss have been designed and will be incorporated into the system after the completion of the initial experiments.

Mechanical System

The mechanical system consists of 1) a gun cart moving on precision tracks on which are mounted the gun, plasma source system, and capacitor banks; and 2) the adjustable *V*-blocks for aligning the pieces of the main vacuum system. The cart contains provisions for tilt and rotational adjustments to permit alignment of the gun with respect to the rest of the main vacuum system. The tracks allow the gun and attached hardware to be moved up to and away from the end of the main vacuum system, thereby facilitating access to the vacuum system and those portions of the gun located inside the vacuum system. The adjustments built into the cart allow adjustment of the parallelness of the Pyrex end-plate with respect to the main vacuum system to better than 0.0001 inch with good reproducibility.

High Voltage and Controls

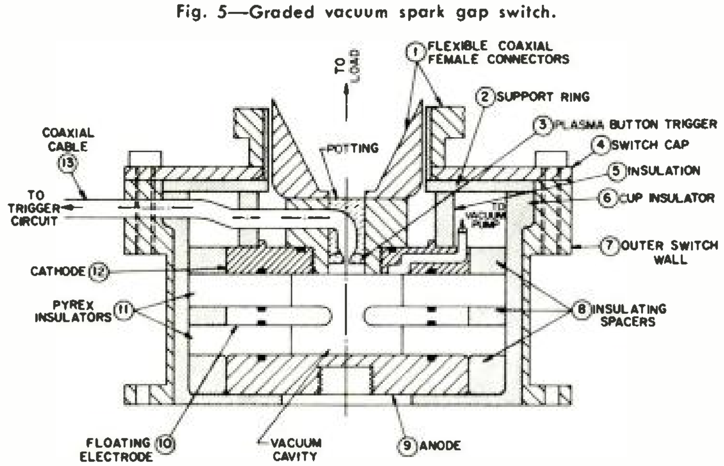
The high-voltage system consists of a 0-to-20-kv, 5-kw power supply and high-voltage switching and protection circuitry for charging the capacitor banks. A sequence-timing circuit has been designed and is being installed to allow completely automated charging of the capacitor banks and firing of the system. Automation of the firing cycle was necessitated by charge-leakage problems, photographic problems, and the desire to reduce the number of individuals required to perform an experiment. The control panel contains switches for remotely controlling all high-voltage switching, the magnet, and circuitry for generating the firing pulse. Safety interlocks are also included.

EXPERIMENTS AND INSTRUMENTATION

In discussing the instrumentation system, it is necessary to consider simultaneously the types of experiments to be carried out and the techniques available for the performance of these experiments. The measurements being made can be divided into two sub-classes: first, those measurements such as charging voltage, magnetic field, etc. which are common to all experiments; and second, those measurements peculiar to specific experiments.

For the first type it was necessary to provide a means of measuring the voltage to which the capacitor banks are charged, the magnet current, the main-vacuum-system pressure, switch-vacuum-system pressure, and capacitor-bank discharge current as a function of time for each of the two banks. The only nonstandard measurement is that of capacitor-bank discharge current as a function of time. The problem is to measure currents ranging from one kiloampere to one megampere over time scales ranging from 2 to 0.2 μsec. Such measurements have necessitated development and incorporation of special shunts into each of the capacitor bank systems. Further, the shunts must be designed in a fashion consistent with the system

Fig. 5—Graded vacuum spark gap switch.



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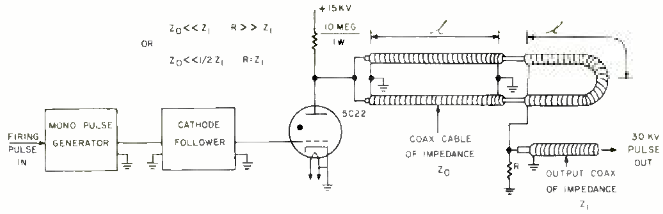

Fig. 6—Trigger pulse generator circuit.

geometry and in a manner to minimize ground-loop problems. The shunt for the source system is merely a segment of the outer wall of the graded-vacuum spark gap switch. The leads are brought in through the outer switch wall by means of special feed-throughs and are attached to the inside of this wall.

The shunt for the main-bank transmission line consists of a piece of resistive element (stainless steel) inserted into the ground-return lead of the parallel-plate transmission line at a point just above the top of the gun cart. The top of the gun cart serves as a ground reference point for the entire system. To calibrate the shunts, the d-c resistance is measured by passing a known current through the shunt and measuring the voltage developed across the shunt terminals. The d-c resistance is then given by Ohm's Law. To determine the resistance of the shunts under operating conditions, i.e., at the ringing frequency of their respective capacitor banks, it is necessary to apply skin-effect corrections to the d-c resistance. The resistance of the switch-current shunt is 35 μohms and the main-bank shunt d-c resistance is 168 μohms. The discharge current vs time is displayed on a Tektronix 555 dual beam oscilloscope and recorded using an oscilloscope camera.

The ultimate information to be gained from the experiments includes the effects of plasma mass, applied-axial-magnetic field strength and geometry, electrode geometry, and plasma density on the efficiency of the gun; plasma velocity; and conversion of rotational to translational motion in the magnetic nozzle. To obtain this information it is necessary to measure plasma velocity, plasma mass or equivalently kinetic energy or momentum, plasma density, and translational acceleration as a function of position in the magnetic nozzle.

Plasma Velocity

The determination of plasma velocity is perhaps the simplest measurement to carry out. There are at least five techniques available for measuring the plasma velocity:

1) The use of electrostatic probes at two points to determine the time of arrival of the plasma at the successive points and thus velocity by time of flight.
2) Application of magnetic probes in a fashion similar to that for electrostatic probes.
3) Application of photomultiplier tubes as in 1) and 2).
4) Measurement of Doppler shift of a microwave signal reflected by the plasma.
5) High-speed photography.

Of these, the use of electrostatic probes is the simplest, although not necessarily the best, approach. All these techniques are capable of providing data on acceleration as a function of position. The most expensive of these techniques is that of high-speed photography. The best is probably the Doppler shift technique. The probe, photomultiplier, and photographic techniques suffer from the fact that the boundaries of the plasma are not well defined.

Experiments with the plasma source have shown that the plasma can have an extent sufficient to encompass simultaneously two probes spaced 2 feet apart. This problem results from the difficulties of generating a plasma in a time sufficiently small to allow the application of impulse time approximation to the type of geometry dictated by experimental considerations and probe geometry. A typical oscilloscope trace produced by a plasma from the plasma source as detected by two electrostatic probes, connected in parallel, positioned 2 feet apart, along the axis of the system is shown in Fig. 7. The large-amplitude high-frequency oscillations at the beginning of the trace show the ringing of the source capacitor bank through the source as picked up on the electrostatic probes acting as antenna. The basic information available from this trace is the time of firing of the source, the ringing frequency of the source, the time of cessation of firing of the source, the time of arrival of the plasma at the first probe, and the time of departure of the plasma from the last probe. From the latter information, the velocity of the plasma front, the approximate extent of the plasma, and the velocity of the tail of the plasma may be ascertained. It is clear that no information is obtainable about acceleration of the plasma as a function of distance. This dearth presents a dilemma, since information about acceleration is highly desirable. Differentiation of the signal from each probe with the resultant outputs connected in parallel and fed to a high-speed oscilloscope offers a possible solution.

Plasma Mass

The measurement of plasma mass is the most difficult of the measurements to be made in this type of experiment. No completely satisfactory technique has been developed by any of the researchers in this field. The problem is compounded in the present experiments by the fact that the plasma toroid must achieve dimensions on the order of 1 foot in diameter to achieve 95-percent conversion of rotational energy to translational energy in the magnetic nozzle. The resultant large extent of the plasma complicates measurements. Techniques applied in the past to mass (or, equivalently, kinetic energy) measurements include ballistic pendulums and calorimetric techniques. In either of these approaches the major problem is to ensure that all the plasma is captured by the detector. Most often, some unknown fraction of the plasma is back-scattered out of the detector, resulting in an unknown experimental error. Another possible approach is the use of a dynamic-pressure detection apparatus such as a quartz crystal. The problem of mass measurement is therefore one for which no satisfactory solution has yet been found.

Plasma Density

There are several techniques available for measuring plasma density, including Langmuir (electrostatic) probes and microwave techniques. It appears that the best techniques available for this type of experiment is to use a microwave bridge to detect phase shift due to the presence of the plasma in one leg of the bridge. This technique assumes that the extent of the plasma is known. The bridge generally operates in the millimeter-wave region. A typical microwave bridge circuit is illustrated schematically in Fig. 8. This technique poses problems for this type of experiment because of the wide bandwidth imposed on the video detection system by the short time scales involved.

Translational Acceleration

The verification of the magnetic nozzle effect requires the simultaneous meas-

Fig. 7—Plasma oscilloscope trace.

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urement of plasma velocity, acceleration, and plasma extent as a function of axial distance from the electrodes. The only measurement involved here not discussed yet is that of determination of plasma extent. The simplest, but by far the most expensive, technique is high-speed photography. This approach is treacherous, since there are experimental indications that the extent of the plasma is much greater than that indicated by the luminosity. Other approaches to this measurement problem include the use of an array of probes, either electrostatic or magnetic, spaced radially from the axis and connected to an array of oscilloscopes; an array of photomultipliers similarly connected; or, possibly, microwave techniques. The complexity of the instrumentation for this measurement depends a great deal on how closely the actual behavior of the magnetic nozzle approximates that indicated by theory. If the magnetic nozzle works as expected, then the experiment will be relatively simple. Any departure from predicted behavior immediately will result in a rapid increase in complexity of instrumentation. The expected behavior is that the outer edge of the plasma ring will follow the magnetic field line on which it leaves the electrode. If this is the case, the application of two arrays of equally spaced velocity measurement probes, whose radial position is contoured to the appropriate field lines, would provide verification of the theory in one simple experiment.

APPLICATIONS

As mentioned at the beginning of this article, the first actual application of plasma acceleration devices will probably be to space propulsion. These devices provide high specific impulse I_{sp}, low thrust, power-limited engines for space propulsion, satellite maneuvering, and attitude control. Specific impulse is the ratio of thrust to weight of fuel expelled per unit time, and may be expressed as $I_{sp} = v_e/g$. Thus, high specific impulse implies large exhaust velocities v_e. The specific impulse range for magnetohydrodynamic plasma accelerators is 5×10^3 to 10^6 seconds. The advantage of this type of engine lies in low propellent consumption and, therefore, high payload-to-total-vehicle-weight ratios—as high as 0.95. The exhaust power for a rocket propulsion device for fixed propellent consumption rate varies as v^2_e, while the thrust varies as v_e. For plasma-acceleration devices, the exhaust power is provided by separate energy source and, hence, the engine is power-limited. As a result, as the specific impulse is increased, the thrust must be reduced. A better defining parameter than thrust is the ratio of initial acceleration, a_i, to the acceleration due to gravity, g; that is, a_i/g. Typical ratios lie between 5×10^{-4} and 10^{-6}.

In using high-specific-impulse, low-thrust engines, mission time is traded for reduced propellent consumption and, hence, high payload-to-total-vehicle-weight ratios. For any given mission, it can be shown that for constant thrust programming, there is an optimum specific impulse. The further away the destination, the higher the optimum specific impulse. In a space vehicle, the power for powering such engines will come from nuclear power plants now in the early developmental stages and which eventually will possess specific weights of 10 lbs/kw electrical or less.

The next application for plasma acceleration devices is as an injector for entropy-trapping fusion machines[7]. Here, the accelerator is used to give a tight bunch of plasma a large amount of directed energy. The tight bunch of plasma is then capable of forcing its way between the magnetic lines of force along the axis of cusped field geometry or at the midpoint between the pickets in a picket-fence geometry (Fig. 9). Once

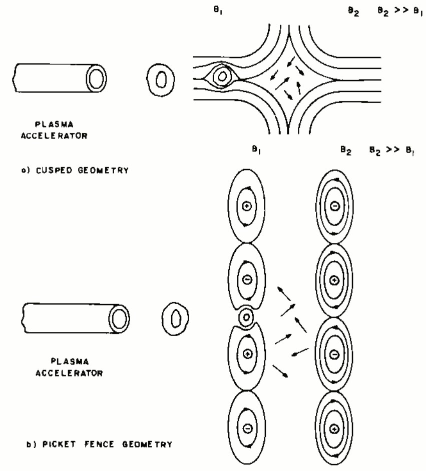

Fig. 9 — Entropy trapping machines. Top: cusped geometry. Bottom: picket-fence.

inside the field-free region, the directed energy becomes randomized and the plasma can no longer escape unless the highly improbable event of all the plasma coming back together in a bunch with the bunch having the appropriate velocity vector occurs. The advantage of this fusion machine over others is the fact that the plasma is contained within a field-free region, and hence, there are no sychrotron (cyclotron) radiation losses.

Other possible, but much less studied, applications include use as a high-energy accelerator, as a source of neutralized electron beams, and perhaps eventually as a source of r-f power. The application as a high-energy particle accelerator is particularly enticing since $\vec{j} \times \vec{B}$ forces with achievable fields and currents are at least 10^{12} times those producible by electric fields.

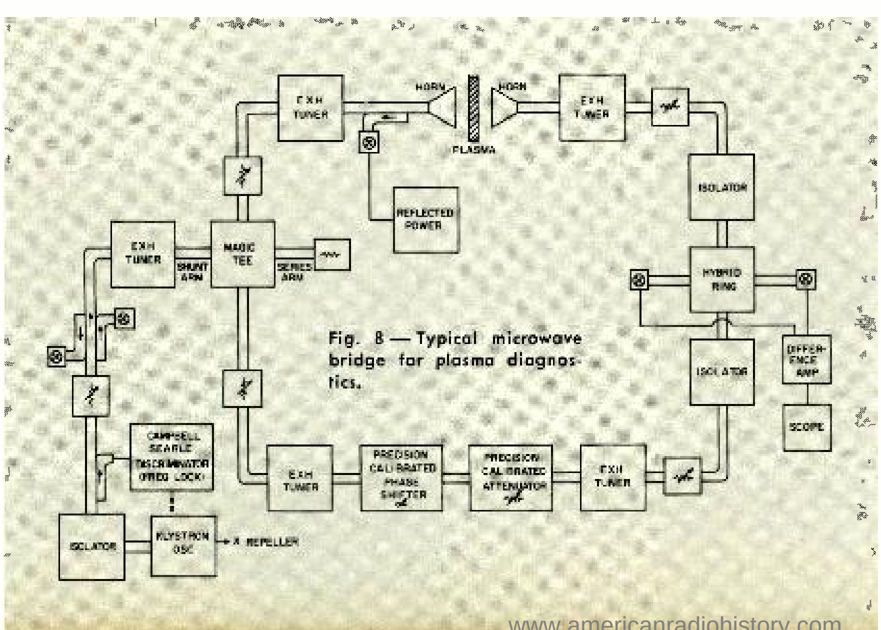

Fig. 8 — Typical microwave bridge for plasma diagnostics.

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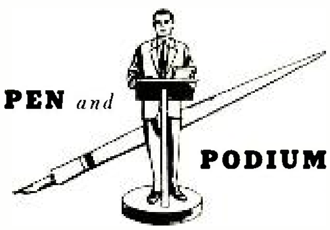

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M. Glicksman: IRE Canadian Electronics Conference, Toronto, Canada, Oct. 2-4, 1961

Television Image Enhancement Techniques
W. S. Pike: Conference on Scanning Techniques in Biology & Medicine, Oct. 15, 1961

Electronic Sound Absorber
J. C. Bleazey: Audio Engineering Society, New York, N.Y., Oct. 9, 1961

Solar Cells — The Present State of the Art
P. Rappaport: American Rocket Society, New York, N.Y., Oct. 10, 1961

Generation of a Synthesized Plasma
J. R. Fendley, K. G. Hernqvist: 14th Annual Gaseous Electronics Conference, Schenectady, N.Y., Oct. 12, 1961

Fundamental Reflectivity of Gray Tin Single Crystals
M. Cardona: German Physical Society Meeting, Vienna, Oct. 15, 1961

More About Threshold Logic
R. O. Winder: 1961 Fall General Meeting, Detroit, Michigan, Oct. 15-20, 1961

Television in Biology and Medicine
V. K. Zworykin: Comite International de Television Congress, Milan, Italy, Oct. 16, 1961

Pressure Effects in Germanium Tunnel Diodes
R. M. Williams: 1961 Electron Devices Meeting, Washington, D.C., Oct. 26-28, 1961

After Treatments of CdS Single Crystals Grown by the Chemical Transport Method
J. A. Beun, R. Nitsche and H.V. Bolsterli: Mtg. on Physics & Chemistry of Phosphors, East Berlin, Germany, Oct. 27, 1961

Processing of Information
H. F. Olson: Philosophical Society, Philadelphia, Pa., Oct. 27, 1961

A Print Out System for the Automatic Recording of the Spectral Analysis of Spoken Syllables
H. F. Olson and H. Belar: Acoustical Society of America, Cincinnati, Ohio, Nov. 9, 1961

The Nature of the One-Ion Models of the Ferrimagnetic Anisotropy
P. J. Wojtowicz: Conference on Magnetism, Phoenix, Arizona, Nov. 12, 1961

High Temperature Susceptibility of Garnets: Exchange Interactions in YIG and LuIG
P. J. Wojtowicz: Conference on Magnetism, Phoenix, Arizona, Nov. 12, 1961

Permalloy-Sheet Transfluxor — Array Memory
G. R. Briggs and J. W. Tuska: Conference on Magnetism, Phoenix, Arizona, Nov. 13, 1961

Flux Reversal in Ferrite Cores Under the Effect of a Transverse Field
Kam Li: 7th Conference on Magnetism & Magnetic Materials, Phoenix, Arizona, Nov. 15, 1961

Hydromagnetic Instabilities in Electron-Hole Plasmas: Theory and Experiment
M. Glicksman: Plasma Physics Div. of American Physical Society, Colorado Springs, Nov. 15-18, 1961

Medical Electronics
V. K. Zworykin: University of Bologna, Bologna, Italy, Oct. 1961

Compatible Monophonic Reproduction of Sound from Stereophonic Disc Records
H. F. Olson: Audio Engineering Society, New York, N.Y., Oct. 13, 1961

Patents Granted TO RCA ENGINEERS

Based on Summaries Received over a Period of about Two Months.

DEFENSE ELECTRONIC PRODUCTS

Transmitter
3,002,161—Sept. 26, 1961; M. S. Feryszka

Automatic Gain Control Circuit
3,005,094—Oct. 17, 1961; C. H. Taylor

Transmitter Gate Circuits
2,995,664—Aug. 8, 1961; D. E. Deuitch

Spacer for Mounting Electronic Elements on Supports
2,999,895—Sept. 12, 1961; C. M. Smith

Beam Convergence Apparatus for Tri-Color Kinescope
3,002,120—Sept. 26, 1961; B. R. Clay

Methods and Means for Providing a Three-Dimensional Signal Display
3,003,146—Oct. 3, 1961; F. D. Covely, 3rd

Gate Circuits
3,004,255—Oct. 10, 1961; E. R. Wainshilbaum

ELECTRON TUBE DIVISION

Information Handling Devices
2,999,167—Sept. 5, 1961; F. Sterzer

Method of Delaminating Laminated Glass Structures
2,999,781—Sept. 12, 1961; R. E. Davis

Shift Circuits
3,002,108—Sept. 26, 1961; F. Sterzer

Electrical Heater Unit
3,002,076—Sept. 26, 1961; M. K. Massey

Electron Tube
3,004,185—Oct. 10, 1961; G. M. Rose, Jr.

Tube Insertion Device
3,004,649—Oct. 17, 1961; H. C. Waltke and R. W. Green

Cathode-Ray Tubes of the Focus-Mask Variety
3,005,921—Oct. 24, 1961; R. H. Godfrey

Cathode-Ray Tubes of the Focus-Mask Variety
3,005,927—Oct. 24, 1961; R. H. Godfrey

RCA INTERNATIONAL DIVISION

Mechanism for Feeding Strip Material
2,999,621—Sept. 12, 1961; C. G. Mayer and J. B. Killow

RCA VICTOR RECORD DIVISION

Off-Center Indicator
3,000,005—Sept. 12, 1961; R. C. Moyer

HOME INSTRUMENTS DIVISION

Signal Amplitude Discriminatory Circuit
3,005,048—Oct. 17, 1961; H. C. Goodrich

Battery Charger
3,005,141—Oct. 17, 1961; C. H. Emmons

BROADCAST AND COMMUNICATIONS DIVISION

Film Viewer and Reproducer
3,002,434—Oct. 3, 1961; H. G. Reuter, Jr.

Frequency Modulation Multiplex Arrangement
3,005,167—Oct. 17, 1961; A. H. Bott and F. E. Talmage

Single Film Rerecording System
3,002,055—Sept. 26, 1961; O. B. Gunby

ELECTRONIC DATA PROCESSING

Escapement Mechanism
2,998,873—Sept. 5, 1961; A. Burstein

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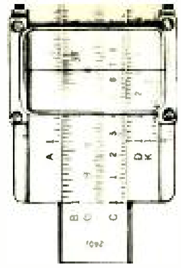
Engineering  **NEWS** *and* **HIGHLIGHTS**

FORMER IEP ACTIVITIES REASSIGNED

The activities formerly grouped under "Industrial Electronic Products" (IEP) have been reassigned to other RCA operating units and into separate operating units, as follows:

Electronic Data Processing (formerly the EDP Division of IEP) is now a separate operating unit under **T. A. Smith,** Executive Vice President, EDP. Headquarters are in Cherry Hill.

The newly named *Broadcast and Communications Products Div.* (formerly Broadcast and TV Equipment Div. of IEP) is responsible for the operation of the Meadow Lands Plant and for the following product lines (in addition to its previous responsibilities in high-power transmitters; video cameras, recording, and broadcast equipment, etc.): mobile communications and audio-visual products manufacturing; RCA Radiomarine engineering and manufacturing; microwave equipment engineering and manufacturing; and Detroit industrial machine tool equipment. **C. H. Colledge** is Division Vice President and General Manager, B&C.

The RCA Service Co. is now responsible for: mobile communications engineering and marketing; RCA Radiomarine marketing; audio-visual products engineering and marketing; and graphic products. These are grouped under **G. W. Pfister,** Division Vice President, Commercial Services.

DEP is now responsible for the Commercial Aviation Equipment product line and **J. R. Shirley** Mgr., Aviation Equipment, will report to **H. R. Wege,** Vice President and General Manager, Data Systems Div., Van Nuys, Calif.

The Electron Tube Division is now fully responsible for the Special Products Line, including Citizen's Band Radio.

Refer to *Engineers in New Posts*, p. 59, for staff announcements in EDP, B&C, and the RCA Service Co. relative to the above changes. (Also see p. 60 for important procedure changes in getting company approvals for technical papers in these areas.)

EXTENSIVE TRAINING PROGRAM UNDERWAY FOR NEW HI ENGINEERS

A series of *Engineering Training Program* lectures is now underway in Indianapolis for new engineers in the Home Instruments Division. The program combines formal lectures and ample time for informal discussion, and consists of ten sessions, as follows (bold-face names are RCA men delivering the lectures):

1. *Introduction to RCA,* **Zimmerman** (completed).
2. *Economics,* **Delk, Rigsbee,** and **Anderson** (completed).
3. *Return of Assets,* **Lincoln** (completed).
4. *Merchandising and Styling, early Jan., 1962, 2 hrs.* Product conception, customer requirements, competition, relationship Engineering; Materials, Sales, changes, **Huxtable** and **Hanselman.** Styling concepts, trends, sources, etc., **Madawick.**
5. *Production Control and Purchasing, late Jan., 1962, 1½ hrs.* Requisitions, relationships with engineering and purchasing, scheduling, etc., **Gallagher.** Economical buying, payments, relations with engineering, scheduling parts for the factory, engineering contacts with vendors, etc., **Allen.**
6. *Business Plans, Sales, Advertising, early Feb., 1962, 2 hrs.* Market research, business plans, etc., **Atkinson.** Markets, distributors, dealers, sales meetings, feedback from the field, etc., **Saxon.**

DR. PAN HONORED WITH MAJOR AWARD

Dr. Wen Yuan Pan has been awarded the highest honor of the Chinese Institute of Engineers, New York, N.Y.—their "Professional Accomplishment Award," in recognition of his *distinguished contribution to*

IRE AND AIEE CONSIDER MERGER

First steps to consider consolidation of the two largest engineering societies in the world, the American Institute of Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE), were taken recently. A committee has been formed to determine the feasibility and form of such consolidation. The proposed new organization would be international in scope and involve 150,000 member engineers, scientists, educators, and industrialists. AIEE was organized in 1884 and has approximately 70,000 members from the United States and Canada. IRE, organized in 1912, has a total membership of 91,000 and is international in scope. Approximately 6,000 members now belong to both societies.

RCA INTERNATIONAL TO BUILD 3,060-MILE TELECOMMUNICATIONS NETWORK

The International Cooperation Administration (ICA) has awarded a $16.4 million contract to the RCA International Div. for a 3,060-mile telecommunications network linking Turkey, Iran, and Pakistan.

Described as an important part of the U. S. Mutual Security Program, the network will extend from Ankara (as the westernmost terminus) to Teheran and thence to Karachi, thus connecting the three host-country capitals. When completed it will be turned over by the ICA to the host countries.

The system will be known officially as the Cento Telecommunications Network, taking its name from the Central Treaty Organization of which Turkey, Iran, Pakistan and the United Kingdom are members.

Charles A. Passavant, the Division's Mgr., Communications Administration, will be Project Manager. RCA Victor Company, Ltd., will provide design and build all microwave radio equipment, including the MM-600 radio relay system. Advisory services will be rendered by the RCA Service Company and RCA Institutes, Inc.

(*Editor's Note:* Watch for an RCA Engineer article from RCA Victor, Ltd., on an MM-600 microwave system in the next issue.)

Advertising policies, media, analysis of effective advertising, costs, timing, etc., **Williams.**

7. *Cost Factors in Production Designs, late Feb., 1962, 2 hrs.* Standards, Standardization Committee, policing, changes, etc., **Obenland.** Cost factors in manufacturing, value analysis, etc., **Weisel.**
8. *Financial, early March, 1962, 1½ hrs.* Engineering budgets, capital expense, project budgets; expense reports, overhead cost, etc., **Terry** and **Hendrix.**
9. *RCA Laboratories, late March, 1962, 1½ hrs.* Organization, responsibilities, advanced development, etc., **Dr. Pan.**
10. *Patents, early April, 1962, 1½ hrs.* Importance to RCA, what is patentable, keeping records, patent disclosures, patent law, RCA practice towards receiving and releasing information to outsiders, etc., **Whitaker, Harris.**

the field of uhf techniques and to the enhancement of the prestige of this Institute in the advancement of world civilization. The award was made at their 1961 Annual Meeting.

Dr. Pan received the E.E. degree in 1939 and Ph.D. in 1940 from Stanford University. He was a research associate at the Radio Research Lab. at Harvard University during the last war. Since 1945, he has been with RCA. He is now Mgr., Advanced Development, of the Home Instruments Div. (His group is now located at the RCA Laboratories, Princeton.)

STERNBERG HONORED TWICE BY ARS

Sidney Sternberg, Chief Engineer of the DEP Astro-Electronics Div., Princeton, has received double honors from the American Astronautical Society (ARS). On Sept. 28, 1961, he was awarded a *Certificate of Achievement* by the ARS Board of Directors, in recognition of his important contributions to the success of the Tiros satellite program; and, on Oct. 13, 1961, Mr. Sternberg was elected a *Fellow* of the ARS.

—*J. Cartwright*

RECORR RECEIVES ACADEMIC AWARD

K. H. ReCorr, Measurement Standards Laboratory, ETD Harrison, received an award from the American Statistical Association in recognition of his undergraduate work in statistics. Mr. ReCorr recently received his BA degree from Rutgers University.

—*T. M. Cunningham*

McCORD HONORED FOR ARTICLE

H. W. McCord, Test Engineering, ETD Harrison, received an award from *Electronic Design* for his article entitled "Reduction of Cable Capacitance Loading," which was voted the "Most Valuable of the Issue" idea for design in the April 1961 issue.

—*T. M. Cunningham*

HOBLEY RECEIVES ARTICLE AWARD

The Society of Licensed Aircraft Engineers, London, England, has honored **P. Hobley,** Mgr., Instrument Services Dept., RCA Victor Ltd., Montreal, with its 1960 Gold Badge — its highest award for a technical article, and the first time it has gone to a member outside of Great Britain. The article, "An Introduction to the Reliability Concept," has been reprinted several times and circulated widely.

PANEL DISCUSSION SLATED ON AUTOMATED DESIGN

A Panel Discussion on "Automated Design" will be held at the PUB Restaurant, Camden, N. J., on Feb. 6, 1962, at 8:00 P.M. preceded by Dinner at 6:30 P.M. The Panel is sponsored by IRE-PGEC and the AIEE. Moderator will be M. H. Wagner, DOD, Washington, D.C. Panel members include: J. Hurtzberg of Burroughs, **B. Patterson** of RCA, P. Chinnitz of Sperry Rand, Kathe Jacoby of Philco, and N. Prywes of the University of Pennsylvania. Reservations may be made with Helen Yonan, IRE office, Philadelphia. (Evergreen 6-0100, Ext. 8106.

—*S. F. Dierk*

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PROFESSIONAL ACTIVITIES

DEP-DSD, Van Nuys, Calif.: **Mr. Siskel,** Manager of the Analog Data Handling Group, Design and Development Engineering, was awarded the *Stanford-Sloan Fellowship* and is now attending Stanford University in Palo Alto for one year.

During the period from September 27, 1961 to October 6, 1961, the Engineering Management of the Data Systems Division attended a Management Planning Program at the Biltmore Hotel in Santa Barbara. The program, which was attended by the management staff in three shifts, was an intensive two-day workshop designed to provide an opportunity to study management problems of allocating funds to the various functions of a business to assure a profitable operation.—*D. J. Oda*

B&C, Hollywood, Calif.: Kurt Singer of the Film Recording and Television Systems Operations group was named an SMPTE Fellow.—*C. E. Hittle*

DEP-ACC, Camden: **D. B. Dobson** is Publicity Chairman of the 1963 Aerospace Support Conference to be held in Wash., D.C., in August, Sheraton Park Hotel.

Alan A. Paris, Manager Navy Data Link Projects, former chairman of the Professional Group on Military Electronics, was appointed Vice Chairman of the membership committee of the Philadelphia Section of the IRE, as well as to the administrative committee member of PGMIL.—*H. Huber*

DEP-SurfCom, Cambridge, Ohio: **P. J. Riley,** Mgr., Reliability & Value Engineering, Cambridge, Ohio, has been appointed to the Technical Planning Committee for the 1962 IRE International Convention.

DEP-ACC, Burlington: **G. Harmon** attended the UCLA Design Course on Automatic Test Equipment.—*D. Dobson*

Herbert Engel and **Gerald Mahoney** attended the UCLA Symposium on Guidance and Control of Aerospace Vehicles in August. **Stanley Patrakis** attended a symposium on Electronic Packaging, August 16-18, sponsored jointly by U. of Colorado and *Electronic Packaging Magazine.* **Robert Wilcox** is serving on the Administrative Committee, IRE/PGAC, and the Technical Committee on Automatic Controls, a C85. **Walter H. Phoenix** is Sec./Treasurer of Inst. of Management Sciences and Asst. Coord. of Professional Groups, Boston Section, IRE. The following are company-sponsored courses at Burlington: Rapid Reading, Data Processing, Slide Rule Use, Effective Speaking, and Blue Print Reading.

—*R. E. Glendon*

SCM, Mountaintop, Pa.: **R. P. Duncan, J. M. S. Neilson, R. H. Pollack, N. Smith** and **H. Weisberg** of Industrial Rectifier Engineering, presented a series of seminars on design, applications and characteristics of the new RCA high power and stack rectifier lines to personnel of the Industrial Operation Sales Department June 12, August 17, and September 14 at Mountaintop, Pa., and Somerville, N.J.—*M. N. Slater*

ETD, Harrison, N.J.: Several engineers from the Electron Tube Division in Harrison are participating in the affairs of the Northern New Jersey Section of the IRE. **Edward J. Byrum,** Manufacturing Engineering, has been appointed chairman of the Publications Committee and Editor of the IRE-NNJ Newsletter. **Howard Cook,** Commercial Engineering, is now Associate Editor of the Newsletter. **Campbell Gonzalez,** Applications Laboratory, has been appointed RCA membership chairman for the NNJ-IRE; and **T. M. Cunningham,** Engineering Administration, is a member of the Program Committee.

Harrison engineers participating in the activities of the IRE Professional Group on Engineering Writing and Speech are as follows: **Charles A. Meyer** and **Eleanor McElwee,** both of Commercial Engineering, and **Edward J. Byrum,** Manufacturing Engineering, are on the National Administrative Committee of PGEWS; **W. A. Smith,** Commercial Engineering, has been appointed Chairman of the NNJ-PGEWS; and **Dr. I. Stacy,** Chemical and Physical Laboratory, has been appointed Membership Chairman for the NNJ-PGEWS.

—*T. M. Cunningham*

B&C, Camden: **R. J. Smith,** Mgr., Audio and Mechanical Devices Engineering, in Broadcast Studio Engineering, has been appointed Chairman of EIA Sub-Committee TR4.4 on Studio Facilities. In this capacity he is automatically a member of the parent Committee TR4 on Broadcast Transmitting Equipment.—*J. H. Roe*

Home Instruments, Indianapolis: **E. Montoya** is Editor, and **R. C. Graham** is Ass't Editor of the Indianapolis IRE Section monthly publication; both are group leaders in Radio and Victrola. **M. C. Mehta** is a member of the IRE Program Committee.

—*R. C. Graham*

Record Div., Indianapolis: **Dr. A. M. Max,** Mgr., Chem. and Phys. Lab., is teaching *Modern Physics* courses at Butler University and Purdue University Extension.

—*M. L. Whitehurst*

MALCARNEY ELECTED TO RCA BOARD OF DIRECTORS

Election of **Arthur L. Malcarney** to the RCA Board of Directors of the Radio Corporation of America was announced on Dec. 4, 1961 by RCA Chairman **David Sarnoff.** Mr. Malcarney, who since 1957 has been Executive Vice President, Defense Electronic Products, will fill the vacancy on the RCA Board created by the resignation of **John L. Burns.**

O. B. HANSON, RCA-NBC RADIO AND TV PIONEER, DIES

Oscar B. Hanson, pioneer radio and TV broadcasting engineer, died on Sept. 26 after suffering a heart attack. Mr. Hanson had retired in March 1959 as Vice President, Engineering Services, of RCA, but had continued to serve as a consultant. He had been associated with RCA, NBC, and predecessor companies for 38 years.

RCA VERY ACTIVE IN QC SYMPOSIUM

The Eighth National Symposium on Reliability and Quality Control to be held in Washington, D.C., Jan. 9-11, 1962 has as its theme "A Progress Report on Reliability." RCA management and engineering personnel are making significant contributions to the success of this program. **Harold M. Gleason,** Product Assurance Administrator in ACCD, is Vice Chairman of Publicity for the Eastern United States and Foreign Countries. The Area Publicity Chairman for Eastern Pennsylvania is **Joseph F. Chalupa,** ACCD. Secretary of the management committee is **M. M. Tall,** Administrator, Defense Reliability and Maintainability. DEP Staff. **V. R. Monshaw,** DEP Central Engineering, is Vice Chairman of Finance for the Symposium, and **H. D. Voegtlen,** RCA Service Co., is the ASQC representative on the Symposium Board of Directors. A paper entitled, *Maintainability Predictions and Measurement* is being given by Messrs. **Miles** and **Retterer** of the RCA Service Co., Cherry Hill, and another, *Methodology for Systems Reliability Analysis* is being given by **B. Tiger,** DEP Central Engineering.

Another highlight of the program will be the presentation of the movie film *Agree in Action* which describes in detail RCA's approach to reliability testing and verification, a forty minute color and sound film produced by the Motion Picture Production Group in ACCD.—*J. Chalupa*

RCA LABS DEVELOP IMPORTANT NEW HIGH-PERFORMANCE THERMOELECTRIC MATERIAL

The RCA Laboratories have developed a new thermoelectric material that produces more electricity directly from high-temperature heat on a practical basis than the best previously known materials.

The new alloy has been tested in units measuring ¼ by ¼ by ½ inch, but capable of producting nearly 3 watts by conversion from heat sources approaching 1000°C. It was developed by **Dr. B. Abeles, Dr. G. D. Cody, Dr. J. P. Dismukes,** and **Dr. E. F. Hockings,** working under the general direction of **Dr. Fred D. Rosi,** Associate Laboratory Director, Materials Research Laboratory. The material resulted from basic studies with specially-developed techniques to obtain the most precise measurements yet made of heat flow in semiconductors. These studies disclosed that germanium-silicon alloys have far lower heat conductivity at high temperatures than had been expected on the basis of existing theory. Such lower heat conductivity means greater operating efficiency, since a higher percentage of the heat is put to work within the material. The alloy also was found to be extremely stable up to 1000°C.

RCA LABS ANNOUNCES TINY EXPERIMENTAL THIN-FILM TRANSISTOR

An ultraminiature experimental transistor, so small that 20,000 can fit on a postage stamp, has been tested at the RCA Laboratories in Princeton. The transistor is made by depositing thin films by evaporation on an insulating base.

The new device may open the way to new ultraminiature mass-production transistor circuits for many applications, especially in electronic computers and perhaps ultimately in other equipment such as thin-screen wall-type receivers.

Details of the unit were described at a recent conference at Stanford University by **Dr. P. K. Weimer** of the RCA Laboratories technical staff, who was responsible for its development. It is believed to be the first time that transistors having useful performances have been produced entirely by the thin-film technique of evaporating all materials upon an insulating base.

ETD PHOTOCELL GROUP NOW AT MOUNTAINTOP, PA.

The Electron Tube Division Photocell Manufacturing and Engineering Activity under the direction of **J. K. Johnson** is now established in the Mountaintop Plant, for which SC&M is the landlord division. **Dr. C. P. Hadley,** Manager, Photocell Engineering, has moved to Mountaintop from Lancaster and has with him the following members of his staff: **Dr. G. S. Briggs, R. W. Christensen, K. S. Ling,** and **E. Fischer. A. M. Splinter,** formerly at Lancaster, is Manager of Production Engineering and has brought with him **T. Howard, H. W. Kuzminski,** and **J. Merges** as members of his staff.

—*M. N. Slater*

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ENGINEERS IN NEW POSTS

Dr. George H. Brown has been appointed Vice President of the newly established Research and Engineering organization, reporting to **Dr Elmer W Engstrom,** President, RCA. Dr. Brown's organization is as follows: **R. A. Correa,** Vice President, Patents and Licensing; **Dr. J. Hillier,** Vice President, RCA Laboratories; **C. J. Hirsch,** Administrative Engineer; **H. Kihn,** Staff Engineer; **E. A. Laport,** Director, Communications Engineering; **E. M. Leyton,** Staff Engineer; **D. F. Schmit,** Staff Vice President, Product Engineering; and **S. W. Seeley,** Administrator, Microwave Communications Project.

In the Research and Engineering organization, **D. F. Schmit,** Staff Vice President, Product Engineering, announces his staff as follows: **W. O. Hadlock,** Editor, RCA ENGINEER; **P. F. Siling,** Director, RCA Frequency Bureau; **C. M. Sinnett,** Director, Product Engineering Professional Development; and **S. H. Watson,** Manager, Standardizing.

Dr. J. Hillier, Vice President, RCA Laboratories, announces his staff as follows: **H. W. Leverenz,** Associate Director, RCA Laboratories; **A. A. Barco,** Director, Systems Research Laboratory; **A. N. Curtiss,** Manager, Administration; **Dr. J. S. Donal, Jr.,** Administrator, Special Programs; **R. S. Holmes,** Director, Project PANGLOSS; **R. K. Kilbon,** Administrator, Public Affairs; **Dr. L. S. Nergaard,** Director, Microwave Research Laboratory; **Dr. H. F. Olson,** Director, Acoustical and Electromechanical Research Laboratory; **J. A. Rajchman,** Director, Computer Research Laboratory; **D. F. Schmit,** Senior RCA Representative, C Stellarator Associates (Part time; In his capacity of Staff Vice President, Product Engineering, Mr. Schmit reports to the Vice President. Research and Engineering.); **W. M. Webster,** Director, Electronic Research Laboratory; and **C. E. Yates,** Counsel.

Effective Dec. 1, 1961, the organization of Electronic Data Processing is as follows: Reporting to **T. A. Smith,** Executive Vice President, EDP, are: **E. D. Foster,** Division Vice President, Plans and Programs; **A. S. Kranzley,** Mgr., Business and Product Planning; **J. W. Leas,** Chief Engineer, Engineering Department; **E. S. McCollister,** Division Vice President, Marketing; **M. W. Poppei,** Mgr., Business Analysis; **J. H. Walker,** Controller, Finance; and **A. K. Weber,** Division Vice President, Production and Project Management.

Reporting to **Mr. Leas,** Chief Engineer, Engineering Dept., EDP, are: **H. H. Asmussen,** Staff Engineer; **C. M. Breder,** Mgr., Engineering Services and Control; **H. M. Elliott,** Mgr., Palm Beach Engineering; **H. Kleinberg,** Mgr., Data Processing Engineering; **J. N. Marshall,** Mgr., Advanced Development Engineering; **R. E. Montijo,** Mgr., Systems Engineering; **J. L. Owings,** Mgr., Data Communications Engineering; and **R. E. Wallace,** Mgr., Custom Projects Marketing.

Reporting to **Mr. Weber,** Division Vice President, Production and Project Management, EDP are: **K. U. Clary,** Mgr., Personnel; **A. G. Daubert,** Mgr., COMLOGNET Project; **H. M. Emlein,** Mgr., Palm Beach Manufacturing Operations; **B. H. Fisher,** Mgr., Facilities Planning; **B. K. Gesner,** Mgr., Management Engineering; **F. G. Wenger,** Mgr., Production Planning and Coordination; and **J. J. Worthington,** Mgr., 601 Project.

Reporting to **Mr. Kranzley,** Mgr., Business and Product Planning, EDP, are: **R. N. Baggs,** Administrator, Special Projects; **M. K. Hawes,** Mgr., Applications Research; **D. S. Himmelman,** Administrator, Advanced Product Planning; **K. Kozarsky,** Mgr., Product Planning; and **L. H. Souder,** Mgr., Product Requirement Analysis and Control.

C. H. Colledge, Division Vice President and General Manager of the newly named Broadcast and Communications Division, announces his organization as follows: **N. R. Amberg,** Mgr., Detroit Industrial Machine Tool Department; **T. J. Barlow,** Mgr., Production Department; **T. L. Dmochowski,** Administrator, International Liaison; **W. R. Fitzpatrick,** Mgr., Personnel; **J. F. Groark,** Controller, Finance; **E. J. Hart,** Mgr., Microwave Department; **A. F. Inglis,** Mgr., CCTV, Film Recording and Scientific Instruments Department; **J. P. Taylor,** Mgr., Marketing Administration; **E. C. Tracy,** Mgr., Broadcast Equipment Department; **M. A. Trainer,** Mgr., Electronic Recording Products Department; and **V. E. Trouant,** Chief Engineer, Engineering.

In the RCA Service Co., **G. W. Pfister,** Division Vice President, Commercial Services, announces the following additions to his staff: **S. E. Arnett,** Mgr., Graphic Products; **F. P. Barnes,** Mgr., Mobile Communications Projects; **A. Fischer,** Mgr., Mobile Communications Marketing; **D. F. Hahn,** Mgr., Radiomarine Marketing; **E. M. Hinsdale,** Mgr., Mobile Communications and Audio-Visual Engineering; and **A. J. Platt,** Mgr., Audio-Visual Marketing.

A. L. Malcarney, Executive Vice President, Defense Electronic Products, has announced that **J. H. Sidebottom** has been named Division Vice President and General Manager, Major Systems Division, (formerly Major Defense Systems Division) in Moorestown. Mr. Sidebottom reports to **W. G. Bain,** Vice President and General Manager, Communications and Aerospace. Mr. Malcarney has assumed direct responsibility for the Defense Marketing function.

In the DEP Astro-Electronics Div., Princeton, **W. J. Sneck** has been appointed Mgr., Astro-Electronics Manufacturing Operations, reporting to **B. Kreuzer,** Division Vice President and General Manager.

In the RCA Service Co., **C. O. Caulton** has been named Mgr., Planning, reporting to **A. L. Conrad,** President, RCA Service Co.

In The DEP Aerospace Communications and Controls Div., Camden, **A.A. Paris** has been named Mgr., Navy Data Link Projects, reporting to **R. Trachtenberg,** Mgr., Communications Engineering.

In DEP Defense Engineering, **C. A. Gunther,** Chief Defense Engineer, has named **J. A. Biggs** as a Staff Engineer.

In the Broadcast and Communications Division, Camden, **R. J. Smith** is Mgr., Audio and Mechanical Devices Engineering, Broadcast Studio Engineering.

In DEP, **W. G. Bain,** Vice President and General Manager, Communication and Aerospace, has announced that the responsibility for the ELCO Program and the ACSI-MATIC Project has been transferred from Communications and Aerospace to the Data Systems Division. In line with this, **H. R. Wege,** Vice President and General Manager, Data Systems Division (headquarters in Van Nuys, Calif.) has announced **D. C. Beaumariage** as Manager of the new *Data Systems Center,* Bethesda, Maryland; Mr. Beaumariage's staff is as follows: **A. M. Kreger,** Mgr., Administration; **H. W. Nordyke,** Mgr., Advanced Data Systems; **R. A. Schow,** Mgr., ACSI-MATIC Project; Mr. Beaumariage is serving as Acting Mgr., ELCO Program.

LEAS NAMED CHIEF ENGINEER, EDP

J. Wesley Leas has been named Chief Engineer, Engineering Dept., of recently reorganized RCA Electronic Data Processing. (See *Engineers in New Posts* for staff announcements.) He replaces **D. L. Nettleton,** who had served as Chief Engineer on the EDP Staff. The reorganization creates an over-all EDP Engineering Department under Mr. Leas. (See RCA ENGINEER, Vol. 7, No. 3, p. 34, for the previous organizational structure.)

Coming to RCA in 1951, he organized the EDP engineering activity, developing it from a small nucleus into an activity of several hundred engineers. He served as its Chief engineer until 1960, a period highlighted by the BIZMAC and RCA 501. He then became Mgr., Data Communications and Custom Projects Dept., for EDP.

Mr. Leas has served as an Advisor to the DOD on data processing, and on a four-man advisory group to the Ass't Secretary of Defense, R & D. He is a Sr. Member, IRE, active in IRE-PGEM, and a member of Eta Kappa Nu, Kappa Kappa Psi, and Sphinx. He was recently honored as the "outstanding Ohio State Alumnus for 1960," for his *outstanding achievements in the field of engineering, as well as his general civic activities.*

ARNOLD NAMED CHIEF ENGINEER OF DEP-ACC, CAMDEN

D. C. Arnold has been appointed Chief Engineer for the Camden engineering operations of the DEP Aerospace Communications and Controls Division, as recently announced by **I. K. Kessler,** Division Vice President and General Manager, ACC. His responsibilities will include work on such projects as DYNA-SOAR and time-division data-link programs.

Prior to joining RCA earlier this year, Mr. Arnold served as Vice President of Alpha Corporation, a subsidiary of Collins Radio Company. In that post, he helped manage large-scale communications systems for the Navy. He received his BSEE from Iowa State University. He joined Collins Radio in 1948 and subsequently held the posts of Director of Research and Development for the Cedar Rapids and Texas Divisions. He is a Senior Member of the IRE.

HARRIS TO HEAD SURFCOM PROJECT FOR COMBAT RADIOS

DEP-SurfCom has named **W. B. Harris,** as Manager of a $9 million project to supply the U. S. Army Signal Corps with 8,598 PRC-25 back-pack radios. The new radio replaces three different types now in use. Mr. Harris will report to **T. J. Tsevdos,** Manager, Programs Management.

—*C. W. Fields*

HOGAN NAMED MANAGER OF SPACE PROGRAMS

On Nov. 21, 1961, **R. E. Hogan** was appointed Manager, Space Programs. In this capacity, Mr. Hogan will monitor the program management and control of assigned space projects. Initially, he is responsible for the following programs at Astro-Electronics Division: NIMBUS, TIROS, RANGER, PROGRAM 35, PROGRAM 621-A, and SERT. Mr. Hogan will report to **W. G. Bain,** Vice President and General Manager, Communications and Aerospace, DEP.

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S. F. (Sig) Dierk, left, formerly Technical Publications Administrator and Editorial Board Chairman for IEP, receives well-earned thanks for his outstanding work from W. O. Hadlock, Editor, RCA ENGINEER. Sig's tireless activities and extra efforts were significant in developing technical papers from IEP engineers of high quality and timeliness. Our best wishes to Sig in his new assignment on Project PANGLOSS, RCA Laboratories.—*the Editors.*

MANAGEMENT SCIENCE SECTION ORGANIZED BY EDP

A Management Science Section has been organized by EDP to expand and upgrade computer usage. The objective of the new group is to develop computer applications which are basic job-oriented programs known as "packages." One of the first packages is the Sales Forecasting Package which is enabling the Home Instruments Division to forecast TV sales with greater speed and accuracy.

There are many potential Management Science applications. Some of them currently under way include (1) PERT—the technique for planning and control developed for the Navy, (2) Scheduling and Allocating Techniques, or Manpower Levelling, (3) Management Decision-Making, and (4) an aid to management called the Human Resources Package.

SERVICE CO. ATOMIC-RADIATION BOOK USED AS COLLEGE TEXT

Atomic Radiation, published and distributed by the RCA Service Company Technical Publications Group at Cherry Hill, is being used as a student text by over 50 colleges and universities in various radiological courses. Discussing the theory, biological hazards, safety measures, and treatment of injury from nuclear radiation, the 110-page book (originally published in 1957) is now in its 7th printing. Check your RCA library for Report No. Z-316.

RCA ANNUAL REPORT GETS PUBLICATION AWARD

In a "Publications Excellence" contest recently sponsored by the New York Chapter of the Society of Technical Writers and Publishers, the RCA *Annual Report 1961* received top honors in the category devoted to reports to stockholders.—*M. P. Rosenthal*

. . . Special credits for this issue

Special credit is due **Ed Enfiejian,** AED Publications, and **Frank Zumbel,** AED Staff Photographer, for their efforts in producing the excellent color-cover photograph for this issue. Both work for **Lou Thomas,** Mgr., Engineering Services, DEP Astro-Electronics Div., Princeton, who was instrumental in planning this issue and in arranging for the AED articles.—*the Editors.*

E. T. Dickey

C. W. Sall

H. J. Carter

ED DICKEY RETIRES; VETERAN OF 42 YEARS WITH RCA RESEARCH PIONEERED MANY RCA PUBLICATIONS PROGRAMS

On Nov. 17, 1961, a group of over 50 from RCA research, engineering, and management, augmented by a long list of well-wishers from throughout RCA, gathered for a "Graduation Exercises" dinner for **E. T. (Ed) Dickey,** whose career with RCA research began when the Corporation was formed in 1919. **Dr. George H. Brown,** Vice President, Research and Engineering, was emcee and **Dr. A. N. Goldsmith** served as "Dean" of Ed's RCA associates.

Ed Dickey joined the Marconi Wireless Telegraph Co. in 1918, after graduating from CCNY. When RCA was formed in 1919, he joined the Research Dept. In 1929 he was with the RCA Victor Division in Camden, moving to the RCA Labs in 1941. During his career, Ed was involved with the inception of many of RCA's publications programs. Ed also was active on numerous committees on standardization with the IRE, RMA, NEMA, ASTM, and ASA. He is a Sr. Member of the IRE, a *Fellow* of the Radio Club of America, and a Member of Sigma XI.

Since 1941, Ed has been Technical Publications Administrator for the RCA Labs in Princeton, and since the inception of the RCA ENGINEER has been Editorial Representative for the Labs. *The Editors* add their appreciation and best wishes to those of Ed's many other RCA associates.

SALL ASSUMES TPA AND ED REP DUTIES FOR RCA LABS, REPLACING DICKEY

C. W. (Chet) Sall has assumed the duties of Technical Publications Administrator and RCA ENGINEER Editorial Representative for the RCA Laboratories, replacing **E. T. Dickey.** Chet is well versed in such work, having held a similar post with IEP in Camden, a couple of years ago. Chet had most recently been with the RCA Labs on Project PANGLOSS.

REASSIGNMENT OF FORMER IEP GROUPS CHANGES PAPERS APPROVALS AND ED REP PROCEDURES

The recent reassignment of former IEP activities (see p. 57) has resulted in changes in the responsibilities for technical-papers approvals, and in a realignment of RCA ENGINEER Editorial Representatives. Since **S. F. Dierk's** IEP Editorial Board no longer exists, their activities (including papers approvals formerly handled by Mr. Dierk) are now carried on as follows:

In Electronic Data Processing, **T. T. Patterson,** 82-2, Pennsauken, is now acting as Technical Publications Administrator; all EDP papers for publication or presentation should be routed through him. Mr. Patterson who has been (and still is) an active RCA ENGINEER Ed Rep, has also been named a *Engineering Editor* for the RCA ENGINEER.

In the newly designated Broadcast and Communications Div., **D. Pratt,** 5-5, Camden, on the staff of **V. E. Trouant,** Chief Engineer, B&C, Camden, is serving as Technical Publications Administrator. However, he will not be handling RCA ENGINEER matters for that Division (other than formal approvals). The Ed Reps listed opposite for B&C should be contacted on RCA ENGINEER matters. *Exception:* **R. N. Hurst** has been named to replace **J. H. Roe** (received too late to change back cover).

W. C. Jackson is both Technical Publications Administrator and RCA ENGINEER Ed Rep for RCA Communications, Inc., New York.

Note: papers approvals for those former IEP groups transferred to the RCA Service Co. (see p. 57) should now be handled through **M. G. Gander,** Technical Publications Administrator, RCA Service Co., Cherry Hill, N. J.

CARTER REPLACES TIPTON AS AN SC&M ED REP

In the Semiconductor and Materials Div., Somerville, N. J. **Hollis Carter** has replaced **Hobart Tipton** as RCA ENGINEER Editorial Representative for Semiconductor Devices. (**Rhys Samuel** continues there as Ed Rep for Microelectronics.) During his tenure, Hobart was responsible for coordinating a number of key RCA ENGINEER articles from Somerville. The Editors extend their appreciation for his efforts.

Hollis J. Carter received a B.S. in Education with a major in Industrial Arts and a minor in Science from New Jersey State Teachers College, Newark, in 1948. From 1948 to 1952 he taught High School Auto-Electric Shop. From 1952 to 1957 he was an Electronics Instructor at the U. S. Army Signal School, Fort Monmouth, N. J. In 1957, he joined Boland and Boyce Engineering Co. as an Electronics Technical Writer. In this position, he was associated with IBM and Bell Laboratories, writing manuals on missile guidance systems. In 1959, he joined the RCA Semiconductor and Materials Division as a Technical Writer. In this capacity, he has written and edited reports on most areas of SC&M work, and is presently engaged in editing and writing engineering *Application Notes.*

. . . An Important Credit

The article on p. 27 of the Oct.-Nov. 1961 issue of the RCA ENGINEER describes in detail a 3-dimensional display. The authors of this article were responsible for the development of the working model and contributed many ideas to the successful accomplishment of this technique. *The authors wish to point out that* **Joseph A. Rush,** an Engineer in Moorestown Missile and Surface Radar Division participated in generating the original concept of the reciprocating reflecting screen and the stroboscopic projection of the image on it, and he has filed an original patent disclosure. The original idea was turned over to the Advanced Techniques Development Group, who prepared the model and added the unique hypocycloid drive among other things to make a working equipment feasible.

—*T. G. Greene*

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The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

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