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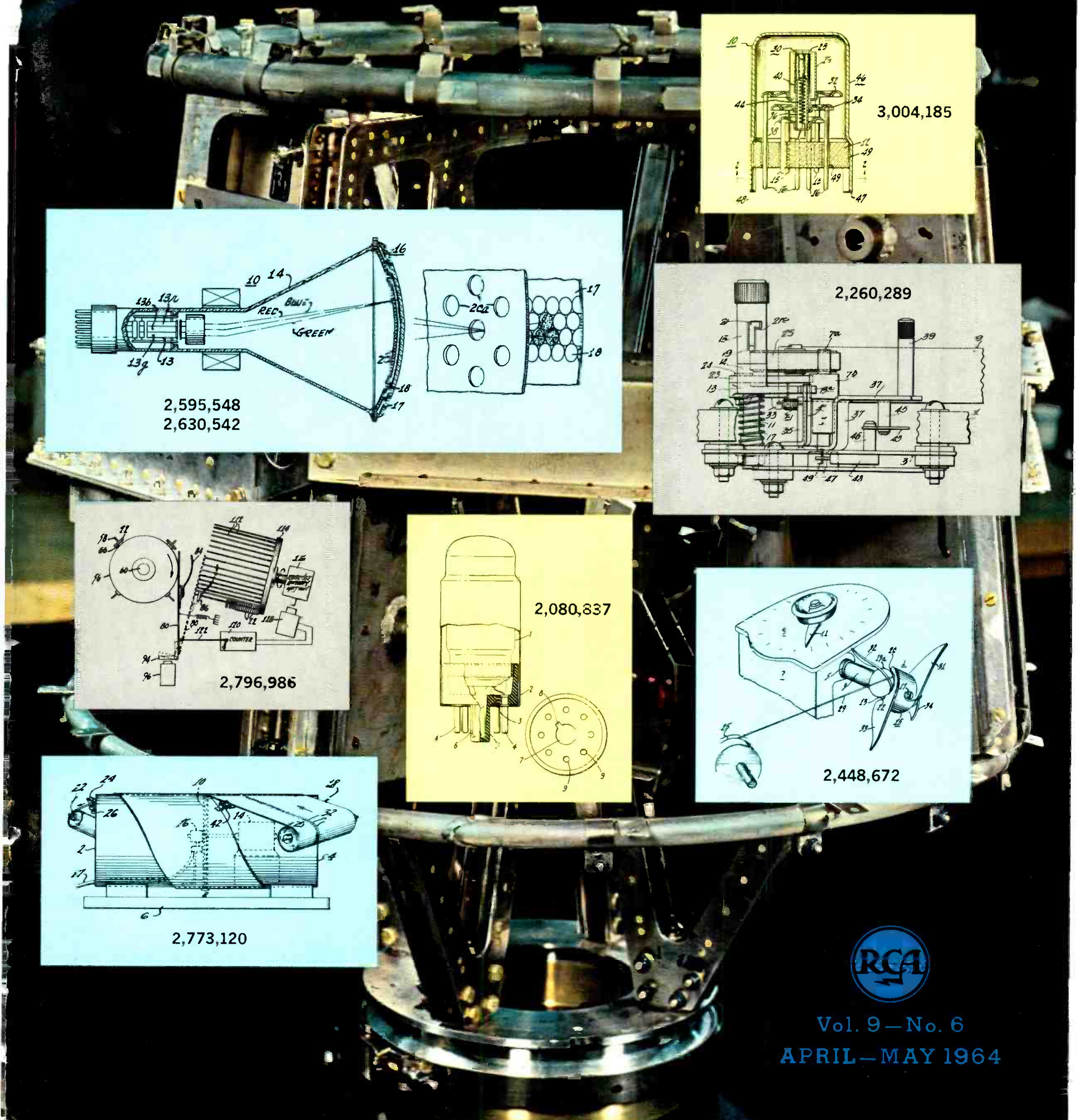
RCA ENGINEER



Vol. 9—No. 6
APRIL—MAY 1964

OUR COVER

A few of the many RCA patents that reflect creative mechanical design effort, against a background photo of a satellite structure emphasize the theme of this issue — mechanical engineering at RCA. The patents shown are discussed in more detail in the article on page 8. (Cover art direction, Jack Parvin. Background photo, Frank Zumbel, Astro-Electronics Division. Patent drawings, RCA Domestic Patents.)

Creative Mechanical Engineering and RCA Patents

It was indeed a happy thought that led the RCA ENGINEER to emphasize in this issue the subject of mechanical engineering, an area sometimes too little celebrated in electronics companies — but nonetheless *vital* to the rapid, even spectacular, strides made by RCA technology in the past three decades.

The montage of patent sketches adorning the cover of this issue accords "cover girl" status to RCA patents for the first time! The fact that these patents relate to mechanical engineering is *not* accidental. They, as well as the papers presented in the pages that follow, are representative of the work of our mechanical engineers, and each is intended as a tribute to their skill and ingenuity.

It has been said that a two-ton truck would be required to move an oscilloscope from place to place were it not for the contributions of the mechanical engineer to "streamlining" that oscilloscope. Slight exaggeration, probably; but the fact remains that much of the compactness and portability, not to mention the reliability, physical attractiveness, and low cost of today's electronic equipment stem directly from the efforts of the mechanical engineer.

No less important are the patents generated by the work of the mechanical design engineer, as are those in all areas of interest to the Corporation. Patents are one of RCA's most valuable assets. From them flow many benefits to the Corporation and to industry at large: new products, scientific progress, professional recognition, and financial return.

As with electronic developments, so with mechanical design: good inventions make good patents, and good patent prosecution at RCA as elsewhere demands close and sympathetic cooperation between the inventor and his patent attorney.

Here at RCA we can be assured that our patent staff will give careful consideration to inventions in all areas of interest to the Corporation, and that each member of the staff is dedicated to his task and stands ready and willing to cooperate in every way possible with RCA's inventors, to the end that the interests of both the inventor and the Corporation are properly served and their mutual growth and success best fostered.

Frank S. Misterly

F. S. Misterly
Staff Vice President
Patent Operations
Research and Engineering
Radio Corporation of America

VOL. 9, NO. 6

APRIL-MAY 1964

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PAPERS

NOTES

DEPARTMENTS

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

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

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

PRINTED IN U.S.A.

"*Who steals my purse steals trash; . . .*
But he that filches from me my good name
Robs me of that which not enriches him.
And makes me poor indeed."
OTHELLO; ACT III, SCENE III, WM. SHAKESPEARE

The Engineer and the Corporation

TRADEMARKS

BASIC PRINCIPLES AND CONCEPTS

J. A. WORTMANN, Trademark Attorney
Patent Operations
Research and Engineering
New York City, N. Y.

RCA's TRADEMARKS and their instant recognition in the United States and foreign markets all over the world are some of the most valuable assets of Radio Corporation of America. If all of our plants and properties were to be destroyed overnight, it seems certain that in making reconstruction funds available the lending institutions would accept these trademarks and the business good will they represent as satisfactory security.

Modern trademarks found their beginning in the identification marks of craftsmen on Egyptian pyramid stones, on ancient pottery and on various items uncovered in Babylonian excavations.

The Constitution of the United States provides for trademarks, copyrights and patents. By various laws in accord with constitutional authority the owner of each of these industrial properies is granted a monopoly.

Exclusive ownership of a trademark is not limited in time as long as the trademark is used in accord with applicable law and maintains its status as an *emblem* of origin and quality. Owners may successively renew trademark registrations in the United States and abroad at statutory intervals. A trademark, therefore, differs from patents and copyrights, which give their owners an exclusive property right for a limited time only.

A strong legal trademark is one of the following or a combination of them:

1) Letters (RCA or NBC).
2) Numerals.
3) Words.
4) Slogans (THE MOST TRUSTED NAME IN ELECTRONICS).
5) Designs.
6) Sounds and three-dimensional devices (the NBC musical notes; a stuffed "*His Master's Voice*" dog, Nipper).

ESTABLISHMENT OF TRADEMARK RIGHTS

Exclusive rights in a trademark are established in the United States, in Canada and the Philippine Islands by priority of *use* of the mark on or for particular goods or services.

In all other foreign countries, exclusive trademark rights are established by priority of *registration* of the mark. This legal concept of ownership by *registration* rather than priority of use obviously involves possible dangers. American manufacturers have indeed at times had the unhappy experience of finding that their trademarks have already been registered in a foreign country by over-ambitious third parties. The manufacturers are then faced with the decision of abandoning their trademark for that country or buying the adverse registration at a generally inflated price.

It is, therefore, important that every trademark be well chosen, always properly used and promptly protected by an adequate registration program at home and abroad.

WEAK TRADEMARKS

In accord with the development of trademark law through the years, the following types of marks are at least initially weak and usually may not be registered until the trademark owner can convince the authorities that the weak mark has by volume and dollar value of use acquired so-called secondary meaning for distinctiveness:

1) A word, term, or device which describes or misdescribes the product or service for which it is used. "*Creamiwhip*" for butter, therefore, in law lacks distinctiveness.
2) Geographical words or designations.
3) Words which primarily are merely surnames.

STRONG TRADEMARKS

A mark which is legally strong is not only less expensive to establish but may also be so maintained and protected. The trademark owner should never lose sight of the fact that even a strong trademark becomes a much sounder investment when it is used for a variety of goods and services. Moreover, the trademark owner should never forget the unfortunate possibility that this trademark (powerful and legally strong on date of adoption) can become weak if other manufacturers after recognizing the strength of the mark in the initial owner's field adopt and use it in their own fields.

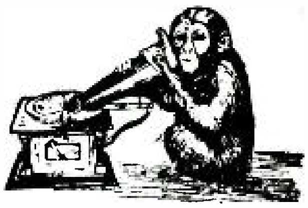
A strong trademark can become so diluted as a result of its use by *third parties* on *other* goods (unless under license by RCA) that the original trademark owner may find himself in the unhappy position of not only having a weakened mark but also being unable with legal safety to expand use of the mark to new goods he markets.

Clearly, therefore, a strong trademark should immediately be used for as many different products and services as possible. Because this procedure has always been used for the trademark RCA in letter or monogram style, our principal trademark and trading name are of outstanding value and renown. It is this standing of the RCA trademark which has caused various courts to recognize that uses of RCA by third parties in alleged unrelated fields were clearly infringements. Accordingly, use of RCA by third parties for such goods and services as rubber goods, rayon material, paint products, real estate, home improvement services and

Fig. 1—Possible damage to the "Dog" trademark (top) was avoided by quickly stopping use of the three "registered 1904" variations shown below.

"HIS MASTER'S VOICE"

TRADE MARK REGISTERED 1904
VICTOR TALKING MACHINE CO.
OF CANADA LIMITED



TRADE MARK REGISTERED 1904
VICTOR TALKING MACHINE CO.
OF CANADA LIMITED

products such as screen and storm doors, cleaning compounds including detergents and many other like situations have been held to be illegal. Even use of RCA purportedly justified by alleged trading names like "*R*ubbish *C*ollectors *A*ssociation," "*R*odeo *C*owboys *A*ssociation," ("*RCA approved* or *RCA sponsored* Rodeos" and red shirts bearing three light-colored letters) or *R*icardo *C*ue *A*lvarez (RCA for strainers, sieves, etc.) are not impossible. Please don't smile, but just keep in mind that even these seeemingly ririculous uses could dilute one of the most famous trademarks and should, therefore, be treated accordingly.

CORRECT USE OF TRADEMARKS

So that our trademarks will always most effectively carry out their function of selling the Company's expanding goods and services it is also essential that they always be used in their approved standard form and as an *adjective* to the specific goods or services. Initially, we must not use different forms of a trademark, since the net result could be a ruling that by choice we have limited our rights to the several specific forms we have chosen and that third parties have the right to devise and use further variations of the trademark. A situation like that illustrated in Fig. 1 must never occur. Moreover, we must not allow one of our trademarks to become a general dictionary synonym for the goods or services trademark identifies. Our electron tubes are *Radiotron* tubes and not "Radiotrons." At the same time, our phonographs are not "Victrolas," they are *Victrola* phonographs.

The possible linguistic dedication fate of an exclusive trademark is a situation which can never be ignored. Present ordinary words of the English language such as aspirin. cellophane, escalator and others were at one time exclusive trademark properties of great value to their respective owners. In some instances, the trademark owner himself has unwittingly and carelessly dedicated his silent salesman property through incorrect usage. In other cases, there is the much more serious problem of the general public seizing upon the trademark as the *generic* product name regardless of its manufacturing origin. Efforts of owners of trademarks like *Scotch*, *Frigidaire* and *Vaseline* to combat this public practice have been successful. During recent years owners of these three trademarks have successfully met what some feared might be an impending death blow to their respective trademarks by the simple procedure of also using the trademark for goods *other* than the product for which the trademark seemed destined to become a dictionary term. As soon as trademark *Frigidaire* was extended from refrigerators to every home appliance in the product line, the owner's position unquestionably improved. The same results occurred with extended use of trademarks *Scotch* and *Vaseline* to every product in the line of the respective owners of these venerable marks.

TRADEMARKS OF PATENTED PRODUCTS

The United States Supreme Court has repeatedly ruled that the trademarks of a patented product will be lost upon expiration of the patent or patents if the trademark has been improperly used. Accordingly, consistent proper use of every trademark is important regardless of patents.

REGISTRATION PROCEDURE

To effect a valid United States registration of a trademark the application must cover a *registrable* mark, must state the date upon which the mark was first used in commerce

JOHN A. WORTMANN was born in the Far East and attended primary education in Germany. He received LLB and LLM degrees at St. John's University. Upon admission to the New York Bar he began his career as house trademark, copyright and Food and Drug law counsel of The Borden Company. He joined RCA in 1951 to assume his present responsibilities. He is an active practitioner in the Patent Office and Court of Customs and Patent Appeals, is a member of the Association of the Bar of the City of New York, and is on the lecturing staff of the Practicing Law Institute.

and must accurately describe the goods or service sought to be protected.

What is and what may not be a legally strong trademark has already been considered. Because a critical "priority" situtiion can always develop in the prosecution of a trademark application (just as in patent prosecution) and because an "interference" may develop involving a prior registration or pending application, records of initial shipments and specimens of the first label, box or other enclosure for the product must be preserved. The Trademark Department prosecutes all applications and maintains all issued registrations.

In setting up adequate registrations for our trademarks in the many so-called *non-use* foreign countries, defensive registrations are often established in all possible related or future interest fields. Almost every country maintains a so-called classification of goods and the appropriate defensive program or programs are not only inexpensive, per se, but effectively close the door to possible dangerous and expensive litigation.

Fig. 2—RCA monogram in Arabic lettering, which is registered by us in the countries where that language is used.

Another valuable defensive registration procedure comprises the making of public record in other countries (India, Japan, etc.) of our trademarks in Arabic, Greek, Sanscrit and other distinct alphabets. The RCA monogram in Arabic lettering (Fig. 2), for instance, is registered for all our present, proposed and possible future goods in every country where that language is spoken. This program, at its inception, incidentally, was not an anticipatory defensive one, but rather a timely, aggressive move to assure that painstaking, successful litigation would keep the door permanently closed to possible further third party attempts to establish a nonexistent right of use of our trademark.

From a practical viewpoint, this trademark registration protection in foreign alphabets is therefore not only an anticipatory defensive move but may be necessary to counter a known "over-ambitious" third-party registration or like pending or proposed application.

The foregoing comments apply to those foreign countries where use of the trademark may be a factor and also to the so called *nonuser* countries. While it is possible in most foreign countries to obtain registration without prior use of trademark, such use of the mark may become important in disputes involving infringing or conflicting trademarks.

This Department is charged with the responsibility for all domestic and foreign trademark matters of every kind.

TRADEMARKS AND RCA ENGINEERS

Whenever in the course of research and engineering a new product is born, it should be remembered that a commercially successful product must have two identifications: 1) its *trademark* and 2) its generic or descriptive name.

Unless a generic name for the product is decided upon and used for the product as soon as it is marketed, please keep in mind that our exclusive trademark for that product can become the descriptive name.

In your work, improper or infringing uses of our trademarks may come to your attention. Even the seemingly minor situation should be promptly reported and neither size nor lack of industry status of misuser or infringer should influence your action. "Legal sleep," or so-called *laches*, may begin even with the most minor or innocuous situation.

Just as we expect others to respect our trademarks there is, of course, a correlative obligation on our part. Therefore, if in the course of preparing one of your reports or technical papers you believe that a word may be the trademark of a third party, please check the situation with my office. If, in fact, the word is someone's trademark, then the trademark status should be confirmed by the author in his typewritten manuscript by using it in full caps (IBM) or initial caps and in quotes ("Mylar").

CONCLUSION

It has, of course, been impossible to do anymore than briefly set forth the important legal highlights of these complicated RCA trademark assets. This paper is not intended to give legal advice for particular problems and does not replace advice in individual problems as they arise. We trust that this primer has been not only interesting, but also helpful in possible trademark matters you may encounter in your work.

VALUE ENGINEERING OR INDUSTRIAL ENGINEERING?

A. S. BUDNICK

Electronic Components and Devices, Somerville, N. J.

Many articles have been written about the techniques of *value engineering*, but few have sought to analyze the subject objectively for a satisfactory answer to the question, "*What is Value Engineering?*" A novice trying to become acquainted with the subject may easily be swamped by a deluge of illustrations of successful programs, be awed by the techniques, and yet not thoroughly understand value engineering and its relationship to the associated field of industrial engineering. In taking an objective look at value engineering, it is advantageous to review accepted procedures and definitions, and then to separate and explore these facts to show how value engineering may be considered as a form of industrial engineering.[1]

WHAT IS VALUE ENGINEERING?

Value engineering may be defined as a technique that yields value improvement by determination of the essential function of an item and the accomplishment of this function at lowest cost without degradation in quality. To fully comprehend the scope of this definition, it must be realized that the term *value* is defined by management and may be altered as time progresses. For example, the space age has had much influence on reliability in the electronics industry. Previously, management placed high value on changes that improved line efficiencies and thereby reduced costs. As reliability has become more and more important, management has often considered ideas valuable that yield improved reliability, although these changes sometimes increase the manufacturing cost of the product. The construction of "white rooms" exemplifies this practice.

The activities of value-engineering groups may broadly be classified into two areas: those related to personnel problems and those associated with the techniques of value engineering. Included in the area of personnel activities are efforts related to the integration of value engineering into an organization, education of persons in value techniques, and the establishment of the proper atmosphere for value investigations.

Experience has indicated that an adequate and thorough value investigation of an item supplies the answers to the following questions:

What is it?
What does it do?
What does it cost?
Can anything else do the job?
What does that cost?

These questions are often referred to as "guideposts" for value-engineering studies. To obtain the desired information, the value-engineering job plan is employed.[2]

The information phase of the job plan initiates the start of a value study. The objective is to gather and review information relating to the product, its uses, its history, and its requirements. Cost figures, blueprints, standards, design procedures, and production reports are studied until the first three questions above can be answered.

At this point, many techniques of idea generation can be employed. The goal is to project a quantity of ideas that may be studied to determine whether "anything else can do the job." In most instances, unusual and revolutionary ideas are encouraged as a technique for obtaining a fresh outlook.

Because most idea-generating techniques frown on the judgment of sug-

ALFRED S. BUDNICK received the BSME (Industrial Engineering option) from the University of Rhode Island in 1959 and the MS in Management Engineering from the Newark College of Engineering in 1962. He joined RCA in 1959 as a production engineer in the Semiconductor and Materials Division at Somerville, N. J. Since then he has achieved a broad background in semiconductor-device manufacturing, having been assigned engineering responsibilities for device assembly; parts manufacturing; and cutting, lapping, and polishing of silicon and germanium substrates. His device experience has included work on n-p-n and p-n-p germanium alloy and drift devices and thyristors. He is presently working on the engineering problems of germanium and silicon planar epitaxial devices. Mr. Budnick is a member of the American Society of Mechanical Engineers.

gestions during creation, the numerous concepts presented are considered in the analysis portion of an investigation. Persons familiar with the product and its processing work with value-engineering personnel to cull out the ideas that indicate the type of solution desired. Decisions to test new ideas may be influenced by financial considerations as well as by time factors. An important function of value-engineering personnel is to keep the criticism objective and encourage acceptance of novel but promising concepts.

After the promising ideas are selected, the actual testing commences. Value engineers then face a serious test. *They must overcome the inherent resistance of human nature to change, so that the people responsible for the item will perform and evaluate the results of tests without bias.* It is not the function of value engineers to perform these tests, but it is their responsibility to obtain the desired data. These data are then reviewed by those charged with the responsibilities for the product and by value engineering. When a decision has been reached, it is presented as a joint effort of all those who participated in the study.

ITS RELATION TO INDUSTRIAL ENGINEERING

The tasks performed in managing a modern industrial organization may be grouped into three general areas of professional activities,[3] as follows: 1) activities basic to engineering and therefore requiring basic engineering skills in existence before scientific management was conceived, 2) functions requiring training in a particular area that is applicable to that function (e.g., accounting), 3) activities concerned with the effectiveness of mechanical equipment and their relationship to the human element.

The scientific method of investigation includes the following steps:

Statement of the problem
Organization of the facts
Analysis
Individual analysis
Application of fundamentals and principles
Improvement and test of solutions

Through this method, it is possible to show that *both* industrial engineering and value engineering belong to the third category of business activities. Reflection indicates that industrial engineering is the result obtained by combining the scientific method and the work efforts associated with the third category of activities.

A more complete definition of industrial engineering includes a relationship to the design, installation, and improvement of systems of men, materials, and equipment. The use of engineering and social-science skills to predict and evaluate systems are also employed.[4] Unfortunately, many people consider industrial engineering and motion and time study as synonymous. This concept may have developed because only a limited number of cost-reduction techniques were readily available during the early years of industrial engineering. The development of alternative materials has broadened the areas of investigation encompassed by industrial-engineering studies and has led to the formation of value engineering, which presents industrial engineering with still another tool for effective cost reduction.

The first step in a comparison between the two fields may best be an examination of their definitions. Value engineering promotes the improvement of value by the development and systematic evaluation of alternatives that will accomplish the essential function of an item with lowest possible cost. Industrial engineering is concerned with the design, improvement, and cost reduction of a system. To accomplish the desired goals of an industrial-engineering study, a determination of the essential function of a system is required. The next step is to investigate and evaluate a number of solutions. A period of systematic elimination and testing then follows until the most advantageous solution is obtained.

It could be argued that the objectives of an industrial-engineering study are not the "improvement of value" concept associated with value engineering; in fact, a study may truly be aimed at some other result. However, further observation shows the intimate relationship between the activities. If management instructs the industrial-engineering activity to work toward value improvement, the steps employed clearly conform to those performed in a value-engineering study. This premise may be defended by reviewing the method of investigation employed by each field. The techniques used by value engineers have been presented previously; for comparison, the job plan used by the industrial engineer is as follows:[5]

Determination of the objectives
Understanding the problem
Suggestion of alternative solutions

TABLE I—Comparison of Job Plans

Scientific Method	*Industrial Engineering Job Plan*	*Motion and Time Study Job Plan*	*Value Engineering Job Plan*
Statement of the problem Organization of the facts	Determine objectives	State the objectives and the work to be performed	Gather information related to the item under study
Analysis	Understand the problem	Analyze activities and record methods	Analyze function to determine value
Individual Analysis	Suggest alternatives	Question each phase of the job	List possible alternatives
Application of fundamentals and principles	Select the proper alternatives	Test new methods through application	Consider and try the most promising alternatives
Improvement and test of solutions	Execute ideas	Evaluate and recommend	Evaluate and recommend

Selection of the proper alternatives
Execution of the ideas

Initially all investigations employ the scientific method. This method is adapted to the objectives of each field, and a job plan is developed leading to the attainment of these objectives. The supposition is that value engineering is another refinement of available techniques, progressing from the broad scope of industrial engineering to the narrower scope of value improvement.

The first two steps of the scientific method require a determination of the problem and the gathering of all facts related to this problem. In industrial engineering, these two steps imply a need to determine the objectives of a study and to understand the system and its related parts. In value engineering, the objective of a study is clearly defined as value improvement. As a result, all that is required initially is information concerning the item.

The initial steps of the scientific method are narrowed in scope as each field adapts the plan to suit its desired goal. When the industrial engineer is requested to perform a value investigation, he merely narrows the methods of industrial engineering to focus on the value concept. This situation is analogous to motion and time study, where the engineer adapts the methods of industrial engineering to develop a job plan for analyzing operations.[6] Motion and time study is recognized as a part of industrial engineering; it follows that value engineering should also be acknowledged as a technique of industrial engineering. Table I shows a typical job plan for time and motion study, and contrasts the scientific method with the job plans of industrial and value engineering.

The argument may be advanced that value engineering is primarily concerned with the use of alternative materials and, therefore, differs from industrial engineering. However, the definition of industrial engineering does not exclude the use of alternative materials but, in fact, recognizes them as one effective source of cost reduction. In addition, consider the accomplishments that have been attributed to value studies. Many changes that result in product redesign for more efficient manufacture are accepted as effective use of value engineering, although no material substitution is employed.[7]

Another comparison that indicates the relationship between the two fields is an examination of the mode of operation and the atmospheres under which they function. Both activities generally are considered as service groups, and there are many areas that are common to both activities. One area mentioned previously is the performance of tests and the required evaluations. Value engineers and industrial engineers should not perform the required testing of new ideas lest they create morale problems and manifest the need for an extremely tech- people responsible for the product to evaluate new concepts. Neither value engineering nor industrial engineering has the direct authority to require the performance of test, and it is doubtful nical staff. Both activities rely on the that this authority could be effectively employed if available. Thus, a large amount of public relations and an understanding of human relations is required. This argument also applies to the accomplishments of value-engineering or industrial-engineering studies. The groups to which ideas are proposed must be "sold" on the recommendations because they are not required to accept suggestions of these service groups. Although external pressures may result in acceptance of suggested ideas, continuous application of pressure may cause resentment of these service groups to develop.

The third aspect of cooperation is the obtaining of new projects. Service groups are considered as consultants to other activities and, therefore, require the help of these activities in locating new and fruitful areas for investigation. Both the value-engineering and industrial-engineering groups must work to gain the confidence of other activities so that problem areas or high-cost areas can be located with a minimum loss in time. Still another problem is caused by the fact that performance of an investigation often forces value and industrial engineering to cut across organizational boundaries. The activities must develop the respect of all portions of an organization to accomplish this goal and not create an excessive amount of animosity. Earning this respect allows value and industrial engineering to accomplish their objectives without the authority to demand cooperation.

Another interesting comparison is provided by relating the personal characteristics required of engineers performing in the value or industrial engineering activities. Education for a value engineer presently consists of practical experience and courses given by qualified personnel. The amount of technical knowledge required is a point that is open to debate. One viewpoint suggests that a general knowledge of engineering and the product is most desirable for value work. Tendencies to view suggestions with an open mind are more prevalent than in the case of personnel thoroughly familiar with the product. Another view states that additional technical information is advantageous in evaluating and choosing the most promising ideas for further evaluation. Regardless of the amount of technical information there must also be a knowledge of accounting methods, an understanding of manufacturing processes, and an ability to research and obtain additional information. Industrial engineering has already progressed to the stage where a degree is given in this field by many engineering schools. The courses cannot provide detailed product experience which can be acquired only by working in the industry, but the education presents a broad scope of engineering techniques, accounting and business practices, introduces personnel to the engineering handbooks, and indicates where additional information may be located.

The personal characteristics required for effective performance have already been implied. To summarize, the value engineer should be mature and not easily discouraged; possess a creative imagination, have a desire and ability to work with other employees, and be organized so that he needs only a minimum of supervision.[8] Industrial-engineering literature phrases the requirements somewhat differently, requiring an ability to get along with people, self-confidence, initiative, and analytical ability.[9] As was true in the other comparisons attempted, no true deviation exists between the two fields in question.

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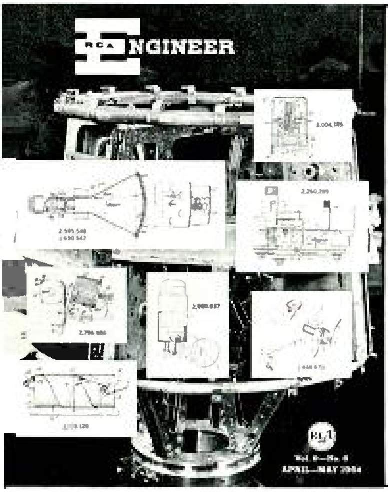


SOME REPRESENTATIVE EXAMPLES OF RCA'S ELECTROMECHANICAL INVENTIONS

Since this issue of the RCA ENGINEER is in great part directed to mechanical and electromechanical aspects of RCA's operations, it seemed only fitting that the cover design should also reflect that activity. While many people think of RCA only in terms of electronic devices and equipment, a considerable portion of RCA technical activity involves mechanical development and design. Over the years, patents have been obtained on many commercially significant electromechanical inventions by RCA engineers and scientists. A few representative examples appear inset on the front cover—actual figures taken from the issued patents of these inventions. The following comments on each of those patents emphasize how important mechanical and electromechanical inventions have been and still are to RCA. Also included is helpful procedural information on how to file a patent disclosure.

PATENT NO. 3,004,185

One of the sketches may be recognized as relating to the rugged, reliable, and novel RCA Nuvistor. Patent 3,004,185 was issued to George M. Rose, Jr. on October 10, 1961. The patent and the claims contained therein are directed to the *novel* and *commercially practical* aspects of the tube.

In the Nuvistor, a ceramic base wafer is used as a platform for supporting the mount assembly that includes a plurality of coaxial tubular electrodes each supported by spaced superimposed flanges. Each flange is in turn supported adjacent its periphery by three support members at least one of which functions as a lead-in and extends through the ceramic base wafer. All of the parts are assembled in loose contacting relationship and are brazed together simultaneously to produce a strain-free assembly. The assembly is then positioned in a metal envelope and the ceramic base wafer is brazed vacuum tight at its periphery to the open end of the envelope. Such a mechanical construction lends itself to mass production and additionally eliminates the more conventionally used glass and mica parts and the earlier spot-welding techniques.

The Nuvistor tube can withstand wide variations of temperature and shock without adversely affecting its characteristics. Its physical construction renders it suitable for operation at high frequencies; it has been used rather extensively in television tuners. Because of its inherent rugged construction the Nuvistor has also been employed for military and industrial purposes.

Credit is due RCA Domestic Patents, Princeton, N. J., for supplying both the writeup on these pages and in selecting the front cover material.

PATENT NOS. 2,595,548 AND 2,630,542

Of the seven patent sketches shown, the one that will most readily be recognized by a majority of our readers is the figure depicting our current shadow-mask color-television picture tube. Associated with the drawing of the tube is an enlargement of a small portion of the mask and the spaced phosphor-dot screen with its trio of red, green, and blue phosphor dots for each aperture in the shadow mask. Outstanding contributions toward the development of the shadow-mask tube are represented in Patent 2,595,548 which issued to Alfred C. Schroeder in May of 1952 and Patent 2,630,542 which issued to Dr. Alfred N. Goldsmith on March 3, 1953. The patent applications that resulted in these patents were filed in 1947.

In addition to the perforated shadow mask and the phosphor-dot screen, the tube includes three closely-space electron guns for projecting three converging beams of electrons through a common deflection field. The deflection field causes all three beams simultaneously to scan the screen of the picture tube. Signals representing the red, green, and blue color content of the image to be reproduced are applied respectively to the control electrodes of the three electron guns thereby to control the intensity of the beams of electrons. As a result, a very wide gamut of brightness, color hues, and color saturations may be obtained. When all three electron guns are permitted to function sumultaneously a white image is produced.

The commercial success of the RCA color television picture tube certainly speaks for itself.

PATENT NO. 2,260,289

Record players and automatic record changers, for years a prime source of home entertainment, have been the target of rather extensive redesign from the standpoint of both cost and performance. One of the prominent inventions in this field is represented in Patent 2,260,289 that issued in October of 1941 to Raymond F. Brady and Paul Weathers. This patent resulted from a requirement that a record player be capable of two or more speeds as, for example, 78 and 33⅓ rpm. This dual-speed feature was accomplished by providing two drive portions of different diameter on the end of the motor shaft. An idler roller was then provided to engage the inside surface of a flange around the periphery of the turntable, and one or the other of the two drive portions on the motor shaft. This simple expedient utilized few parts yet permitted the turntable to be driven at two different rates by the same motor.

The speed change control also includes provisions for moving the idler wheel away from the motor shaft and turntable flange during intervals when the speed is being changed in order to preclude inteference of the idler wheel with the stepped motor shaft.

This particular mechanism is *universally used* in modern record players to permit selection of any one of the four popular record speeds, namely 78, 33⅓, 45 and 16.

PATENT NO. 2,796,986

One would not normally think of the magnetic memory portion of an electronic data processing machine as involving mechanical or electromechanical inventions. The magnetic memory is frequently composed of a very large number of tiny doughnut-shaped memory cores each of which constitutes a storage location for one "bit" of data processing information. These tiny cores are hand wired into a memory and, needless to say, each core must have the proper electrical characteristics or else that core location is no longer available as a place to store information. It therefore becomes imperative that these cores be tested very thoroughly prior to their being wired into memory plane for subsequent use in the electronic data processing machine. A machine for testing the individual cores is represented in Patent 2,796,986 which issued in June of 1950 to Dr. John A. Rajchman, R. Stuart-Williams, and Joseph L. Walentine.

Briefly, under test the cores are aligned along a helical track with their axes vertical. The lead core is then picked up on a pin to measure its magnetic properties. Associated electronic circuits analyze the properties and provide an *accept* or *reject* signal. An *accept* signal operates a wiper arm causing the core to fall into an accept box. Similarly, reject signal causes the core to fall into a reject box. The pin is then brought around to pick up another core for test. A number of separate test pins can be used so that the operations of picking up the core, testing it, dropping it in either the accept or reject boxes can all occur at the same time.

The design principles of this early RCA automatic memory core tester have become *standard for the industry*. The cores are produced in multimillion quantities and each must be tested to insure acceptable magnetic properties before it is wired in a memory plane to ultimately become a part of the magnetic memory of an electronic data processing machine.

PATENT NO. 2,080,837

Some inventions, like hairpins and bottle-caps, enjoy such widespread and universal acceptance that one often takes them for granted without reflecting on the fact that they represent an ingenious solution to what was once a vexing problem. RCA Patent 2,080,837, which issued in May of 1937 to Terry M. Shrader represents a novel invention of this nature. This simple invention, directed to the conventional octal tube base and the socket into which the tube is inserted, made it possible to insert a tube quickly and easily in a socket with the pins properly oriented. *The invention represented in this one patent has been used in connection with billions of radio tubes throughout the entire world for over a quarter of a century.*

PATENT NO. 2,448,672

Many mechanical patents are directed to machines or devices used for the production of parts or components of other machines. To manufacture such components in great quantity at low cost requires the use of rather expensive and complicated machinery. Inventions that simplify these machines while simultaneously increasing their productivity are, of course, always in high demand since they usually yield a substantial reduction in the cost of the component. An invention of this nature is represented in Patent 2,448,672 that issued in September of 1948 to Harry V. Knauf, Jr., on a machine for winding coils used in the cathode ray deflection yoke of a television picture tube.

This machine *revolutionized* the winding of saddle type coils for television deflection yokes which, prior to this invention, were made by a complex machine capable of producing alternate reciprocating and oscillating movements of a mandrel upon which the coil was wound. The Knauf machine is simple, fast, and efficient. Its mandrel rotates continuously at high speed and has ingeniously designed wire-deflecting vanes for directing the wire alternately in opposite directions along the rotation axis of the mandrel and into coil-forming slots.

The invention, although made prior to the commercial sale of home TV receivers, was so basic that it has been used in the manufacture of deflection yokes for every RCA television receiver (color as well as black and white) from the RCA-630TS (circa 1946) to the present-day instruments. This invention has enabled RCA to manufacture yokes for its own use (and for sale to other television receiver manufacturers) which are conservatively estimated to number well in excess of 20 million. *The invention was of such meritorious character that it has received virtually world-wide recognition.*

PATENT NO. 2,773,120

The recording of signals representing speech and music on magnetic tape has been conventional for many years, but with the need for a convenient and economical means of recording video signals, research engineers and scientists were faced with the problem of placing a wide band or spectrum of signals on a magnetic tape without subjecting the tape to objectionably high linear rates of speed. One solution to this problem is represented in Patent 2,773,120 which issued in December of 1956 to Earl E. Masterson. In this particular invention the magnetic tape in moving from the supply reel to the take-up reel is passed once around a mandrel. The mandrel is in fact constituted of two co-axially positioned cylinders with a small space between the opposed ends of the cylinders. Located in this space is a disk or headwheel which carries one or more recording or playback heads. A motor is provided for rotating the headwheel at a fairly high rate of speed. The combined action of the tape motion and the rotary headwheel motion produces a "slant-track" type record on the magnetic tape. When the signal being recorded represents television images, the relationship of the head wheel to the signal is so chosen that the recording head crosses the edge of the tape during a signal blanking interval. Such an advancement in the art provides an inexpensive method for recording television signals and makes wideband multiple-channel instrumentation recording possible. *Recording equipment using this principle has been sold by RCA and others in U. S. and abroad.*

CONCLUSION

Solving problems of a mechanical nature can frequently be more perplexing than finding the solution to problems of an electronics nature. The solution to such problems, particularly if the solution results in a product that is cheaper to make and yet has improved performance, results in important inventions *which may ultimately result in very valuable patent assets*, so far as RCA is concerned.

If you have made any new contributions or improvements in our products, or if you have any new ideas that could be of value to the company from a patent standpoint, it is highly recommended that you make a disclosure of the facts to the RCA Patent Department. In this respect your attention is directed to the attached brief outline of "what to do" under these circumstances.

HOW TO FILE A PATENT DISCLOSURE

It is anticipated that your work at RCA will result in the improvement of our products or processes.

WHEN YOU MAKE AN INVENTION: If you discover or develop something that is new, or works more efficiently or effectively, or is more economical to manufacture, or is better in some other respect than our present product . . .

then you may have made an invention.

WHAT TO DO . . .

First, be sure that all the pertinent data are recorded in your notebook, signed, dated and properly witnessed.

Second, obtain Patent Disclosure Data Sheets (Forms 3009 and 3010) from your supervisor. If he doesn't have a supply of these forms, contact Administrative Services, Domestic Patents, at the RCA Laboratories, Princeton, New Jersey. Telephone WA 4-2700, Ext. 2462.

Third, fill in the Patent Disclosure Data Sheet, fully describing your invention and providing adequate sketches, photographs, or circuit diagrams where appropriate.

Fourth, sign and date the Patent Disclosure Data Sheet and have it signed and dated by a witness who *understands* your invention, preferably someone who has also witnessed tests or notebook entries you may have made.

Fifth, mail your Patent Disclosure Data Sheets to:

Director, Domestic Patents
Radio Corporation of America
David Sarnoff Research Center
Princeton, New Jersey

WHAT HAPPENS THEN . . .

1) You will be notified of the docket number assigned to your disclosure (such as RCA 00,000) and of the patent attorney who will handle the disclosure.

2) The patent attorney will process your disclosure to determine whether a patent application should be filed.

3) You will be consulted and advised of the final decision.

4) If an application is filed in the U. S. Patent Office, you will be asked to sign certain formal papers in the presence of a Notary Public.

5) Shortly after a patent application has been filed in the United States Patent Office, you will receive an honorarium check.

SPECIAL SPECIMEN STAGES FOR THE ELECTRON MICROSCOPE

Creative mechanical design provides new specimen stages for the electron microscope that allow positioning, heating, cooling and chemical reaction of the specimen.

A. J. CARDILE
Scientific Instruments Engineering
Broadcast and Communications
Products Division
Camden, N. J.

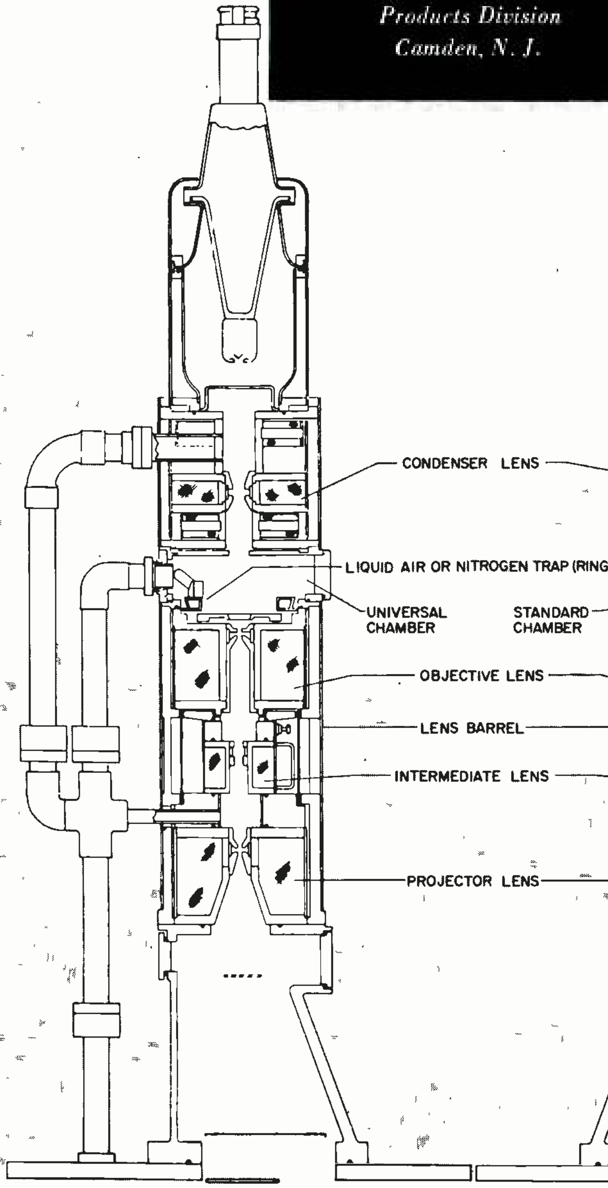


Fig. 1—EMU-3 microscope with universal chamber.

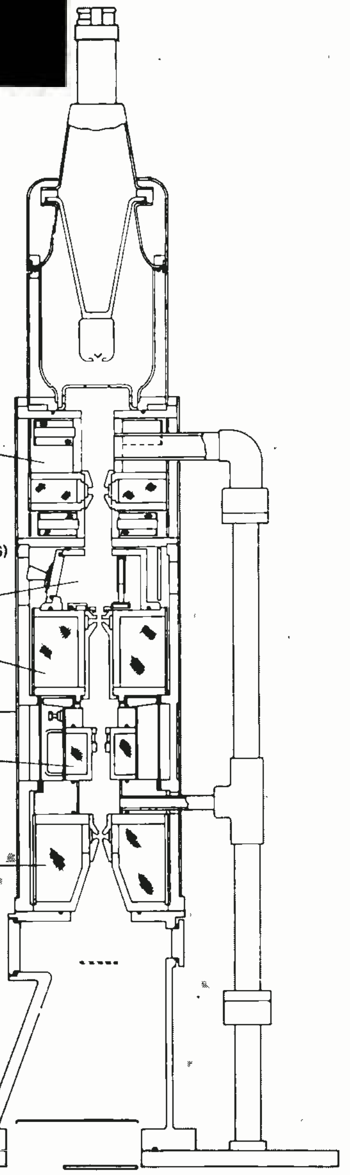


Fig. 2—EMU-3 microscope with standard chamber.

Electron Microscopy is entering a new era; the study of specimens under various environmental conditions has now become a necessity for both the biologist and the metallurgist. Unfortunately, the inflexibility of the conventional electron microscope, with its heavy iron-magnetic circuits, delicate specimen stage and specimen changing mechanisms, has discouraged all but a few of the most determined users from modifying these instruments to provide a wider range of specimen conditions.

The ability to examine the specimen at widely different temperatures is necessary to study its temperature-dependent properties. Existing needs for applying physical stress, for viewing over a wide range of orientations, for the direct examination of surfaces, for the preparation of specimens directly in the microscope, or for the use of dry-box techniques have shown themselves in ingenious (but limited) design modifications made to existing instruments. Now that resolving power is available beyond the needs or capabilities of most specimens, the emphasis in instrumentation is swinging to specimen control. It is this change of emphasis from instrument to specimen that characterizes a new era in microscopy.

REQUIREMENTS OF SPECIAL SPECIMEN STAGES

A complete description of special stages and their purposes would be too lengthy to include in this article. In brief they fall into the following categories: 1) *mechanical stage* for orienting specimens or stretching or twisting them; 2) *thermal stages* for heating specimens; 3) *refrigerated stages* for cooling specimens; and 4) *reaction stages* for carrying out chemical studies of the specimen. Each stage requires the specimen to be moved at least through two rectilinear degrees of freedom, and some through two additional degrees of rotational freedom.

Depending upon the degree of control required in the handling of the specimen, a wide variety of special stage situations becomes desirable. Many of these conditions can be met by the generalized designs of the instrument engineers, but it is also obvious that much special instrumentation will fall to the lot of the individual experimenter. For this reason, the modification of the specimen space to provide adequate room, easy access, and adequate pumping for specialized experimentation is an important step forward in overall instrument mechanical design.

The space cannot be obtained merely by increasing the separation of the condenser and objective lenses, as this works an undesirable hardship upon the

A. J. CARDILE studied Mechanical Engineering at Drexel Institute of Technology evening school. He joined RCA Victor, Inc. in 1935. Starting as a messenger boy he worked in all phases of manufacturing; working leader, cabinet designer (cabinet factory) plant engineering, special assignment reporting to Plant Manager, design draftsman and then twenty-one years in Engineering. As an Engineer he designed test equipment, Broadcast monitoring equipment, Mobile equipment, motion picture equipment, Project Engineer for a joint RCA-Interchemical Corporation development project located at Buchanan, New York. He is presently serving as a Project Engineer in the Scientific Instruments Group. He has six U.S. patents.

illuminating system and actually limits its ultimate performance with respect to spot size and intensity. Moreover, the farther the space is from the specimen, the less useful it becomes. Actually, the essential part of the space is that immediately around the specimen, and this can be gained only by stage and chamber modifications involving flattening and radial expansion. Inseparable from the need for a space increase is the requirement for faster vacuum pumping to evacuate it.

THE SPECIMEN CHAMBER

On the EMU-3 series of electron microscopes, these space objectives are achieved by relatively minor modification of the basic mechanical design, although the nature of the changes requires a major replacement of column parts.

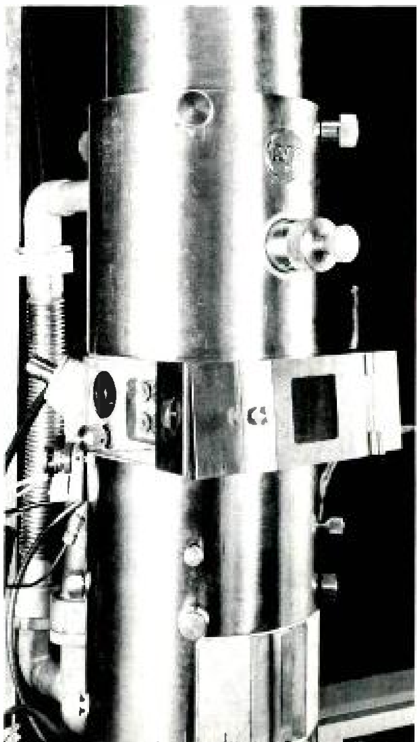
The barrel construction is maintained to supply rigidity, accurate mechanical alignment of optical elements, and magnetic shielding. However, instead of extending the columnar parts (Fig. 2) from the base of the projector coil to the base of the condenser, the assembly terminates (Fig. 1) at the base of a new specimen chamber which is screwed to the barrel and effectively becomes a part of it. The objective spool moves laterally for alignment in the barrel and is sealed off by O-rings at its top against the lower surface of the new chamber and at its bottom against the intermediate lens.

The specimen chamber stage, which had been housed and driven from a chamber screwed to the objective spool, is now contained in the objective spool whose upper plate is extended upward to support the stage drive mechanism and make the upper vacuum seal. Such a design is the same in principle as the standard design and assures obtaining the current high resolving power of 10 angstroms or better when the simple standard stage is used.

Vacuum pumping for the greatly increased volume of the chamber is accomplished through a 1-inch vacuum line leading to a low point on the column manifold. Relatively complete vacuum isolation of the specimen region is accomplished by using a 250-micron beam aperture in the center of the condenser lens and a contrast aperture in the objective pole piece. These apertures have so low a pump speed that they are negligible factors compared to regular chamber pumpout or to the effective speed of the liquid air trap used with the chamber.

The chamber itself permits wide access (Fig. 3) through a large door for change of major stages, or through a small door in the large access door for specimen changes. Eight extra electrical feed-throughs are provided in the chamber walls for heaters, thermocouples, and evaporators. The cooling reservoir for the cooling system is built into the chamber permanently so that no major manipulations are required to change to cold-stage operation (Fig. 4); at the same time, the reservoir and cold baffle can act as a liquid air trap when used with other stage combinations. The walls of the chamber are of magnetic iron to assure adequate shielding from stray magnetic fields, while their thickness provides mechanical strength against external vibrations. The new chamber has been named the *Universal Chamber* to emphasize its wide application to specimen control devices.

Fig. 3—Universal chamber showing specimen heater in place in the stage, cold baffle behind stage, and electrical feed-through in chamber wall.



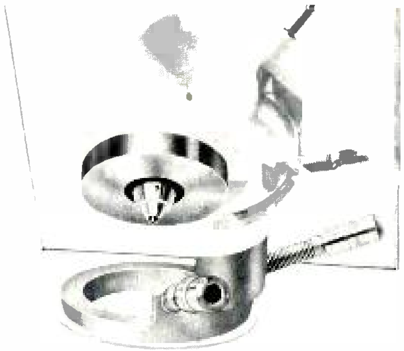


Fig. 4a—Heat exchanger, shown suspended above the reservoir. Specimen cap is seen protruding from the metallized ceramic cone which is the foundation upon which the rotor fin assembly is erected. The flanged top of the specimen holder is seen in the reflected view as the one-inch apertured circle concentric with the top of the heat exchanger.

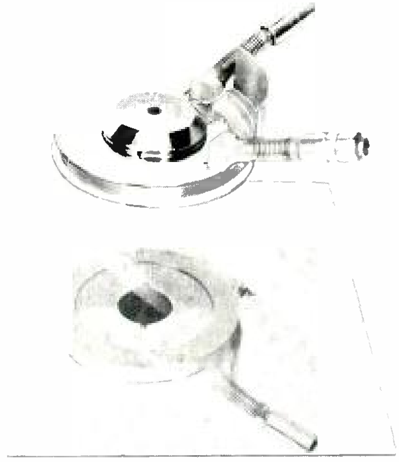


Fig. 4b—In the top view, the exchanger cap is shown resting in place on top of the exchanger. The heater wires may be seen disappearing to the rear of the cold baffle on the reservoir. The reflected (bottom) view shows the specimen holder protruding from the blackened metal of the rotor fin assembly, the metallized ceramic cone support having been removed for display purposes.

EMU-3 COLD STAGE

The EMU-3 cold stage is designed specifically for use with the Universal Chamber. As one of its functions, the reservoir in the chamber accepts a cylindrically-packaged heat exchanger which is the cold stage proper; the cold stage carries the specimen holder (Figs. 4 and 5).

Primarily, the method of heat exchange is a radiative transfer between interlocking, but nontouching, metal fins. Of three heat-exchange possibilities (radiative, convective and conductive), convection was eliminated because of the vacuum requirement. Conductive heat exchange was finally ruled out from the standpoints of 1) mechanical instability resulting from the effects of thermal expansion of materials constituting the conduction pathway, and 2) the necessity of effectively moving the reservoir with the specimen. Another factor was the need to isolate the specimen from any direct mechani-

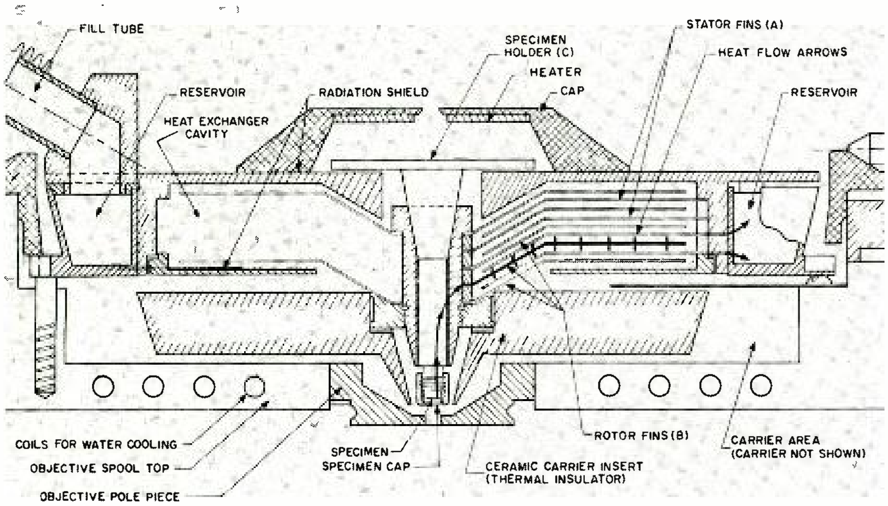


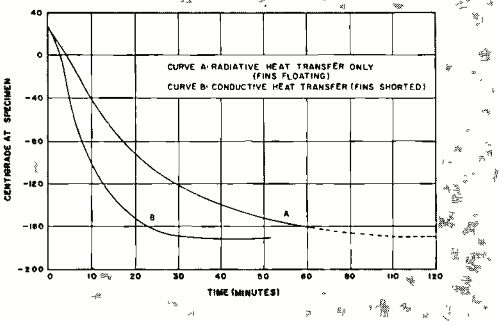
Fig. 5—EMU-3 cold stage.

cal linkage to the reservoir, since *bumping* inevitably occurs as liquids boil away. The final heat exchanger scheme uses radiative transfer; heat flow is shown by the arrows on Fig. 5.

As shown in Fig. 5, circular fins *A*, hereafter called the fixed fins, are stationary with respect to and in thermal contact with the reservoir. Interlocking fins *B* (the free fins) are thermally connected to the specimen holder *C* on the axis, then float free between fins *A* during microscopy. The assembly composed of fins *B* and the specimen holder *C* is supported by a thermally-insulating adaptor which rides in the movable microscope stage. Heat generated in the specimen is conducted away via fins *B* and radiated to fins *A* where it is conducted to the reservoir.

Radiation shields at reservoir temperature enclose the exchanger fins in an isothermal cavity; no fin of either set *A* or *B* sees the chamber walls which are, of course, at ambient microscope temperature. All heat radiated to the cold-stage package from its surroundings is therefore intercepted either by a reservoir wall or a reservoir wall extension. Conduction paths (walls-to-walls or walls-to-fins) are freed from appreciable thermal blocks by close tolerance machining and by the use of mechanically tight, clean, and soft isometallic junctions.

Fig. 6—EMU-3 cold stage—temperature of specimen vs. cooling time (liquid nitrogen refrigerant).



The free-fin assembly carries the specimen holder and rides with the carrier or stage. Because the fins are completely enclosed, only four possible sources of heat input to the specimen exist: 1) beam heating, 2) radiation from the ceiling of the chamber down through the beam passage, 3) radiation from the objective pole piece, and 4) conduction through the stage adaptor itself. Of the four, heat source (1) must be tolerated, but may be minimized by using small illumination spots and low beam currents. Heat source (2) becomes negligible by fitting an apertured metal cap with clearance over the specimen holder so that it rests on the top radiation shield of the exchanger. Heat source (3), which must also be tolerated, is reduced appreciably by using a highly polished radiation shield-liner for the surface of the objective pole piece facing the specimen, and by using coils for water cooling in the top plate of the objective spool; this is used when the operator desires to realize the maximum possible cooling. Heat source (4) may be disregarded as is explained in the following discussion.

Heat conduction from the push rods to the cold stage is reduced by sapphire linkages. Conduction to the cold stage from the objective spool or from the hold-down mechanism is only through the contact points of six ball bearings. The specimen adaptor, therefore, is for practical purposes of heat conduction, thermally insulated from the column. As added insurance, the adaptor that carries the free-fin system and that fits into the cold stage (Fig. 5) is made of ceramic. The ceramic is metallized and polished for two reasons: 1) to lessen heating due to radiation absorption from the top of the objective spool, and 2) to prevent electrical charging.

PERFORMANCE

Cooling curves for steady-state temperatures of the order of −170°C are shown in Fig. 6; it will be noted from Curve *A* that the time for cooling with the free fins floating is approximately 120 minutes. To decrease this cooling time, a mechanical arrangement, controllable from the sides of the chamber, allows the fixed fins to be raised (shorted) into thermal contact with the free fins for precooling by conduction. This decreases cool-down time by a factor of four. After precooling, the free fins are let free for microscopy, and subsequently pure radiation exchange takes over and maintains the specimen at the temperature attained with precooling.

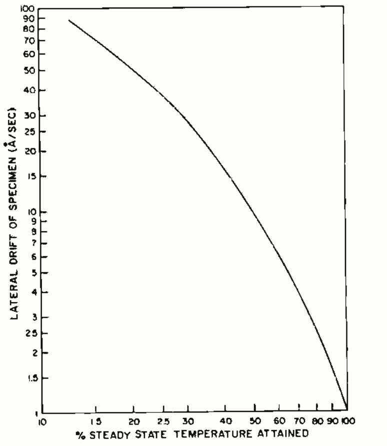
The curve for a steady-state temperature of −170°C with fins shorted is shown in Fig. 6 (Curve *B*). Fig. 7 shows specimen drift in its own plane as a function of percent steady-state temperature reached. At steady-state, the drift is less than 1.7 angstroms/sec. Vertical drift along the column axis is so small as to cause no problem in change of focus over periods in excess of 6 minutes.

HOT STAGE

The EMU-3 hot stage is designed specifically for use with the Universal Chamber. The hot-stage package consists of two basic parts: 1) a machined adaptor of thermally insulated material which rests in the stage, and 2) the heater and specimen holder on the axis (see Fig. 8).

Specimen temperature is raised by resistive heating; heat is transferred to the specimen by conduction. To localize the heat at the specimen and produce a heater current flow which does not generate a magnetic field, the heater is shaped like a cone. The specimen rests at the apex of a double-conductive cone, shown schematically in Fig. 9. The continuous conductive surface is a resistance film bonded to a ceramic substrate and the maximum heating current required is but a fraction of an ampere. In this way, heat is applied maximally at the specimen and most efficient use made of electrical energy in attaining a

Fig. 7—EMU-3 cold stage—specimen drift vs. % steady state temperature attained.



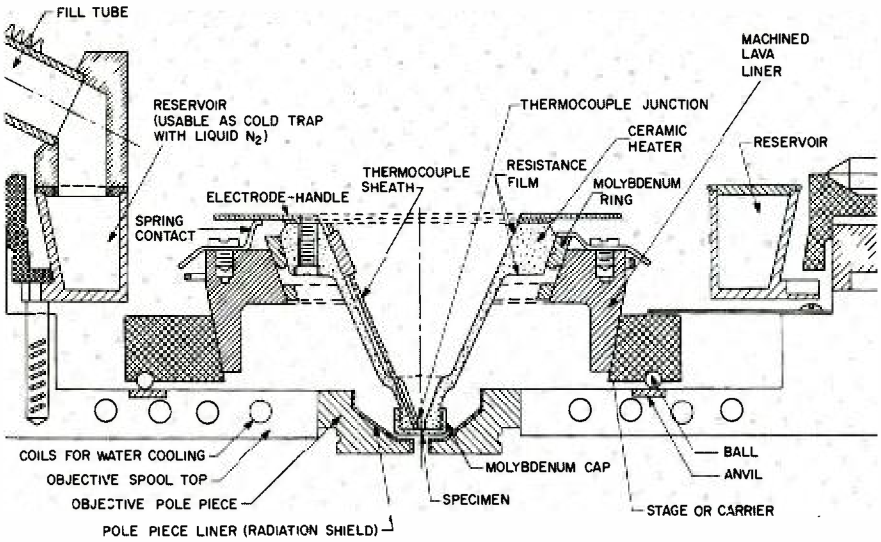


Fig. 8—RCA EMU-3 hot stage.

given temperature. Equally important, the concentric cones of oppositely directed currents give rise to a negligible net magnetic field. This assures that the heater field does not interfere with the optics of the column.

The hot stage is designed to give maximum mechanical stability at any steady-state temperature. As shown in Fig. 8, the ceramic adaptor has a tapered fit into the stage of the Universal Chamber. This is the outermost of a series of concentric tapered fits about the column axis; this axis passes through the specimen. The specimen is, therefore, always on the center of a cylindrically symmetrical system. The mating of concentric tapered surfaces keynotes the mechanical design; because of stress from the tapers, such mating assures that any tendency toward lateral motion at the specimen is converted into a tendency to axial motion. Because of the depth of focus of the electron microscope, axial motion of the order of microns at the specimen can be tolerated with little loss of resolution; whereas, lateral motion of the order of angstroms will limit resolution intolerably.

In addition to the outer taper, the machined adaptor has an inner taper into which fits a molybdenum ring; the ring, which serves as an electrical contact, has an inner taper also, and this surface is the support for the heater. Five carefully angled and concentric surfaces thus insure that the elements seat precisely, reproducibly, and stably into each other. The specimen is held by a screw-on molybdenum cap, directly onto the heater and at the center of the system.

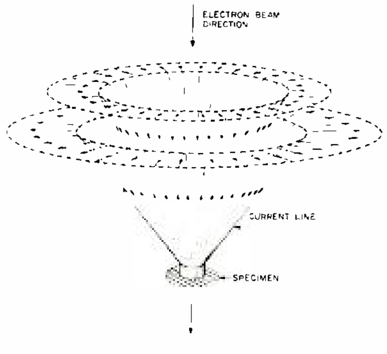


Fig. 9—Heater current development in the hot stage.

The heater is provided with a tantalum-sheathed platinum/platinum-rhodium thermocouple whose junction rests on the specimen periphery. Measurement connections may be made via feed-throughs built into the Universal Chamber wall.

THE HOT STAGE IN OPERATION

The conversion from normal microscopy to hot-stage microscopy consists only of inserting the lava adaptor into the hot stage and making electrical connections to the vacuum feed-throughs. The specimen holder-heater is all that has to be inserted or withdrawn when specimens are changed.

Fig. 10 shows the parts of the hot stage package; the molybdenum cap, which retains the specimen, is shown lying near the apex of the conical heater-holder. The reflected view, looking down the cone, shows the holes for thermocouple insertion; the adaptor is at the right.

Fig. 11 shows the heater in place in the adaptor; electrical connections to the heater are made simply by fitting the heater into the molybdenum support ring in the adaptor. In the reflected view, the molybdenum specimen retaining cap is seen screwed into the heater. The adaptor fits into the stage of the Universal Chamber, and the heater is extracted or inserted as specimens are changed, being handled as an ordinary specimen holder. The entire hot-stage package can be mounted in or demounted from the Universal Chamber in 1 minute.

CONCLUSIONS

A good commercial product is a commodity that satisfies human wants. How well it succeeds depends upon how well the engineering team can develop the embryo idea into a useful design. Design considerations, such as styling, human engineering, and production must have a powerful influence in the development of the product design. However, one must remember that the customer is a basic, if passive, part of the design team. It is always necessary, but not always easy, to acquire the necessary feedback of ideas from the scientists throughout the world who use the electron microscope. Yet customer acceptance is an important function, for a product cannot exist without a customer.

Due consideration is then given to all aspects of design from which a model is built and tested to rigid standards to prove the design. Intensive use of this new tool soon brings to light inconvenient or undesirable features of its design, as well as unnecessary or missing items. The electron microscope has been no exception to this pattern of design experience.

ACKNOWLEDGEMENTS

The project herein described from the viewpoint of mechanical engineering involved the efforts in varying degrees of all of the members of the Scientific Instruments Engineering Group. In particular, Dr. John Coleman was primarily responsible for the advanced development of the hot and cold stages. G. F. Burger and J. J. Schuler contributed many valuable ideas in construction and test of the various models. The author was project engineer for the program.

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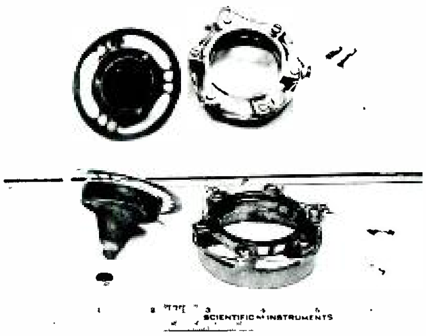
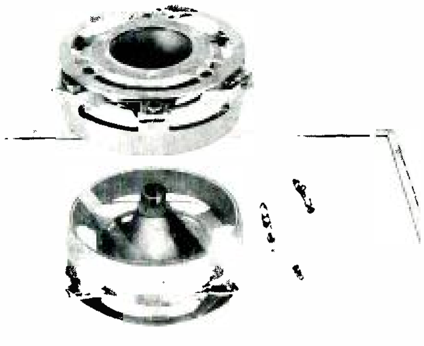


Fig. 10—The parts of the hot stage are seen in both direct and reflected views. To the left is the conical heater-holder and specimen retaining cap. To the right is the liner.

Fig. 11—The heater is seen in place in the liner. The specimen retaining cap may be seen in place in the reflected view of the underside of the assembly.



THE ROLE OF THE MECHANICAL ENGINEER AT RCA LABORATORIES

In electronic research and development, the physicist, the chemist, the metallurgist, the ceramicist, and the engineer pool their talents to devise new theories and experiments that result in new techniques, materials, and devices. The work at RCA Laboratories is exceedingly varied, since the whole spectrum of electronics must be covered. The mechanical engineer, therefore, is confronted with a variety of problems which may range from electron tubes to hydraulic pumps, from microscopically-small integrated circuits to large broadcast antennas. Almost everywhere there are cross links connecting mechanical engineering with the various phases of physics, chemistry, and solid-state electronics. This paper describes some R & D problems and their solutions by the mechanical engineering staff at RCA Laboratories.

R. G. OLDEN
RCA Laboratories
Princeton, N. J.

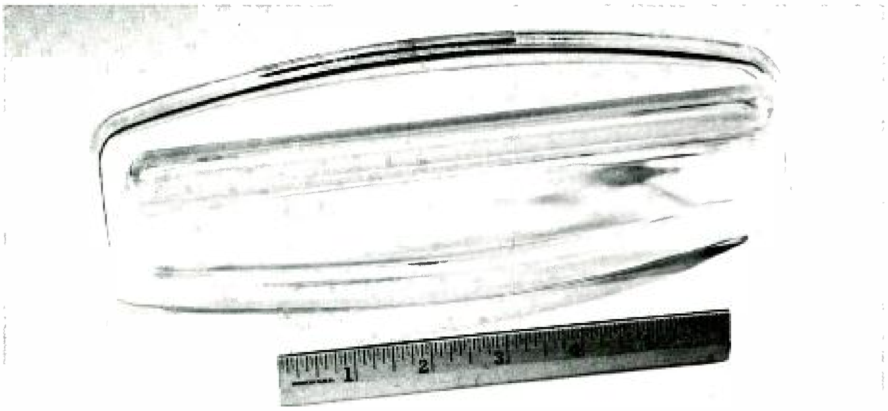
To cope with mechanical problems, a small but highly competent staff of mechanical engineers exists at the RCA Laboratories. Some of them are members of the various research groups while others form the nucleus of a central engineering group. While the former are more or less specialized in their field the latter apply their knowledge to any and all problems presented to them. A look at some of the mechanical engineering problems, past and present, that have been encountered by this group will clarify the nature and scope of the work involved.

MODERN MACHINING METHODS—ULTRASONIC MILLING AND PHOTO-ETCHING

Up-to-date machining methods are available and are used routinely. An example is the ultrasonic milling of a glass face plate for a thin-window cathode ray tube (Fig. 1). The slot and the tapered sides are ground in the conventional way. The rounded ends of the slot, however, are milled on an ultrasonic milling machine. This is a convenient alternative for grinding the ends with a pencil-type wheel.

Another of the modern machining methods, *photo-etching,* was employed to great advantage in the fabrication of light but strong printer bars. A medium-speed electromechanical printer (Fig. 2), developed by Maurice Artzt, employs a bank of seven such printer bars, side by side, to print alphanumeric data serially with facsimile technique. Each of the seven printer bars is activated individually by a magnet. Since each bar must be able to oscillate with a frequency of 1,050 cps, they had to be designed as light as possible, yet rigid enough to resist bending when full force is applied to print through several layers of carbon paper.

The printer bars are stacked with a minimum of clearance in order to ob-



◀ Fig. 1—Ultrasonically milled slot in thin-window cathode-ray-tube header.

Fig. 2—Electromechanical printer showing stacked printer bars.

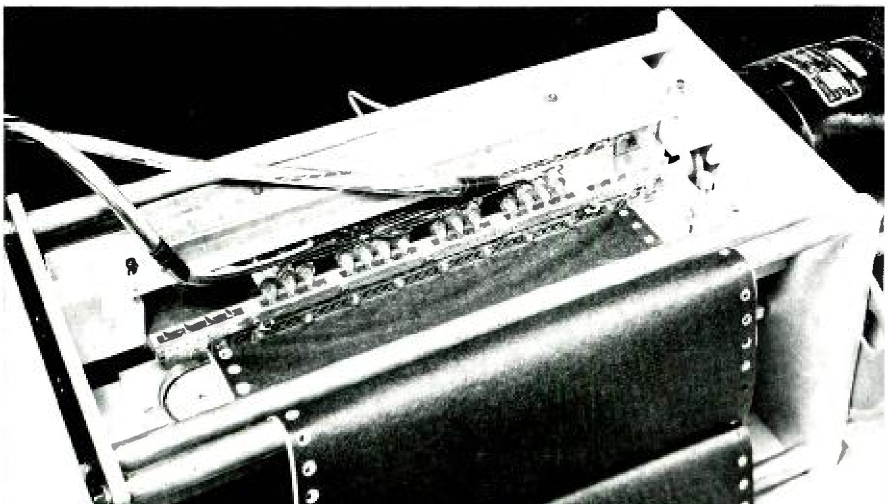
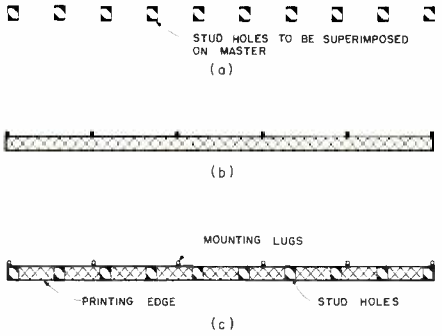


Fig. 3—Printer bar in three stages of development: a) openings for supporting lugs; b) printer bar structure; c) completed bar. ▼



tain closely spaced dots on paper. Any burrs or bends in the bars are therefore intolerable. The material from which the bars were to be made was specified as 0.010-inch-thick tempered spring steel.

Photo-etching was chosen as the best method to fabricate these printer bars. The steps involved in this process are as follows: A master is made from a sheet of special Mylar. One side of the Mylar has a thin red film which can be cut with a knife and peeled away in those areas which are to be removed by etching while the remaining red portions represent the final shape of the work piece.

In order to increase the accuracy, two masters were cut on a coordinatograph four times larger than the finished part. The openings for the supporting studs on one of these masters are shown in Fig. 3a. This master was superimposed on the other master of the bar proper, Fig. 3b, in seven different positions, corresponding to the seven printer bars, and photographed twice in each position. The lattice structure which showed through the stud holes was inked out in the negatives.

After suitable photographic reduction, the two negatives were then placed, one on each side, on the blank spring steel blades 0.013 inch thick, which had

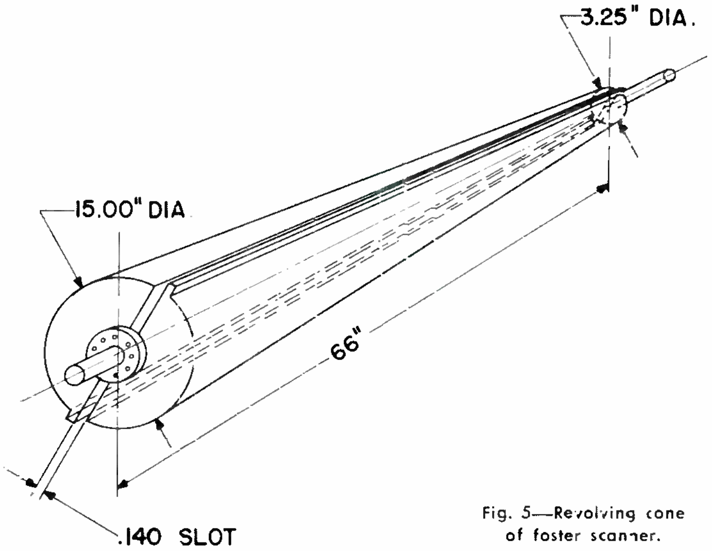


Fig. 5—Revolving cone of foster scanner.

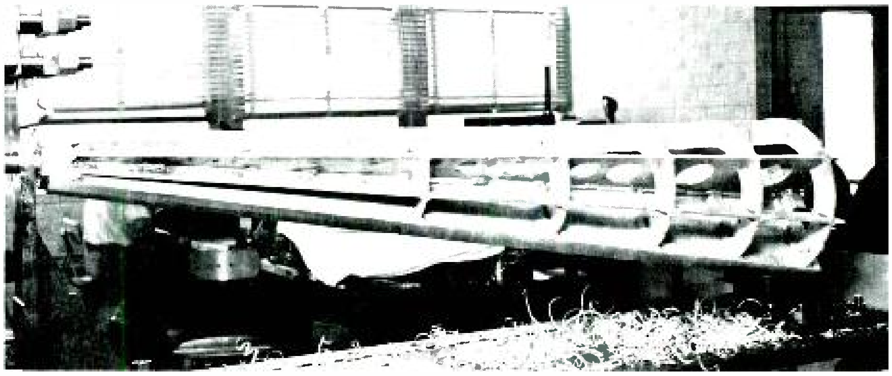
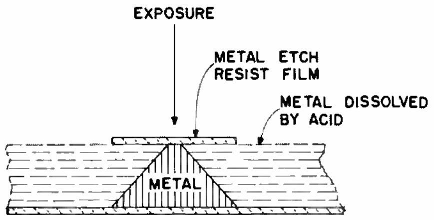
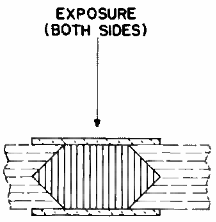


Fig. 6—Revolving cone during fabrication.



UNDERCUTTING EFFECT WHEN ETCHING FROM ONE SIDE OF THE METAL SHEET.



UNDERCUTTING EFFECT WHEN ETCHING FROM BOTH SIDES OF THE METAL SHEET.

Fig. 4—Undercut due to one-sided and two-sided etching.

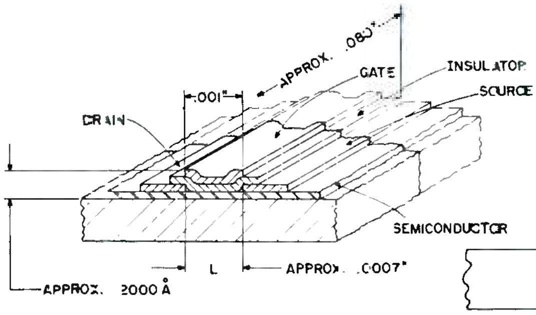


Fig. 7—Thin-film transistor.

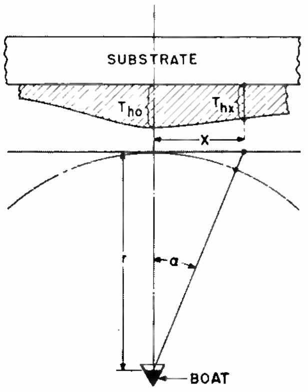


Fig. 3—Geometrical condition leading to the penumbral error.

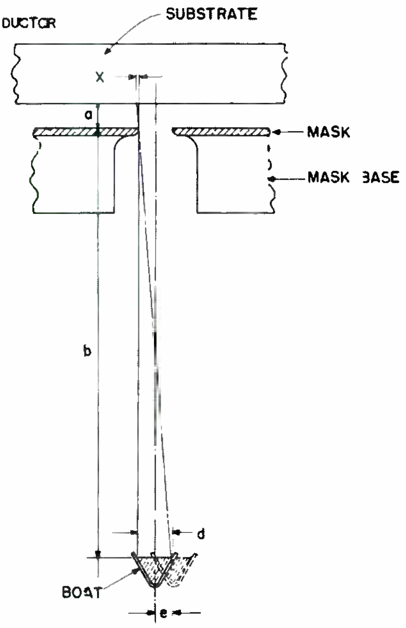


Fig. 9—Deviation in thickness of the evaporated layer.

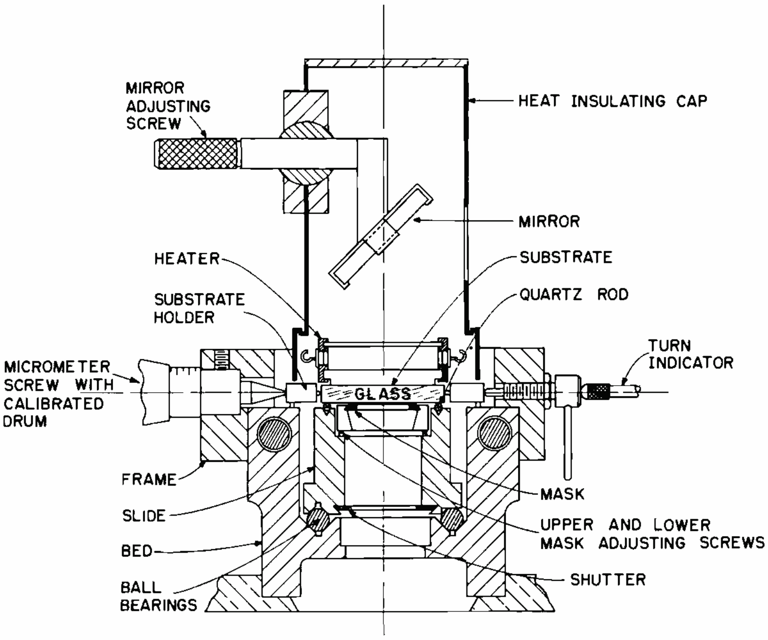


Fig. 10—Cross-section through the evaporation jig.

been coated with a metal-etch-resist film. After exposure to light on both sides the metal blanks were developed, so that the resist film remained only in the areas to be preserved. Since the metal strips carried resist images on both sides, etching took place on both sides, thus reducing the amount of undercut, as illustrated in Fig. 4.

The final operation consisted of grinding both sides to the desired thickness (0.010 ± 0.00025 inch), drilling holes in the mounting lugs, and grinding the printing edge flat and parallel to the center line through the holes in the mounting lugs. The completed printer bar is shown in Fig. 3c.

MECHANICAL DESIGN OF A RADAR ANTENNA

Several years ago RCA Laboratories was awarded a contract to develop and demonstrate a high-definition airborne reconnaissance radar system capable of detecting objects as small as a passenger automobile on a highway at ranges up to 10,000 yards. This project was a research investigation and in no sense was it a hardware development of a military prototype. However, one flyable research model was built and flight tested in a large Navy patrol bomber that was used as a convenient flying laboratory. The entire radar system was designed and built at RCA Laboratories. In addition, the preliminary design and final specifications for a gyro-stabilized antenna mount and the specification for the radome for the antenna were also developed there.

Many intriguing mechanical problems were solved during the design of this equipment. In addition to the usual problems of packaging, pressurizing, weight reduction and vibration isolation, the design of the scanning antenna is of particular interest to mechanical engineers. The scanning action is produced mechanically by a Foster scanner which employs a variable path length type of transmission system. (Many descriptions of Foster scanners are available in the literature.[1]) The heart of the Foster scanner is a revolving split cone turning inside a stationary split cone. Fabrication of the revolving cone was especially interesting. It is truncated: $3\frac{1}{4}$ inches in diameter at the small end, 15 inches in diameter at the large end, and 66 inches long, split into two separate and equal halves by a slot 0.140 inch wide from end to end and passing through the center line of the cone. A shaft is attached at each end as shown in Fig. 5. Fig. 6 shows half of the revolving cone about half way through the fabrication process. The flat section which extends through the middle is visible, as well as the ribs that support the conical sheet. Because of electrical requirements, two longitudinal raised ribs, one on each side of the center slot were required. This, then, precluded turning the conical section on a lathe. Instead, the conical surface was generated by revolving the cone on its own axis while it was supported on the bed of a large planer. The requirements for the cone assembly were that it revolve at 900 rpm and that the variation of the 0.140-inch space between halves not exceed 0.003 inch. Because of the slender proportions of the cone, centrifugal force caused the 0.140-inch space to open much more than 0.003 inch at 900 rpm. A method was developed jointly with the electrical people whereby the halves are tied together mechanically, yet appear to be open electrically.

Another mechanical development required by the scanning antenna was the high-speed potentiometer and timing commutator that provided synchronization between the scanning antenna and the CRT display device. A minimum life of 200 hours at 1800 rpm was desired. This was far better than anything available at the time. A successful design was developed using a molded plastic resistance element with a silver graphite brush for the potentiometer, and coin silver bars and glass-melamine spacers with silver graphite brushes for the commutator. The potentiometer-commutator assembly was driven at twice the speed of the Foster scanner rotor by means of a molded rubber timing belt which gave excellent jitter-free synchronization between the scanner and indicator.

PRECISION EVAPORATION JIG

One of the newest and most promising semiconductor devices to come out of the Laboratories is the thin-film transistor (TFT).[2] It is a semiconductor device based on the field effect phenomena. The advantages of the TFT over vacuum tubes and conventional transistors are the small size of the units with the possibility of easy interconnections to other thin-film components.

While thin-film devices are well understood and experiments correspond excellently with the theory, a great deal of engineering work is required to produce units which work well. It is not too difficult to produce one TFT, but the design of a row of several hundred interconnected units within a small area with predictable electrical characteristics and reliability of performance presents real problems because the fabrication difficulties increase in at least a square function as the density of units per square inch is increasing.

Basically the TFT consists of a narrow semiconducting channel between two electrodes, called the source and the drain. A thin dielectric film insulates the channel from a metallic gate electrode. All three films are deposited on a substrate by evaporation. The current flow between source and drain is regulated by biasing the gate electrode. Fig. 7 shows some typical dimensions of a TFT.

The substrate should be a ground and polished body, flat within ±0.0005 inch per inch, of insulating material such as glass, quartz, ceramics, etc. The normal procedure consists first of slicing and grinding and then finishing the plate with a polishing and lapping operation. The quality of the surface where the TFT is to be deposited is given in light fringes. One light fringe is approximately a half wavelength of a light wave of 6,000 angstroms (A):

$$7 \times 3000\,A = 21{,}000\,A = 2 \text{ microns}$$

In the above equation, 7 is an arbi-

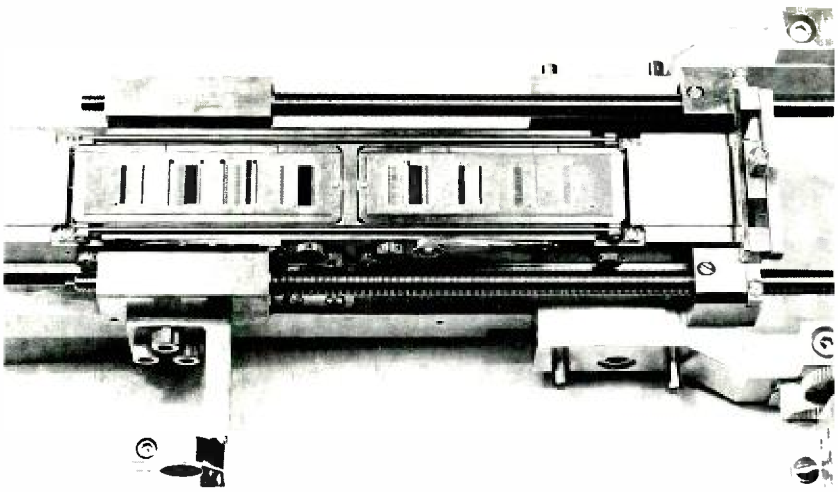


Fig. 11—Close-up of mask slide carrying several masks.

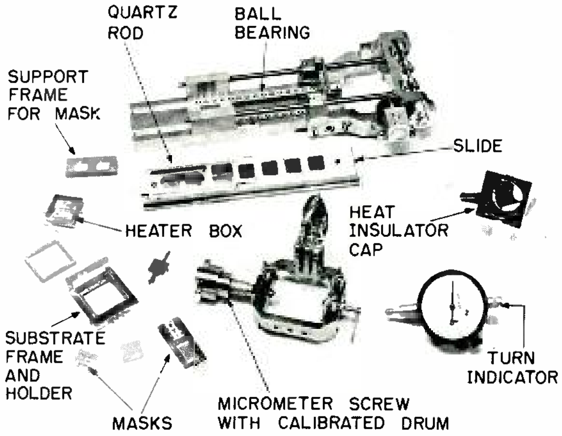


Fig. 12—Details of the evaporation jig.

trarily chosen number. Since a lapping compound with an average particle size of 5 microns is considered a fine powder, the preparation of the substrate is an expensive operation.

The thermal expansion of the substrate should match that of the evaporated material. Since it is not possible to match the heat expansion of all the layers, their sequence should be taken into consideration in selecting the substrate material.

Other aspects to be considered are mechanical properties like hardness, tensile strength, and elasticity.

Electrical properties like dielectric strength and dielectric constant are important as is the thermal conductivity for dissipation of the heat generated by the current flow.

One of the most important and most critical tools in making thin-film devices is the evaporation mask. Masks can be made mechanically by machining, but this process has only scant application because of the severe limitations imposed by tool sizes and tolerances. A more advantageous method utilizes photo-etching similar to the fabrication of printer bars described earlier in this paper. While the tolerances achieved with this process (± 0.0001 inch) are sufficient, there are shortcomings, mainly due to the thickness of the mask. In order to minimize the undercutting effect of the photo-etching process the mask should be as thin as possible; but on the other hand, geometrical correctness of the evaporated structure can be achieved only if the mask is flat and free of deflection and therefore thick enough to be self supporting. The result of these contradictory requirements often is a compromise that is not always satisfactory.

These disadvantages are overcome by using masks that are fabricated by a combination of photo-etching and electroforming techniques. Such masks are made at the RCA Laboratories or by companies specializing in this field. They consist of a supporting structure, which may be oxygen-free copper up to 0.030 inch thick, formed by photo-etching. On this support is deposited a layer of nickel, about 0.0005 to 0.001 inch thick that forms the mask proper.

The openings in the mask and mask support are produced separately by photo-etching. These etched openings are larger than called for by the specification. The final size of the holes is achieved by careful and accurate electroforming.

Openings of 0.0005 inch with an edge definition of 0.0001 inch are standard dimensional requirements.

One of several sources of faults in the fabrication of TFT's is the penumbral error. This is the uncertainty in edge definition arising from the fact that the evaporation source is not a point but has a finite dimension. The geometrical conditions are shown in Fig. 8. The error is aggravated when several boats are arranged on a turntable. Then the eccentricity has to be taken into account. From Fig. 8 it can be seen that the penumbral error is:

$$X = \frac{a}{b}(d + e),$$

where: a = the distance between mask and substrate, b = the distance of the boat from the top of the mask, d = the width of the boat, and e = the eccentricity. Frequently encountered values are $a = 0.003$ inch, $b = 10$ inches (this distance may vary between 3 inches and 20 inches), $d = 0.25$ inch, and $e = 0.050$ inch. Under these conditions the penumbral error X is approximately 0.0001 inch which is within the acceptable limits.

Another reason for faulty construction can be found in deviations in the thickness of the evaporated layer. If we could presume that the source material is located in the center of a sphere (or spherical section) on which a layer is to be deposited, then it is evident that its thickness would be uniform since the distance of every point on the sphere from the source is constant. In practice, however, the substrate is a flat plate and the distance of the source from different points on the substrate varies (Fig. 10). This constitutes one of the reasons for variations in the thickness of the evaporated layer.

If in Fig. 9, T_{hx} is the layer thickness at a distance x from the center line, then:

$$T_{hx} = T_{ho} f$$

$$f = f_1 f_2$$

Fig. 13—L. Meray-Horvath checking mask alignment in the shadowgraph.

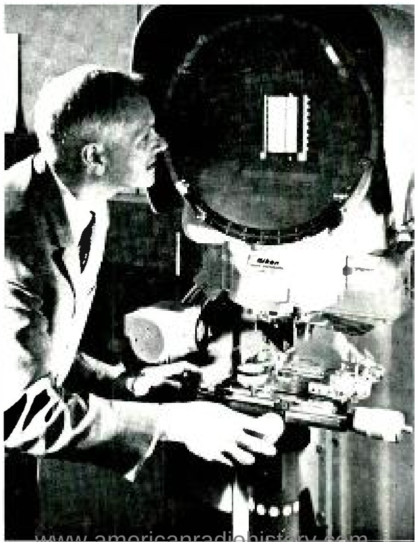


Fig. 14—H. P. Lambert mounting the jig for evaporation.

Where:

$$f_1 = \cos\alpha = \frac{r}{(r^2 + x^2)^{1/2}} \text{ (Lambert's law)}$$

$$f_2 = \frac{r^2}{r^2 + x^2} \text{ (Inverse square law)}$$

Substituting:

$$f = \left[\frac{r}{(r^2 + x^2)^{1/2}}\right]\left[\frac{r^2}{r^2 + x^2}\right] = \left[\frac{1}{1 + \frac{x^2}{r^2}}\right]^{3/2}$$

$$T_{hx} = T_{ho}\left[\frac{1}{\left(1 + \frac{x^2}{r^2}\right)}\right]^{3/2}$$

For T_{ho} = 1.000 angstroms, $r = 4$ inches. $x = 1$ inch, T_{hx} = 915 angstroms, which means a decrease in thickness by 8.5%.

The requirements and specifications for the design of a new evaporation jig were very severe. First and foremost was the demand for precision: the error in straight-line registration of the masks and in repeatability should not exceed ± 0.0005 inch at constant temperature. Further, the jig should be constructed so that the substrate could be heated to a temperature of 400°C without heating the remainder of the jig excessively high. There should be a calibrated device to correct dimensional changes due to thermal expansion. The mask holder should be able to accommodate masks of different size, the existing stock as well as new ones. Electrical and temperature measurements should be possible during the evaporation process. And finally, the materials for all parts of the jig should be chosen so that the device could be subjected to an ultra-high vacuum.

Previously used techniques fulfilled one or the other of these requirements but the goal of heat and precision simultaneously was not attempted.

The jig proper comprises the bed, the drive, and the mask slide. The cross sectional view. Fig. 10. shows that the bed contains two *V*-grooves for the ball bearings on which the mask slide rolls. The latter is a many times normalized, ground and polished track which carries the masks. On top of the mask slide are two longitudinal quartz rods on which the substrate rests. The masks are aligned with adjusting screws so that their upper surface is not more than 0.0005 inch below the substrate. Fig. 11 is a close-up of the mask slide carrying a number of masks in two units. Fig. 12 is an exploded view showing some of the details.

The jig has already been used extensively and has given excellent results. Its alignment and repeat accuracy are fully satisfactory. Although no full-range temperature measurements have been made it could be shown that the substrate could be heated to substantially higher temperatures than the rest of the machine. This is accomplished by clamping a heater, shown in Fig. 12, over the substrate. A heat-insulating cap which encloses the substrate and the heater protects the surrounding parts.

The insulating cap contains a mirror and an opening in the side so that the masks can be optically aligned even with heater and cap in place. A micrometer screw with calibrated drum on one side of the bed and a turn indicator, calibrated in tenths of thousandths of an inch, on the other side make it possible to compensate for thermal expansion. Provisions were made for electrical and thermal measurements during evaporation.

In this assignment, too, more than sound mechanical engineering knowledge was required. A thorough familiarity with evaporation techniques and a more than nodding acquaintance with semiconductors was necessary to build a successful device which satisfied such severe demands.

WETTING DEVICE FOR ELECTROLYTIC FACSIMILE RECORDER

Some time ago the author was confronted with a most interesting problem in electrolytic facsimile printing. In this process the recording paper has to be, at the moment of printing, saturated with the aqueous electrolyte in order to make it electrically conductive and supply to it the color forming agent or agents. Conventionally the wetting of the paper had been done by drawing it through a trough. This method had the disadvantage that it necessitated cleaning the container after each day's run, a disagreeable job since the recording solution was corrosive and also caused black spots on hands, clothing, etc. The chemist on the project, H. G. Greig, had found that the electrolyte could be formulated in two separate solutions, a diazonium compound and a coupler, and that thereby the shelf life of each solution was increased to several weeks. Once combined, however, the life of the solution was limited to a few hours. The problem now was to eliminate the trough altogether, but to mix the two solutions intimately and apply the mixture to the paper in such a way that the latter would be thoroughly damp at the printing point. This innovation would eliminate the unpleasant job of cleaning the trough, and would make the recorder automatic. The problem was made somewhat easier by the fact that only small amounts of liquid were necessary; 1.2 cm^3 of each solution per minute was sufficient to replace the liquid taken up by the recording paper.

After some experimentation we decided to use the capillary action of the aqueous solution for the purpose of wetting the paper. When directed at a wedge-shaped opening of the proper material, a drop of water will spread quickly along it. The speed with which the spreading takes place depends on the wetting characteristics of the materials involved. Since wetting can be expressed in terms of the contact angle the search was concentrated upon the latter. The angle of contact between a solid and a liquid may be defined as the angle which the tangent to the liquid at the interface forms with the surface of the solid, measured through the liquid. It is presumed to be zero for clean glass and pure water, indicating perfect wetting. However, for ordinary glass and water the values given in the literature vary greatly. It was therefore decided to conduct a series of experiments to determine the relative wettability of a number of commonly used metals and plastics. As was expected, the results showed that glass was the material to use.

The first arrangement is shown in Fig. 15. The paper is drawn under a *U*-shaped glass rod that rests on a glass plate, which is slightly inclined in the direction of the paper motion. The two recording solutions are fed, drop by drop into a funnel-shaped container above the center of the glass rod; they run down its steeply sloping side and fall on the glass rod. There the liquid finds the wedge-shaped space A and quickly spreads along it to both sides. Upon reaching the edge of the paper the fluid finds the capillary space B underneath the paper and spreads along it until the two portions meet again under the paper. The latter is now surrounded by a thin meniscus of liquid, sufficient to wet the paper thoroughly if its level is maintained, and held in place by capillary action.

As was mentioned above, small but

Fig. 15—First model of wetting device for electrolytic facsimile recorder.

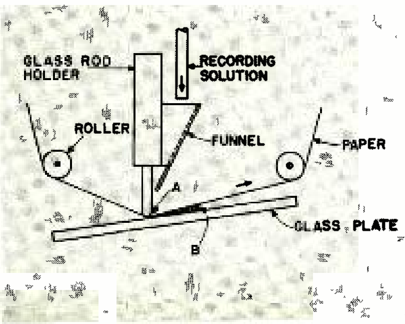
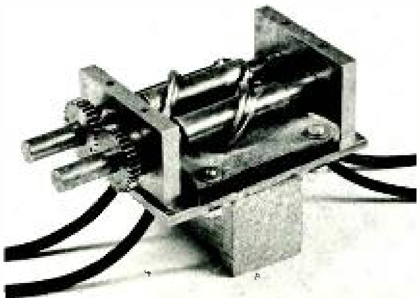


Fig. 16—Double-octing metering pump.



ROGER G. OLDEN was educated in Vienna, Austria. He received his BS degree in 1921 and an Engineering Diploma in Mechanical Engineering from the Technical University of Vienna in '1928. From 1929 to 1938 he was engaged as Engineer in the Mechanical Engineering Department of the City of Vienna. In 1942, Mr. Olden joined the RCA Laboratories, Princeton, N. J., where he has devoted his talents to electrolytic facsimile and electrophotography. During the last 10 years he has made major contributions to Electrofax, the thin-window tube, and high-speed printing. He has 12 U. S. Patents. In 1950, Mr. Olden received an "RCA Laboratories Achievement Award" for his contribution to basic improvements relating to facsimile recorders. His paper on "Electronic Facsimile" appeared in the Encyclopedia Americana for the year 1952. In addition, he has published papers in the "RCA Review" in 1957 and 1961.

equal and metered amounts of each component of the recording solution had to be supplied and maintained. This requirement necessitated a small, double-acting metering pump which at the time was not commercially available. A way out of this dilemma was found by designing a novel peristaltic pump which satisfied the specifications. The first breadboard model of this pump is shown in Fig. 16. It consisted of two pieces of small, soft rubber tubing over which was stretched a piece of thin, soft but strong fabric. A helical rotor depressed each tube through the fabric and as the rotor turned, the point of depression moved along the tube, thus pushing the liquid ahead and creating a vacuum in its wake, sucking up more liquid. Eventually the two rubber hoses were arranged 180° apart inside a cylindrical housing with a single rotor to act on both.

The wetting of the recording paper as described above was convenient and sufficient but the mixing of the two component solutions proved to be far from satisfactory. Streaks of different colors indicated that a much better mixing action had to be found. Consequently, the two solutions were combined in a common glass tube, with the hope that this would effect sufficient mixing. It was soon found, however, that while the mixing was improved, it was still not good enough.

A solution to this problem was finally arrived at by reasoning along the following line: if a drop of liquid is directed against the corner of a small, thin-walled cup with flat bottom of, say, ½ inch diameter, then the liquid spreads rapidly along this corner, obviously describing a circular motion. Succeeding drops, however, quickly fill up the cup and the action is lost. Therefore, a hole was punched in the center of the bottom. Now the liquid was confined to the circular corner formed by the annular ring at the bottom and the side wall, and held there by surface tension. The cup was dimensioned to hold ten drops. The eleventh drop ran over the side, found the hole in the center which caused the surface tension to break down so that all eleven drops now fell on the glass rod where they quickly spread and surrounded the paper. With the surface tension broken, each succeeding drop of the combined liquid went through the cup after first moving around the circular path. This proved to be an excellent mixing action and the discoloration and streaks disappeared.

Now the recorder was fully automatic. By turning on the pump a few seconds before the paper started to move, the latter was dampened and ready for recording when it reached the printing point. Similarly, when the message was finished the pump was turned off first with the paper still moving. By the time the last printed line had moved out of the recorder the paper had taken up all the liquid above and below it on the wetting device. Thus, the operator was spared all the handling of the solutions.

Still the problem was not entirely solved. Every evening, when the recorder was turned off, the paper was left clean and ready for the next run but on following mornings it was found that the paper was black and covered with dried solution. This was a puzzle, especially since no leak in the lines could be detected. Eventually we discovered that the recording solution generated gas that pushed a plug of liquid out onto the paper. The remedy for this problem was simple and quickly found. In each feed line a small air bag was installed over which was put a low power resistor. The resistor was electrically coupled to the pump so that it warmed up immediately when the recorder was turned on. The heat generated by the resistor caused the air to expand and to escape in small bubbles through the mixing tube until a steady state was reached. When the recorder was turned off the cooling air contracted and sucked in some of the liquid. Gas developed during the night now could leak out without forcing any liquid out of the lines. The wetting device in its final form is shown in Fig. 17 and in the photograph Fig. 18.

Fig. 17—Final form of wetting device.

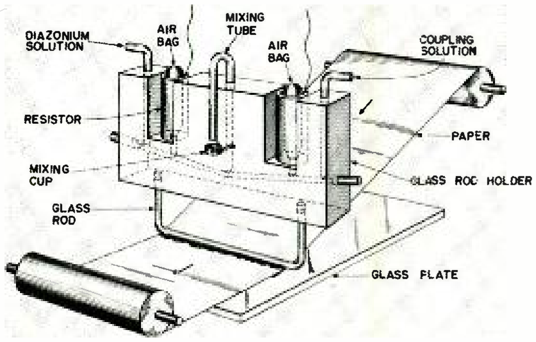
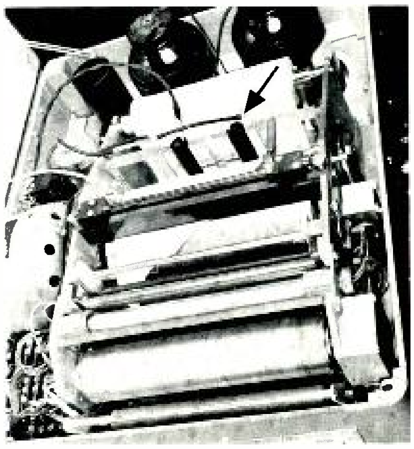


Fig. 18—Electrolytic facsimile recorder showing wetting device (arrow) and pump.



CONCLUSION

Many more samples of the mechanical engineering work at the RCA Laboratories could be presented. It is hoped, however, that the few which have been described will acquaint the reader with the problems, the challenges, and the rewards which are a part of the daily work at RCA Laboratories.

ACKNOWLEDGMENTS

For their contribution to this paper, the author is grateful to: M. A. Leedom of Engineering Services for his contribution on printer bar fabrication; L. Meray-Horvath of the Electronic Research Laboratory for the description of the evaporation jig; and R. G. Shankweiler, Manager, Engineering Services for his description of a high definition radar.

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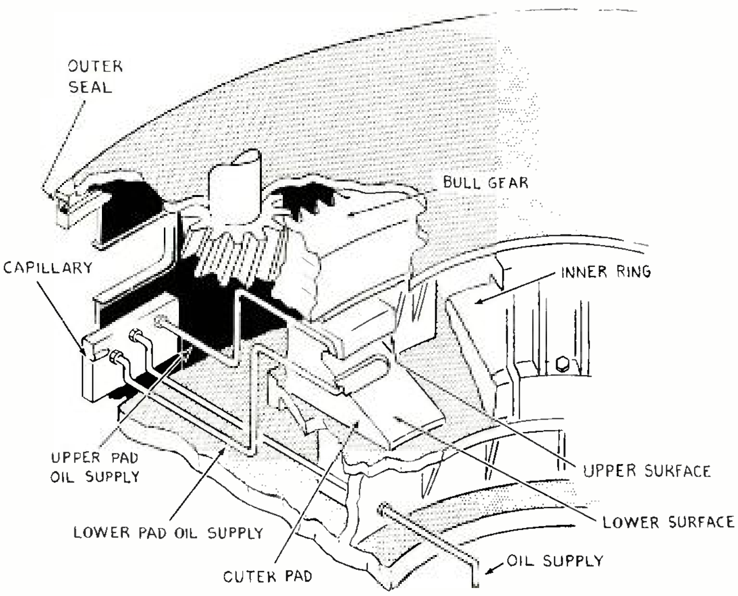


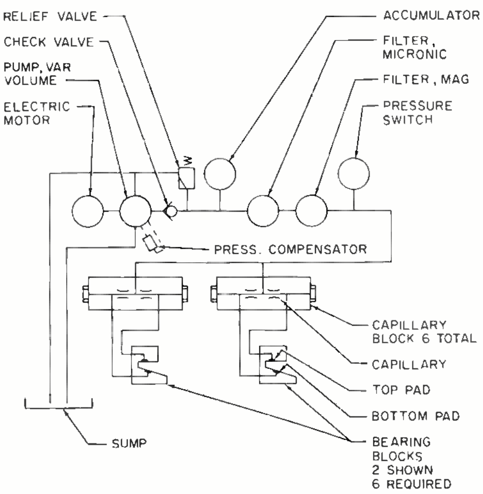
Fig. 1—Physical arrangement of the hydrostatic bearing.

DYNAMIC RESPONSE OF A HYDROSTATIC BEARING

The excellent friction characteristics of hydrostatic bearings are of great interest to RCA antenna pedestal engineers. Two bearing prototypes were developed over the past years to study hydrostatic bearing characteristics to aid in the evolution of a comprehensive analytical approach to the bearing dynamics. The first RCA antenna pedestal to use a hydrostatic bearing was the AN/MPS-25; this bearing was designed to support a 20,000-pound turntable and a 20-foot radar antenna. The work described in this paper considers a more recent hydrostatic bearing designed to support the 30-foot antenna dish and the rotating structure of the AN/FPQ-6 Missile Precision Instrumentation Radar (MIPIR).

J. C. SPRACKLIN and **G. M. ROBINSON, Ldr.**
Missile and Surface Radar Division
DEP, Moorestown, New Jersey

Fig. 2—Schematic of the hydrostatic bearing.



The specifications of the antenna pedestal for the MIPIR tracking radar were probably as exacting as any considered. heretofore.[3] For example, the pointing accuracy in a 40-mph wind was to be 0.01 mils-RMS. the dynamic range of continuous tracking 100,000:1, and the structural natural frequency 10 cps.

As with any design, the choice of the hydrostatic bearing involved a compromise of many desired chartceristics. The low friction and long life of the bearing are obvious advantages; but, would it be compatible with the other antenna pedestal parameters and, more importantly, is it practical?

PHYSICAL CHARACTERISTICS OF THE HYDROSTATIC BEARING

It is not the intent of this paper to describe the mechanical design of this bearing in detail, but rather to consider its effect on the dynamic response of the antenna pedestal. However, the physical characteristics of the bearing described herein are significant, as the practical limitations of mechanical design do effect the dynamics of the pedestal.

The supporting structure of the hydrostatic bearing is considerably more complex than the usual four-point, angular-contact bearings used on most radars. This is due in part to the large preloading forces required to achieve the necessary bearing rigidity, and partly to the incorporation of adjusting features of individual pads used to set the bearing clearances to the required values. The hydraulic oil-supply system for the bearing is more critical than the usual lubricating oil supply. The large volume of oil required for proper heat dissipation is more susceptible to the collection of dirt—and requires more exotic filtering systems. Since the loss of oil pressure while under power would precipitate a catastrophic failure of the bearing, adequate controls are mandatory to assure an adequate flow of oil until the rotating turntable can be stopped.

ARRANGEMENT OF BEARINGS AND OIL SUPPLY

Fig. 1 shows the arrangement of the bearing elements and Fig. 2 shows the hydraulic schematic of the bearing; the bearing consists of six pads mounted on the bearing support and an inner ring piloted on the turntable spiggot. The six pads are spaced equidistant between supports for the stationary bull gear. Each pad is supplied with an independent, regulated oil flow to the top and bottom of the bearing surfaces. The flow controlling device, in this case a fixed capillary, is mounted outside the reservoir for ease of access. The oil power supply consists of a fixed displacement pump with its associated relief valves, check valves and filters mounted in the base of the pedestal. A low-pressure switch disables the servo system in the event of a pressure failure. A hydraulic accumulator provides a reserve of oil to operate the bearing until the servo system can be stopped; in practice, the accumulator provides 30 seconds of bearing operation.

PRECISION BEARING CONTROL

To achieve the close control of the bearing surfaces necessary for proper bearing operation. each pad is provided an independent means of radial adjustment. Such adjustment can provide reasonable control over the bearing clearances without excessively tight diametrical tolerances. The excellent grinding facilities available in this country today permit the surfaces to be held within 0.0007 inch of true location; thus, an average clearance between pad and ring of 0.0017 inch is permitted.

Hydraulic Impedance

Control of the hydrostatic bearing is achieved by isolating each pad from the oil source, permitting each pad to act independently in reacting to applied loads. The first requirement is to define the hydraulic impedance of the bearing. The basic equation of the flow of oil through a slot is:

$$\text{Flow} = \frac{\text{slot width}}{\text{slot length}} \times \frac{(\text{slot thickness})^3}{12 \times \text{absolute viscosity}} \times \text{Pressure Drop}$$

The pad impedance can be evaluated best by using an analog field plotter in which current is applied to an electrical model of the bearing simulated on conductive paper. An alternate to this method is to sum the flow paths from the oil supply grooves according to the above equation. Fig. 3 shows the geometry of the top and bottom pads.

Once the top-and-bottom-pad characteristics have been established, a plot of the pressure distribution for each pad can be made at each value of slot thickness or bearing height. These curves assume all other conditions of the flow equation remain constant; for nominal conditions, the viscosity and bearing geometry will not change. The flow, of course, would change as the impedance changed unless some means were used to control it.

Oil-Flow Control Methods

There are three means of controlling the flow of oil to each pad in the bearing; first, there are commercially available flow regulators that will provide a constant flow of oil. Such devices are expensive and very sensitive to dirt.

A second means, and by far the simplest, is to place (in the supply line to each pad) a capillary having an impedance magnitude large enough to isolate each pad from the oil supply. Thus, an impedance change of an individual pad will not change the total impedance of the capillary complex; this method of control is very inefficient. since the hydraulic power supply must be capable of delivering several times the pressure required to operate the bearing.

A third method is a modification of the capillary system in which a pressure-controlled capillary is installed in the supply line to each pad; this capillary is then moved to change impedance, depending upon the pressure requirements of the pad.

This third means has the greatest possibility of control as the feedback can be adjusted to compensate for bearing loading by providing additional oil as it is required. However, such a compensated capillary has two limitations; it is expensive and complex, and it is difficult to design the control device with enough response to be compatible with the dynamic characteristics of the antenna pedestal.

The solution to each type of control is similar; in the final design a simple capillary was used. The flow-control devices were discarded due to their expense and complexity and the compensated capillary was abandoned due to its cost and low dynamic response.

The bearing dynamic equations for the final design are shown in the *Bearing Analysis.* Also presented is a brief analysis of the compensating capillary to show its interesting characteristics. (Fig. 4 shows the schematic and nomenclature for the compensator.)

CONCLUSION

An analytical solution of this type is easily incorporated into the dynamics study of the radar system and specifically to the MIPIR servo study, since the transfer functions become an integral part of the angle servo systems. The conical section is a compromise between the mechanical and dynamic considerations. While the conical bearing is not by nature as rigid as a bearing with orthogonal surfaces, it does permit ease of alignment and simplicity of control. The alternate would be a three-surface bearing with separate top, bottom, and radial pads; these would become bulky, more difficult to machine and generally require greater oil flow.

Test verification of the data presented for the simple capillary is generally good. No attempt has been made to incorporate test results in the data presented; no dynamic response has been taken other than normal servo frequency responses. Testing has indicated that in order to achieve the desired results, the bearing clearances had to be reduced from a nominal 0.002 inch to 0.0017 inch. This is believed to be due to variations in individual pads and the ring due to normal tolerance accumulations. With this corrected clearance setting, good correlation was achieved with the static equilibrium equations. A rather large discrepancy existed in the flow requirements of the bearing; however, a suitable adjustment in capillary size permitted satisfactory operating conditions. At present, the first bearing has been in operation more than two years without difficulty.

GEORGE M. ROBINSON received his BSME in 1950 and his MS in 1952 from the Massachusetts Institute of Technology. He served two years as ordnance engineer at Watertown Arsenal and then supervised and performed research for six years in the fields of friction, wear, lubrication and bearings at the Laboratories of the Franklin Institute of Philadelphia. In 1958, Mr. Robinson joined RCA Missile and Surface Radar Department where he has been leading a group in the design and development of a variety of electro-mechanical components relating to radar pedestals. From 1956 to 1961, Mr. Robinson was an Adjunct Professor of Mechanical Engineering at Drexel Institute of Technology and is a Member of ASME and ASLE.

JOHN C. SPRACKLIN received his Bachelor of Science degree from the U. S. Coast Guard Academy in 1952 and his MS in Mechanical Engineering from Drexel Institute of Technology in 1958. After serving as an Engineering Officer in the Coast Guard, Mr. Spracklin joined RCA Missile and Surface Radar Department in 1957. He has been responsible for the development of a variety of mechanical components and systems associated with radar pedestals and was chiefly responsible for the successful development of the hydrostatic bearing currently in use on the AN/FPQ-6 radar pedestal.

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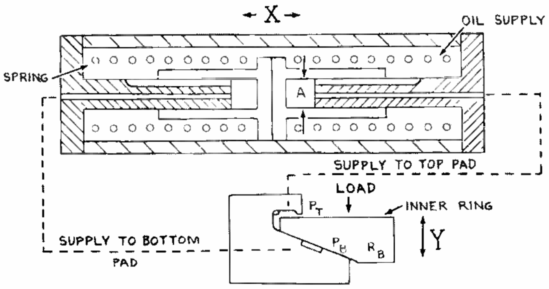
Bearing Analysis, *next page* ▶



A—piston area, 1.00 in².

M—piston mass, 3.89 x 10⁻³ lb-sec²/in.

Kₛ—compensator spring, 180 lb/in.

B—bulk modulus of oil, 5 x 10⁵ psi.

V—oil volume, 3 in³.

R_E—leakage coefficient from piston chamber = $R_B + R_C$, 2.6 x 10⁻³ in⁵/lb-sec.

R_B—bearing pad resistance.

R_C—capillary resistance.

$Q_{T,B}$—flow from piston chamber top & bottom, in³/sec.

$P_{T,B}$—top and bottom pad pressure, psi.

Fig. 4—A compensating capillary.

BEARING ANALYSIS

Analysis of the Compensating Capillary

The operation of the compensating capillary involves the movement of the bearing inner-ring; for example, downward, by reducing the impedance of the upper pad and increasing the impedance of the lower pads. This change directs a greater pressure in the lower pad and lessens the pressure in the upper pads, tending to develop forces equal to the applied load. To increase this effect, the compensator cylinders are moved to the right due to a larger pressure in the lower pad; such motion to the right has the effect of decreasing the impedance in the control capillary, permitting an even greater pressure in the lower pad. This action tends to amplify the inherent stability of the bearing and if done correctly will provide an extremely stable inner ring.

The unbalanced areas and nonlinear flow characteristics of the bearing prohibit a simple closed solution to the dynamics of this compensator. The simplest solution to this and other bearing equilibrium problems is to plot the motion and forces of the bearing to find steady-state positions for various loads. The values used in Fig. 4 were chosen in such a manner.

The response to a given applied force to the bearing can be solved using the equation of motion of the compensator for a given set of operating conditions, as follows (F_p = force on piston):

$$F_p = \frac{M\,d^2x}{t^2} + K_s x + (P_T - P_B)\,A$$

Flow:

$$Q_T = P_T R_E + V\frac{dP_T}{dt}\frac{1}{B}$$

$$Q_B = P_B R_E + V\frac{dP_B}{dt}\frac{1}{B}$$

$$Q_T = \frac{-dx}{dt}A$$

$$Q_B = \frac{+dx}{dt}A$$

Combining:

$$2\frac{dx}{dt}A = R_E\,(P_T - P_B) + V/B\,\frac{d}{dt}(P_T - P_B)$$

Using Laplace notation:

$$2S\,x\,A = P_T - P_B\,(R_E + S^{V/B})$$

$$\frac{P_T - P_B}{x} = \frac{2SA}{R_E}\left(\frac{1}{\frac{V}{R_E B}S + 1}\right)$$

Let $V/R_E B = \tau_1$ seconds; then:

$$F_p = \frac{\tau_1 S^3 M + MS^2 + KS\tau_1 S + K_S X + \frac{A^2}{R_E}Sx}{\tau_1 s}$$

$$\frac{\Delta X}{\Delta F} = \frac{1}{K_s}\left[\frac{\tau_1 S + 1}{\frac{\tau_1 M}{K_s}S^3 + \frac{M}{K_s}S^2 + \tau_1 + \frac{A^2}{K_s R_E}S + 1}\right]$$

An examination of the terms of the last equation will indicate that within the frequency region of interest (0 to 30 cps) only one term is pertinent and the equation will simplify to:

$$\frac{\Delta X}{\Delta F} = \frac{1}{K_s}\left(\frac{1}{\frac{A^2}{K_s R_E}S + L}\right) = \frac{1}{180}\left(\frac{1}{2.1S + 1}\right)$$

Therefore, the response of the compensator is attenuated above 0.1 cps to the point where it is of little value. It is impractical to attempt to raise this response to a useful region of 10 cps due to the physical size of the components.

The Final Design: A Simple Capillary

With the elimination of the other means of control, a simple capillary with its inherent inefficiency proved to be the best means of control. The most practical means of analysis is to plot the various steady-state loading conditions for the bearing and determine the slope of the load line and develop a series of influence coefficients about an operating point. Fig. 7 shows the pressure-versus-film-thickness curves for a set of top and bottom pads. From these curves and the geometry of the bearing, the

Fig. 3—Bearing geometry for top and bottom pads.

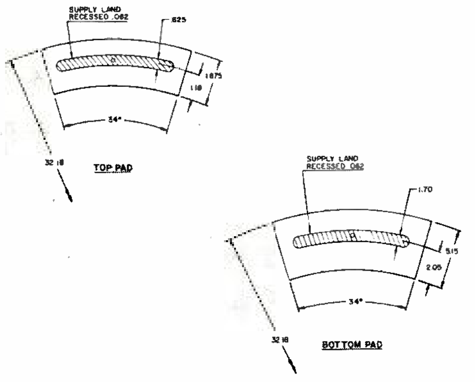
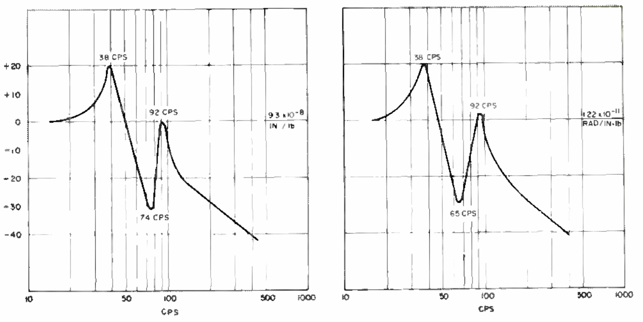


Fig. 5—Transfer functions for primary modes.



$$\frac{X}{F_X} = 9.3\times10^{-8}\,\frac{\left[\left(\frac{S}{74}\right)^2+1\right]}{\left[\left(\frac{S}{38.3}\right)^2+1\right]\left[\left(\frac{S}{92.2}\right)^2+1\right]}$$

$$\frac{\theta}{M_0} = 1.22\times10\,\frac{\left[\left(\frac{S}{65.4}\right)^2+1\right]}{\left[\left(\frac{S}{38.3}\right)^2+1\right]\left[\left(\frac{S}{92.2}\right)^2+1\right]}$$

constants in the bearing matrix can be evaluated. Considering the normal spacial coordinates X, Y, Z, θ_x, θ_y, θ_z the forces about the axes can be written as follows:

$$\Sigma F_x = \frac{\partial F_x}{\partial x} dx + \frac{\partial F_x}{\partial y} dy + \frac{\partial F_x}{\partial z} dz + \frac{\partial F_x}{\partial \theta_y} d\theta_y + \frac{\partial F_x}{\partial \theta_x} d\theta_x$$

$$\Sigma F_y = \frac{\partial F_y}{\partial x} dx + \frac{\partial F_y}{\partial y} dy \cdots$$

$$\Sigma F_z = \frac{\partial F_z}{\partial x} dx + \frac{\partial F_z}{\partial y} dy \cdots$$

$$\Sigma M_x = \frac{\partial Mx}{\partial x} dx + \frac{\partial M_x}{\partial y} dy \cdots$$

$$\Sigma M_y = \frac{\partial M_y}{\partial x} dx + \frac{\partial M_y}{\partial y} dy \cdots$$

$\Sigma M_z = 0$ turning axis of bearing

For a simplified analysis, the response to coplanar forces will be considered; in a symmetrical bearing, this will not detract from the analysis. Therefore, the general equations reduce to:

$$\Sigma F_x = \frac{\partial F_x}{dx} dx + \frac{\partial F_x}{\partial z} dz + \frac{\partial F_x}{\partial \theta_y} d\theta_y$$

$$\Sigma F_z = \frac{\partial F_z}{\partial x} dx + \frac{\partial F_z}{\partial z} dz + \frac{\partial F_z}{\partial \theta_y} d\theta y$$

$$\Sigma M_y = \frac{\partial M_y}{\partial x} dx + \frac{\partial M_y}{\partial z} dz + \frac{\partial M_y}{\partial \theta_y} d\theta_y$$

For a given set of operating conditions and a nominal film thickness of 0.002 inch, the partial derivatives are continuous and reasonably invariant.

$$\partial F_x = -2.4 \times 10^{-7}\, dx + 1.36 \times 10^{9}\, \partial\theta_y$$
$$\partial F_z = 1.50 \times 10^{8}\, dz$$
$$\partial M_y = 7.12 \times 10^{8}\, dx - 7.00 \times 10^{10}\, \partial\theta_y$$

A determinent solution provides these equations of motion of the bearing; units are in inches, pounds, and inch-lbs. torque:

$$dx = -9.87 \times 10^{-8}\, dF_x - 1.92 \times 10^{-9}\, dM_y$$
$$dz = 6.67 \times 10^{-9}\, dF_z$$
$$d\theta_y = -1.01 \times 10^{-9}\, dF_x - 3.38 \times 10^{11}\, dM_y$$

These equations describe the motion of the bearing under coplanar loading; obviously, loading in other planes can be resolved in a similar manner to provide a complete solution.

The bearing under consideration is a conical bearing which creates cross coupling of forces and the axes in which they cause motion. From the equations of motion, it is seen that motion in the x axis can be developed from a moment about the y axis. Such cross coupling complicates the dynamic solution of the bearing requiring four separate transfer functions to be developed to describe the motion of the bearing:

$$\frac{X_1}{F_x} = F(t) \qquad \frac{\theta}{M_\theta} = f(t) \qquad \frac{x}{M_\theta} = f(t) \qquad \frac{\theta}{F_x} = f(t)$$

F_x and M_θ are the coplanar forces and moments x and θ the linear and angular displacements. Assuming a pure inertial load or mass on the bearing, the general dynamic equations of the antenna pedestal and bearing are as follows:

$$F_x = M\frac{d^2x}{dt^2} + A_1x - B_1\theta$$

$$M_\theta = I\frac{d^2\theta}{dt^2} + B_2\theta - A_2x$$

Where: M = antenna pedestal mass, I = antenna pedestal inertia about bearing axis, and A_1, B_1, A_2, B_2, are influence coefficients of equations:

$$dF_x = A_1dx + B_1d\theta_y \text{ etc.}$$

Let:

$$\tau_x^2 = \frac{M}{A_1} \qquad K_1 = \frac{B_1}{A_1} \qquad \tau_\theta^2 = \frac{I}{B_2} \qquad K_2 = \frac{A_2}{B_2}$$

Using Laplace notation:

$$F_x\, A_1\, \tau_x^2\, S^2x + x - K_1\theta$$
$$M_\theta = B_2 = \tau_\theta^2\, S^2\theta + \theta - K_2x$$

For $x/F_x = f_e$, assume $M_\theta = 0$. Solving the two equations simultaneously and simplifying:

$$\frac{x}{F_x} = \frac{\tau_\theta^2 S^2 + 1}{A_1K_1K_2\left[1 - K_1K_2\right]\left[\frac{\tau_x^2\tau_\theta^2}{1 - K_1K_2} S^4 + \frac{\tau_x^2 + \tau_\theta^2}{1 - K_1K_2} S^2 + 1\right]}$$

Similarly, for $\theta/M_\theta = f_T$, $F_x = 0$:

$$\frac{\theta}{M_\theta} = \frac{\tau_x^2 S^2 + 1}{B_2\, K_1K_2\left[1 - K_1K_2\right]\left[\frac{\tau_x^2\tau_\theta S^4}{1 - K_1K_2} + \frac{\tau_x^2 + \tau_\theta^2}{1 - K_1K_2} S^2 + 1\right]}$$

For $x/M_\theta = f_t$, $F_x = 0$:

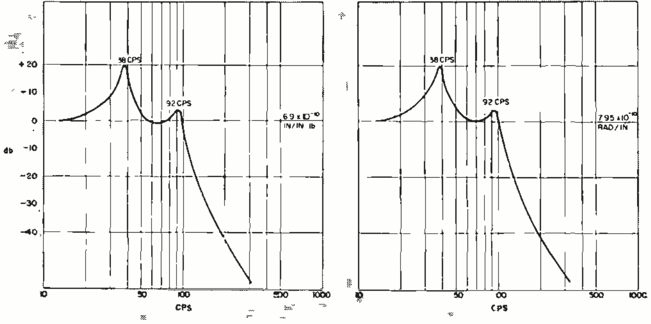
$$\frac{x}{M_\theta} = \frac{K_1}{B_2\, K_1K_2\left[\frac{\tau_x^2\tau_\theta^2}{1 - K_1K_2} S^4 + \frac{\tau_x^2 + \tau_\theta^2}{1 - K_1K_2} S^2 + 1\right]}$$

For $\theta/F_x = f_t$, $M_\theta = 0$:

$$\frac{\theta}{F_x} = \frac{K_2}{A_1\left[1 - K_1K_2\right]\left[\frac{\tau_x^2\tau_\theta^2}{1 - K_1K_2} S^4 + \frac{\tau_x^2 + \tau_\theta^2}{1 - K_1K_2} S^2 + 1\right]}$$

Figs. 5 and 6 show Bode plots of the response of the bearing to the primary and secondary modes of motion; these plots show the familiar two degrees of freedom of motion curves available in vibration texts.

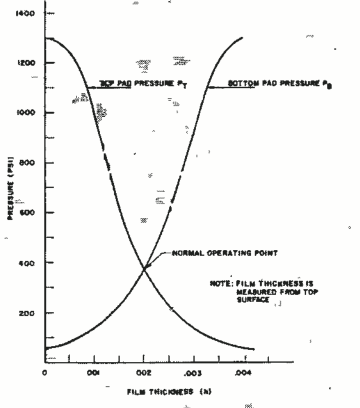
Fig. 6—Transfer functions for secondary modes.



$$\frac{X}{M_\theta} = 6.9 \times 10^{-10} \frac{1}{\left[\left(\frac{S}{38.3}\right)^2 + 1\right]\left[\left(\frac{S}{92.2}\right)^2 + 1\right]}$$

$$\frac{\theta}{F_x} = 7.95 \times 10^{-10} \frac{1}{\left[\left(\frac{S}{38.3}\right)^2 + 1\right]\left[\left(\frac{S}{92.2}\right)^2 + 1\right]}$$

Fig. 7—Pad pressure distribution curves.



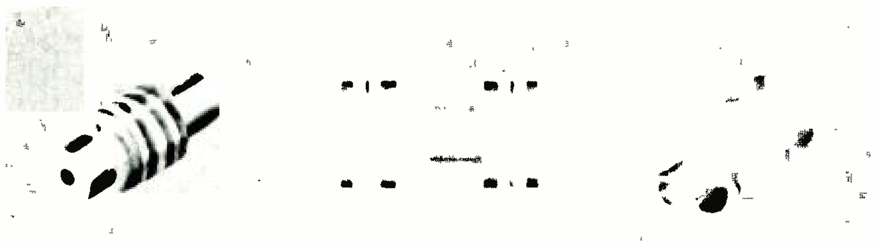

Bellows Flexible Disc Oldham

Fig. 1—Three typical couplings: the bellows, the flexible-disc, and the oldham.

LINEARITY ERRORS IN INSTRUMENT COUPLINGS

When it is necessary to connect two rotating shafts, flexible couplings are used to accommodate combinations of parallel and angular misalignment of the shaft centerlines without inducing excessive loads into bearings, housings, or the shafts themselves. In precision instrument applications, it is also desirable to have the motion of the driven shaft exactly duplicate that of the driving shaft. This is especially true in radar data-takeoff units where an instrument coupling must transmit the accurate angular motion of precision gearing to synchros, encoders, variable resistors, etc. The inability of an instrument coupling to provide perfect duplication of motion between its input and output ends, while essentially free of torsional loading, is defined as "coupling nonlinearity." This paper describes a unique test fixture and procedure for determining such nonlinearity.

R. D. SHERWOOD

Missile and Surface Radar Division, DEP, Moorestown, N. J.

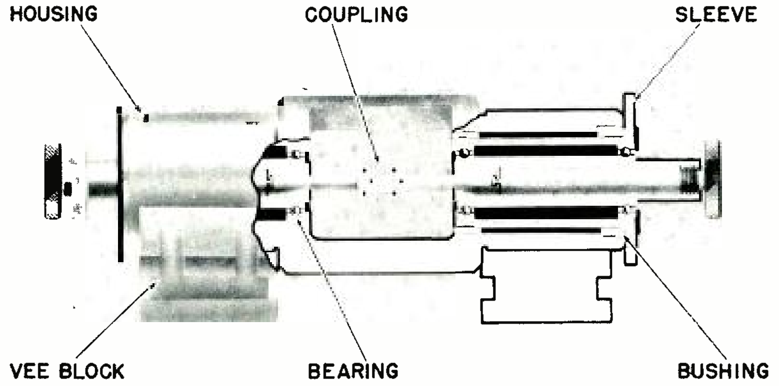
Fig. 1 shows the following three typical instrument couplings—*bellows*, *flexible-disc*, and *oldham:*

The *bellows coupling* consists of two hubs connected by a one-piece phosphor-bronze or beryllium-copper bellows. It accommodates shaft misalignment through flexure of its several convolutions.

Flexible-disc couplings are usually composed of three rigid members connected by beryllium-copper discs; discs are riveted alternately to the three solid parts of the coupling in a manner which duplicates the configuration of a double universal, or Hooke's joint. The flexing action of the discs permits operation between misaligned shafts.

The *oldham coupling* has two flanged hubs connected by a center sliding element. One face of the sliding element has a tongue projection which fits into a slot in the mating side of one flange; the other face has a slot which engages the tongue projection of the second flange, 90° from that of the first. In this manner, the center sliding element is provided with a set of *x-y* coordinates on which to slide, relative to the two flanges which engage misaligned shafts.

Fig. 2—The mechanical arrangement of coupling test fixture.



Although these three couplings are not the only types of instrument couplings in existence, they are the most widely used. Most other types of couplings include in their design one or more of the basic configurations just described. With respect to size, instrument couplings usually do not exceed 2 inches in length and $1\frac{3}{4}$ inches in diameter. The shafts connected by these couplings are usually $\frac{3}{8}$ inch or less in diameter.

NONLINEARITY TEST FIXTURE

To determine the amount of nonlinearity and other individual characteristics of instrument couplings, a rather unique test fixture has been designed (Fig. 2); the mechanical portion of the test fixture consists of a one-piece cylindrical housing having an opening at its center to accept the coupling to be tested. The two ends of the housing have accurately machined outside diameters which rest in a matched pair of vee-blocks. The housing is bored to accept two precision preloaded ball bearings in the left end; the other end contains a sleeve which can be rotated in two bronze bushings. The sleeve in turn also houses two precision preloaded ball bearings; the ball bearings carry two hollow shafts having female tapers at their near ends. Several solid shafts of various diameters and lengths accommodate the various size couplings to be tested; each solid shaft has a matched male taper which can be inserted into the hollow shaft and seated at the taper by a threaded retaining rod.

The inside diameters of the two bushings and the mating outside diameters of the sleeve are machined off-center so that the sleeve will rotate within a double eccentric. This feature provides variable, parallel misalignment of the coupling shafts from 0 to 0.015 inch. A means of locking the sleeve to the main housing permits couplings to be tested at any desired amount of offset within this range. Provision for setting angular misalignment of shafts is not possible in this type of design nor adaptable to the means of measurement involved.

HOW NONLINEARITY IS MEASURED

In the normal mode of operation, a coupling connects two shafts mounted on bearings within a housing; the shaft rotates with respect to the stationary housing. This same relative motion can be developed by rotating the housing about the coupling and shafts while one of the two shafts is restrained from turning. This is the principle upon which the test fixture operates in the measurement of coupling linearity errors. These errors are manifested as small variations in the angular relationship between the two shafts while the housing is rotated within the vee-blocks. To establish a zero or reference, a lever is clamped to the left-hand hollow shaft and allowed to rest on a vertical support; thus, free rotation of the shaft is prohibited while it remains free to accommodate radial movement due to machining tolerances throughout the assembly. Therefore, the left-hand shaft becomes the input or driving shaft while the other becomes the output or driven shaft.

Use of Auto-collimator

Measurement of the small angular variations developed between the input and output shafts is accomplished through the use of an auto-collimator which is accurate to 2″ of arc. Essentially, an auto-collimator is an optical telescope with an internal illuminator whereby a pair of target wires placed at the focal plane of the objective are projected as bundles of parallel light. When these bundles of parallel light are returned to the objective by reflection from an optically flat mirror, they are automatically refocused in the plane of origin at unity magnification. Under these conditions, both the projected and returned images can be examined simultaneously with a built-in filar micrometer microscope, usually calibrated in seconds of arc. Any small angular variation in the position of the reflector, with respect to the optical axis of the auto-collimator, is viewed as a lateral change in the position of the returned image—regardless of the distance between the objective and the reflector. Therefore, when the field of view of the auto-collimator is necessarily split to view the two reflectors simultaneously (reflectors are at unequal distances from the objective), their angular variations can be read directly by the auto-collimator using the filar micrometer.

This principle is applied to the test fixture by placing an optically flat mirror on each of the two hollow shafts shown in Fig. 3. By using a sharp-edged mirror to split the projected image and an adjustable mirror to reflect the split image to the output shaft mirror, the returned images from both the input and output mirrors are placed adjacent; thus the images can be viewed simultaneously by the auto-collimator. This permits the angular variations of the two shafts to be observed with respect to each other, regardless of where they may be located in space; further, the angular differences between shafts can be viewed at an infinite number of points during the rotation of the housing.

Several-Sided Polygons

In the past considerable effort has been expended in attempting to make these same measurements using several-sided optical polygons. A polygon was mounted on each of two shafts which engaged the coupling to be tested. One shaft would then be rotated in increments so that two auto-collimators could view each succeeding face of the two polygons; the one on the driving shaft being the input polygon and the other the output polygon. The number of measurements possible during one complete revolution was automatically limited to the number of faces on the two polygons—usually 16 or 17. The validity of this type of test was also nearly always compromised by unavoidable angular accelerations and decellerations created through manual indexing of the input shaft. Because these accelerations acted upon the relatively high inertia of the polygons, the instrument couplings were subjected to varying amounts of torque, thereby reducing the accuracy of the linearity test.

The mechanical and optical arrangements shown in Figs. 2 and 3 eliminate the drawbacks imposed through the use of optical polygons.

Nonlinearity Test of Flexible Coupling

Fig. 4 shows a test fixture set up to test the non-linearity of a flexible disc coupling. The entire assembly is set up on a granite table to eliminate even slight vibrations which would otherwise blur the returned images in the auto-collimator to the point where they could no longer be seen.

The test fixture can be operated in either one of two ways. By continually rotating the housing in one direction, the maximum positive difference and maximum negative difference between the input and output images can be picked off. After repeating the process in the opposite direction of rotation, the addition of the larger positive difference to the larger negative difference will determine the peak-to-peak nonlinearity of the coupling; this peak-to-peak value will of necessity include some amount of backlash, as will be seen later.

The housing can also be manually indexed a discreet number of degrees and stopped while the difference between input and output images is being recorded. By doing this throughout 360° rotation (one revolution) in one direction and then repeating the same procedure through one revolution in the opposite direction, an actual plot of "linearity error versus angle-of-rotation" can be developed: such curves show the nonlinearity characteristics, the peak-to-peak value, and the backlash.

Fig. 3—The optical arrangement of the coupling test fixture.

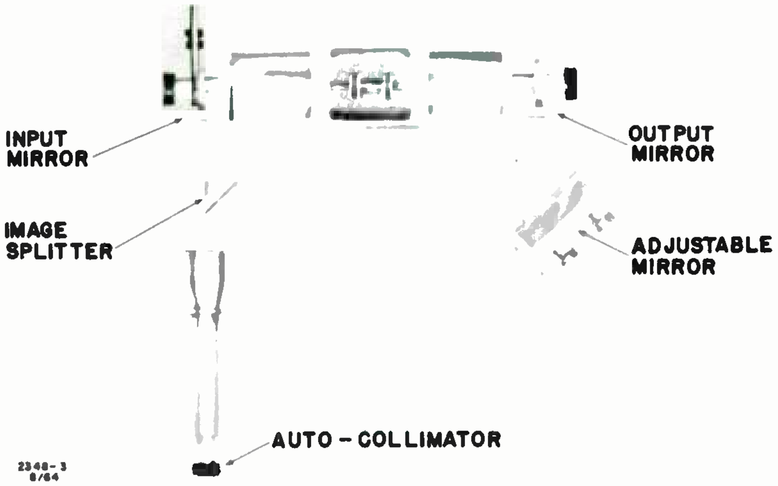
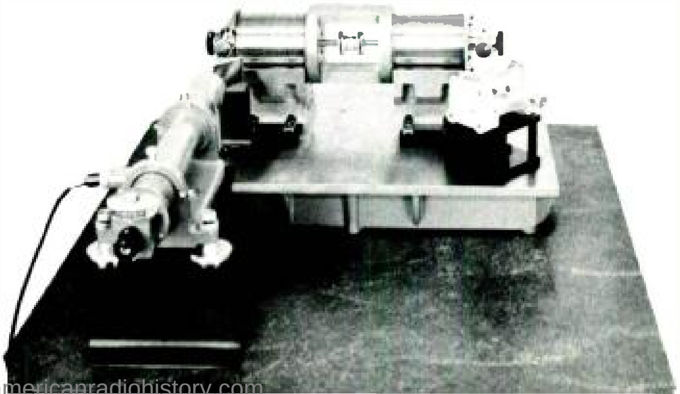


Fig. 4—The coupling test fixture for nonlinearity checking.



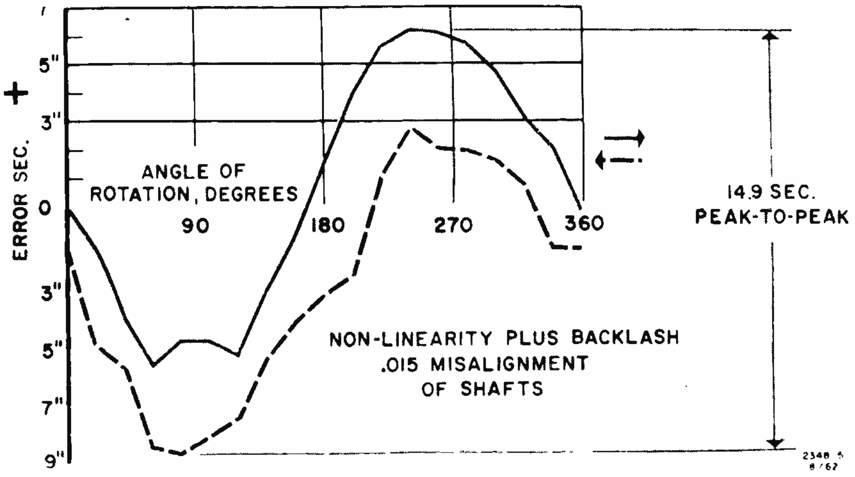


Fig. 5—Nonlinearity for a flexible disc coupling.

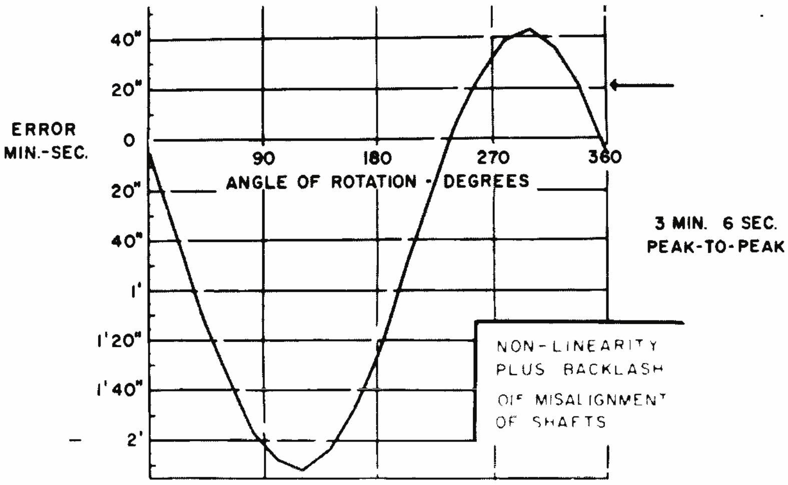


Fig. 6—Linearity-error curve for a bellows coupling.

A Typical Nonlinearity Curve

Fig. 5 is a non-linearity curve of a flexible-disc coupling plotted from data taken in the second method just described. At 0.015-inch parallel-shaft misalignment, the coupling developed nearly 15″ peak-to-peak nonlinearity. These curves are characteristic of flexible-disc couplings; they are basically sine waves with random spikes and discontinuities attributable to nonuniform flexing of the discs.

The solid curve of Fig. 5 represents the number of seconds of arc by which the output of the coupling led or lagged the input during rotation in one direction; the Fig. 5 dotted curve represents the same condition for the opposite direction of rotation; thus, the vertical difference between the two curves at any given angle of rotation must represent lost motion or backlash.

Because the coupling's construction precludes any free angular play within the coupling itself, it is concluded that backlash is *apparent* as opposed to *true* backlash. This can be explained as follows: during a full nonlinearity test for any given angle of rotation, the discs are flexed first in one direction and then in the other; if the discs are not perfectly elastic but retain some small amount of residual flexure, apparent backlash will be developed. Again, because of the nonuniform flexing action of the discs, apparent backlash varies from about 2″ to 6″ of arc for this coupling.

ACCURACY OF MEASUREMENTS

An indication of the accuracy of a test is available by checking the error value existing at 0° and 360° for one direction of rotation. Since these two angles are actually the same, the errors developed at these two points should be equal. In reality, they usually repeat within about 1″; also, at 0° and 360° both the curves should not share the same value of error, but should be separated by apparent backlash. This separation is obtained by rotating the fixture housing from 0° to 360° and beyond through some large angle, and then reversing the direction of rotation to return to 360° and continue back to 0°.

At 0.015-inch parallel misalignment of shafts, the bellows coupling develops a peak-to-peak nonlinearity plus backlash of over 3′ of arc (Fig. 6). Because of the relatively uniform flexure of its convolutions, this coupling manifests an extremely smooth and nearly perfect sine wave as its linearity error. The two curves are separated by a very nearly constant 10″ of apparent backlash, again attributable to mechanical hysteresis.

Although the ball bearings supporting the output shaft of the test fixture have a very low value of friction torque, they do develop some light drag on the output of the coupling. However, the torsional wind-up caused by bearing friction is only a small percentage of the total apparent or true backlash of any coupling. In any event, this condition of loading (under which a coupling is tested) does not differ from the conditions under which it is operated in actual service.

An Extremely Linear Coupling

Although it is difficult to show on the plot of Fig. 7, the extent of nonlinearity for the oldham coupling is only 2″ or 3″ of arc. Because the coupling from which this data was taken was not preloaded, it developed 9′ of true backlash. Preloading can be included in the design of an oldham coupling but backlash will not be reduced to zero. Depending upon spring strength, usually about 5″ of apparent backlash will remain due to mechanical hysteresis of the spring loading mechanism. True backlash can also be reduced by insuring smaller clearances between a mating tongue and slot.

CHARACTERISTICS OF VARIOUS COUPLINGS

The relationship between peak-to-peak nonlinearity plus backlash versus the

RICHARD D. SHERWOOD received his BSME from the University of Rochester in 1956 and has done graduate work at Villanova University. He joined RCA in 1956 and left shortly after for two years of active duty as an officer, U.S. Navy. In 1958, he returned to RCA, completed the specialized training program, and accepted a permanent position in the Radar Antenna Pedestal Design and Development group. Since then, he has been responsible for the design of the MPS-25 pedestal lifting device, the drive and data gearing units of the FPS-16 Mod I radar pedestals, the data gear boxes of the MIPIR pedestals, and instrument servo gear boxes for the TRADEX Program. He assisted in the initial design of the BMEWS Data Corrector gear boxes and has worked on project LOLA (Lunar Orbital & Landing Approach Simulator). Mr. Sherwood has been active in the American Gear Manufacturer's Association, including membership on the AGMA Master Gear Committee.

parallel-shaft misalignment for the three types of couplings in question is shown in Fig. 8. For the *flexible-disc* and *bellows* couplings, the amount of peak-to-peak error is directly proportional to the amount of shaft misalignment shown by the two sloping lines of Fig. 8.

The Flexible-Disc Coupling

At zero offset between shafts, the flexible-disc coupling retains about 3.5″ of peak-to-peak error composed of a few sporadic spikes, some apparent backlash, and only a trace of the basic sine wave. This remaining error is caused by the inability to align the two shafts of the test fixture absolutely.

The Bellows Coupling

At zero shaft misalignment, the bellows coupling also retains about 10″ of error, again caused by imperfect shaft alignment. Even if the shafts could be brought into perfect alignment, a small amount of torsional windup would remain, because of the bearing friction in the output end of the test fixture.

Taking these remaining errors into account, the flexible-disc coupling develops about 0.8″ of arc peak-to-peak nonlinearity plus backlash per one-thousandth-inch parallel misalignment of shafts. The bellows coupling has a rate of about 11⅓″ of error per 0.001-inch offset.

The Oldham Coupling

The oldham coupling on the other hand maintains an essentially constant 9′ of error for all values of shaft offset. The 2″ or 3″ of nonlinearity existing at 0.015-inch misalignment disappears at zero offset leaving the true backlash as its total error. Backlash will remain constant and the coupling will remain linear regardless of the amount of misalignment between shafts if the sides of both the tongues and slots are perfectly straight and exactly parallel. As mentioned before, preloading can reduce backlash to nearly zero throughout the range of misalignment.

PRECAUTIONS TO MINIMIZE NONLINEARITY

Several things can be done to minimize linearity errors in instrument couplings which rely upon flexure. Accurate control of the thickness and structural homogeniety of flexing-element materials will permit the most uniform flexure and reduce nonlinearity. Accurate machining and the greatest care in assembly will further improve operation. For example, in a flexible-disc coupling, if the rivets connecting the discs to the central spool and hubs of the coupling distort the discs and cause them to assume a non-flat surface, the discs will be nonuniformly pre-stressed and will deflect at irregular rates; thereby increasing the size and number of the "random spikes" characteristic in the nonlinearity curve of this coupling. The same principle holds true in the attachment of hubs to the convolutions in the bellows coupling.

Increasing the axial distance between the discs of a flexible-disc coupling will decrease the angle of flexure required for a given amount of parallel offset between shafts, resulting in improved linearity. Clearance between shaft and bore becomes effective misalignment whenever the shaft is forced to one side of the bore by set screws or some similar means of attachment. Essentially, anything that reduces the effective misalignment of a bellows or flexible-disc coupling during operation, will improve linearity.

Although a preloaded oldham coupling would seem to be the instrument coupling to use because of its extremely linear character, it too has disadvantages. Because it relies on sliding action to accommodate misalignment, wear can become a problem over a long period of time. If lubrication is used to minimize wear, there is the need to replenish it. Any foreign matter entering in between two sliding surfaces immediately produces angular error; also, a well-designed preloaded oldham coupling is very expensive.

CONCLUSION

Varying the thickness and number of discs in a flexible-disc coupling, changing the thickness of material and number of convolutions in the bellows coupling and improving basic design configurations of all couplings, and the testing of couplings under conditions of angular misalignment are all areas that need further investigation to determine their effects on linearity.

The couplings tested to obtain the data presented in this paper were stock off-the-shelf items and were not modified in any way to change their values of nonlinearity. Since this has not been a statistical study of linearity errors, the magnitudes of errors discussed should be considered as relative and not absolute; however, the individual trends and characteristics exhibited do hold true for each type of coupling described.

Fig. 7—Linearity-error curve for the oldham coupling.

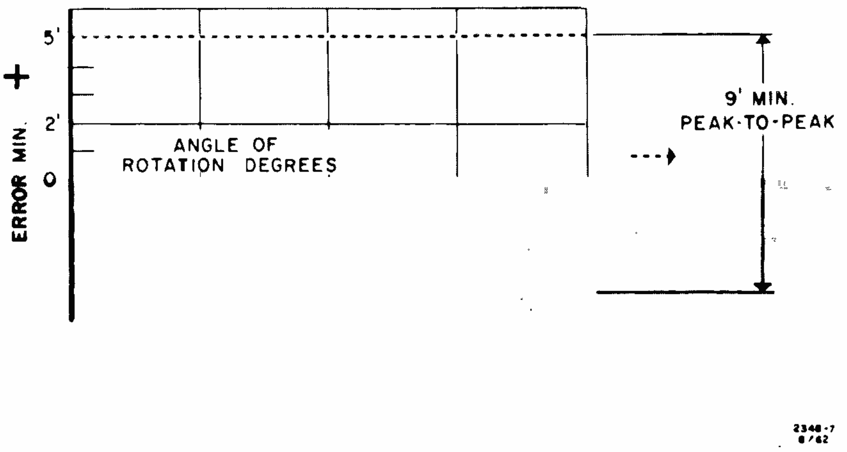
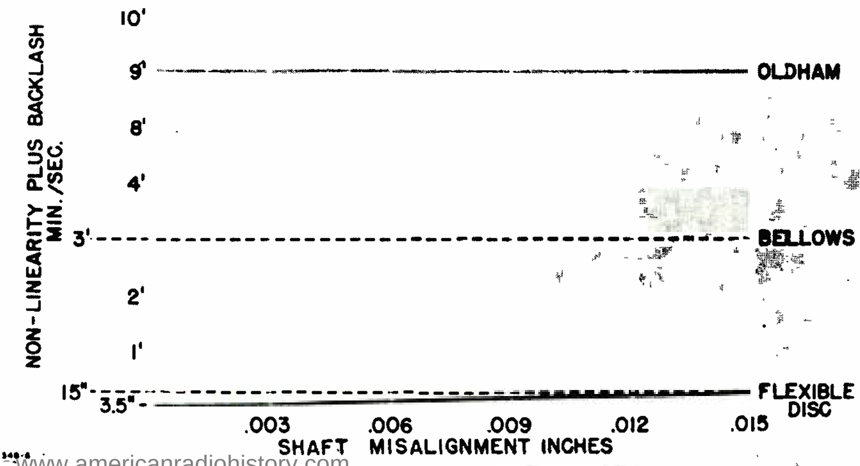


Fig. 8—Peak-to-peak linearity-error vs. misalignment for the three types of couplings.



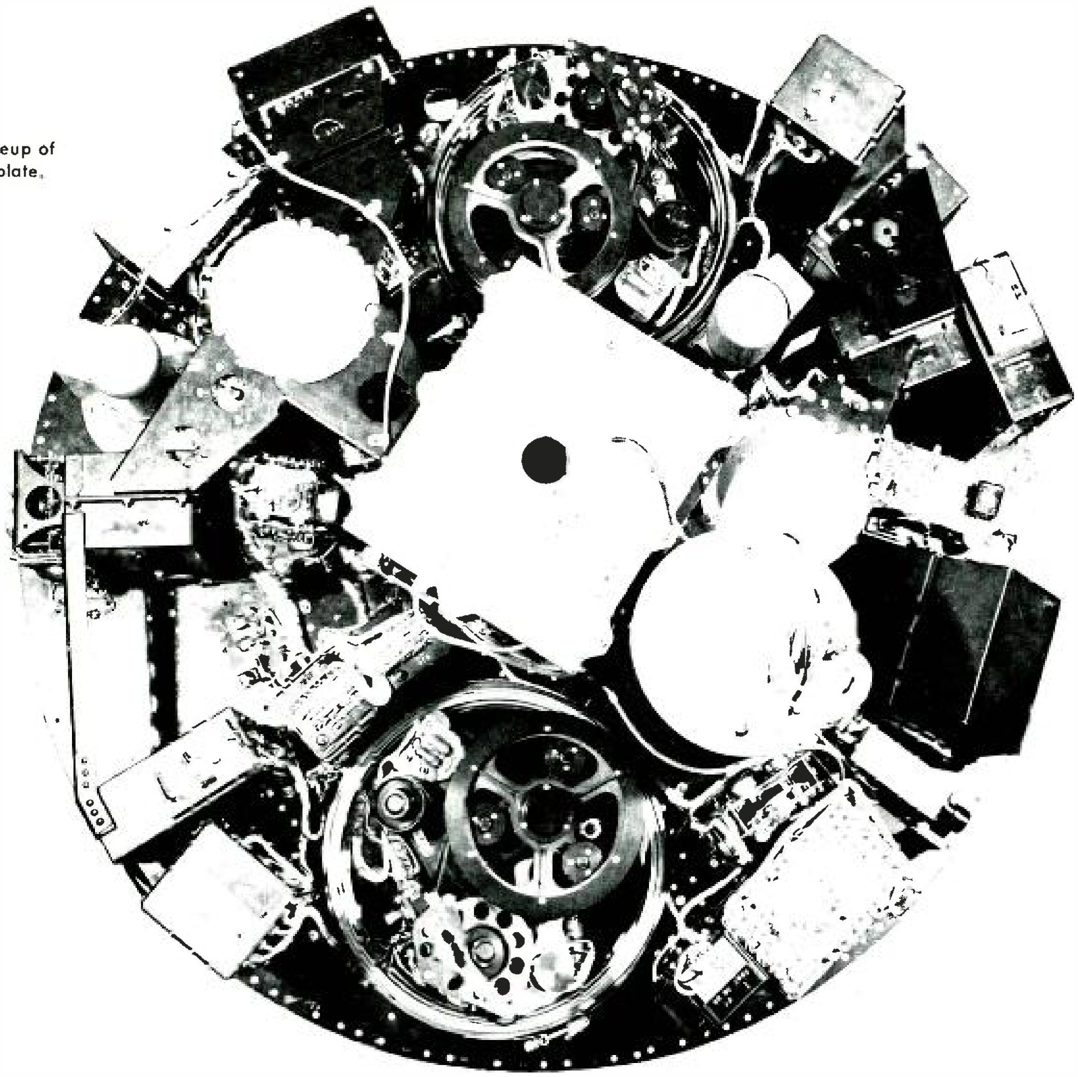


Fig. 1—Closeup of TIROS baseplate.

EFFECT OF SYSTEM CONSTRAINTS ON MECHANICAL DESIGN OF SPACECRAFT

Fig. 2—The RANGER IV subsystem.

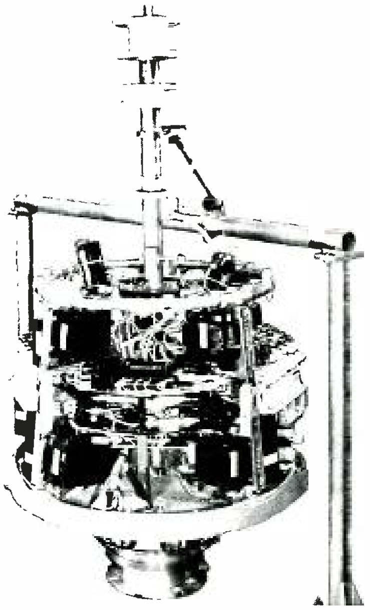


Fig. 3—The RELAY communications satellite.

Basic theories and design concepts of advanced spacecraft do not differ drastically from that of standard aircraft. However, the stringent environmental, launch, packaging, and subsystem mission parameters of present satellite design require a larger scope of knowledge and a more refined application of these basic engineering principles. Spacecraft design requires the efficient integration of the numerous components necessary to perform the specified mission requirements. One important aspect of over-all satellite design is the structure; just how this structure is designed, and effects of the system constraints upon design are considered herein.

L. BERKO, Ldr. **and** **W. CABLE, Ldr.**
Mechanical Analysis *Mechanical Design*

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

PRIMARY objectives in satellite design are to provide a spacecraft of minimum weight and cost, with sufficient structural integrity and reliability to perform the intended mission. Such objectives are achieved by considering three basic groups of interrelated factors: 1) those relating to the specific mission, 2) those set by the launch vehicle, and 3) those set by environments in which the spacecraft must operate.

Additionally, structural design is further influenced by a number of more intangible requirements. Whether state-of-the-art or advanced philosophies are utilized is dependent upon the total time allowed for the design, development, and test phases of the system program. The time schedule also influences the degree and practicality of altering the basic structure to accommodate new developments in component equipment. It is also quite evident that a more highly optimized design offers less system flexibility in weight and volume changes.

Therefore, a longer time for redesign and development must be allowed for more complex design adjustments. Past experience indicates that system flexibility might well be categorized as a function of the structure-to-payload weight ratio. For example, a much higher degree of design flexibility can be realized for a satellite in the 0.15-to-0.20-ratio range, such as TIROS, than in range around 0.10 ratio of the RELAY spacecraft. It is quite realistic to assume that structures with a 0.06-to-0.10-ratio range are practical, but can be attained only through extremely efficient integration of the subsystem components. including thermal-mass and thermal-gradient requirements and the system hardware.

MISSION REQUIREMENTS

The most important mission requirements now being imposed on spacecraft are scientific instrumentation, communications distance, solar distance, operational life, mission type, geometric requirements of the earth-sun probe target, and sterilization.

The weight and power requirements of the scientific instrumentation. as well as the amount of data it must obtain, are very significant factors in determining the size and physical shape of a satellite. The communication distance, solar distance, and operational life determine the size and complexity of the communications and power subsystems.

The mission type determines the need for and the complexity of the guidance and propulsion subsystems for mid-course and approach maneuvers and the like. For example, trajectory-correction subsystems are not required for space-probe missions, but are required for planetary fly-by and orbiter missions. Furthermore, the lighter and simpler communications subsystems required for space probes result in lighter associated subsystems. The planetary orbiter has the most difficult mission, and it requires a retro-propulsion unit that may comprise 75% of the total spacecraft weight. The communications and guidance subsystems are also appreciably heavier for the orbiter-type spacecraft.

Geometric requirements and sterilization are of lesser importance than the foregoing mission requirements. but nevertheless are definite design constraints. The geometric relationships determine the placement, types of motion. and number of degrees of freedom of the spacecraft antenna, and possibly the placement of the platform supporting the probe instruments. Sterilization requirements must be considered for spacecraft that are to land on the moon or the planets. Sterilization of components at 275°F is sometimes difficult to meet. Ethylene-oxide gas is used for surface sterilization following the heat process. Sterilization also requires difficult procedures during the launch phase.

LAUNCH VEHICLE CONSTRAINTS

The launch-vehicle constraints also dictate spacecraft weight, volume, and physical shape, in addition to the thermal and vibrational environments and the payload-to-launch-vehicle interface.

In general, the weight of the spacecraft is determined by the vehicle capability, the definition of the mission, and other miscellaneous factors, including the availability of tracking facilities. Spacecraft volume and physical shape are determined primarily by launch-vehicle shroud considerations, subsystem volume and operational requirements, thermal performance, location of the center of gravity. inertia values, and stabilization requirements.

In an experimental satellite, specific requirements are frequently imposed that may establish the relative location of subsystem equipments. For example, these requirements may include a certain location of cameras to present a clear line of vision, a noninterference pattern for antennas, precise location of sensors with respect to the spin or other reference axis, and so forth. The spacecraft configuration must accommodate such requirements, and in highly integrated assemblies, they often become a dominant structural factor.

The structural and integration designs are dictated to a large extent by the thermal analysis; for example, packaging of equipment must be such that the subsystem operates within its most desirable temperature limits. Also, equipment that dissipates large amounts of heat might have to be located judiciously to serve as a heat source for other equipment. Local masses, finishes, and materials are critical to the heat control of satellites. The effect of these must be considered in the thermal design, in addition to the effects of mechanical (active) heat-controlling devices. The structure design must also take into consideration conductive and radiative paths considered necessary to the thermal performance. It is evident that for optimized designs in the 0.1-weight-ratio range, the thermal requirements must be critically analyzed to avoid canceling the weight advantages gained in the basic structural design. which again demonstrates the importance of efficiently integrating all elements of the payload during the design or pre-hardware phase.

The physical shape of the spacecraft and the location of the subsystem components must be analyzed for problems relative to moments of inertia, stabilization. center of gravity and so on. It should be noted that a concept that satisfies such requirements may not necessarily meet all other mission or stress specifications, and trade-offs must be made to obtain an optimum solution. For example, heavy equipment is preferably located where it would minimize vibratory loading and possibly add rigidity to the assembly, but this placement may not be acceptable for reasons

L. BERKO received a BSAE degree (cum laude) from the University of Notre Dame in 1942, and an MSME degree from Newark College of Engineering in 1952. Mr. Berko worked for the Curtiss-Wright Aeroplane Division from 1942 to 1945, as a stress analyst. From 1945 to 1956, Mr. Berko was assigned to the Wright Aeronautical Division of Curtiss-Wright Corporation. For five of those years, he was involved in both theoretical and experimental aircraft engine stress and vibration analyses. Also, he supervised a group of analytical engineers. From 1956 to 1961, he was a design supervisor with Walker Kidde and Co., working on high-pressure air compressors, high-speed auxiliary power units, filament-wound pressure vessels, etc. Mr. Berko joined the Astro-Electronics Division of RCA in 1961. He has participated in the structural design of the RANGER TV Subsystem. At the present, Mr. Berko is responsible for the structural analyses of spacecraft, as Leader of the Mechanical Analysis group. Mr. Berko is a member of the Institute of the Aerospace Sciences.

W. CABLE received his BSME degree from the Stevens Institute of Technology in 1949. From 1951 to 1959, Mr. Cable was employed by the Eclipse-Pioneer Division of the Bendix Aviation Corp. This activity involved supervision of a group of graduate engineers and technicians; he was responsible for the design, qualification test and production of heat exchangers, over-speed controls, valves, ejectors and variable area nozzle controls. In 1959, he was employed as a staff engineer at the Headquarters Research Center of the American Brake Shoe Corporation and later appointed Chief Engineer of the Kellogg Division. Mr. Cable joined RCA's Astro-Electronics Division in 1961, as Leader of Mechanical Design. He has been responsible for the structures and mechanical subsystems on the RELAY, RANGER, SERT and other classified projects. He has also been responsible for the concept, configuration and program planning of mechanical design elements for several major satellite-system proposals.

of inertia or balance. Deployment mechanisms must be analyzed for their attendant changes in inertia and their effects on satellite stabilization in orbit. Naturally, the placement of the various elements cannot be regarded purely from an ideal mechanical viewpoint. The electrical and total-mission requirements also markedly affect these placements in order to control such phenomena as electrical crosstalk, feedback, and general interference, as well as problems of radioactivity. More specifically, the location of TV cameras, ion engines, antennas, solar cells, and other devices might compromise the inertial characteristics in order to favor the operational requirements of such equipment. Inertia and stabilization requirements may also dictate the shape of the payload: for example, if spin stability is required, the moment of inertia about the spin axis must exceed that about any other axis. This then might require a pancake-shaped spacecraft.

ENVIRONMENTAL CONSTRAINTS

The environmental constraints to be considered in the mechanical design of a satellite are those imposed by the spacecraft itself and those imposed by outer space. In the former category are the constraints associated with the launch, radiation from on-board nuclear reactors, and possibly ground operations. The most important space environment to contend with is the vacuum, in which sublimation or decomposition of certain materials may occur. The dynamic loads that will be imposed by the launch vehicle must be considered in the design of the spacecraft. Buffeting, due to the rough burning and "noise" of the launch-vehicle engine during launch, is generally the most severe vibration environment: loads of 15 g longitudinal and 7 g lateral are common, and shocks of 30 g can last for several milliseconds.

Environmental problems that will be experienced during satellite ground-handling operations must also be taken into account. Loads during the erection and assembly cycle depend to a great extent on the preciseness of human control and may possibly reach 3 g vertically and 2 g horizontally. Severe shocks may be expected during transportation of the spacecraft; accelerations of 4 and 5 g over a wide frequency range may be encountered during truck transportation. (These are the most severe that need be considered in the conventional methods of transportation.)

As for constraints imposed by the space environment on design, pressure and radiation are the determining factors in the selection of materials to be utilized, while the solar constant determines the type of thermal control required to keep equipment temperatures within their proper operating ranges.

The physical properties of most engineering materials will not be affected if they are generally stable in the vacuum environment at normal operating temperatures. Aluminum alloys are the most common structural materials because of their compatibility with the space environment and because of their strength, availability, weldability, and formability. Forged- and cast-magnesium alloys are also used to advantage. The amount of sublimation of these at normal temperatures in a space environment is too small to be structurally significant. Common plating materials such as cadmium and zinc, as well as selenium, will sublime at temperatures likely to be encountered in a spacecraft environment, and the more volatile element in an alloy may be lost from the alloy if the temperature is high enough. No problems are encountered with brass containing 30 to 40% zinc, even up to several hundred degrees temperature, although for aluminum-base alloys, the critical temperature would be around 250°F. Many organic materials degrade in space by breaking down into smaller, more volatile fragments. When these chemical changes result in a weight loss, significant changes may occur in mechanical, electrical and optical properties.

The friction characteristics of unlubricated metals in sliding contact present a problem. Like metals generally seize, and friction will increase even with the use of dissimilar metals in sliding contact. Since many oils and greases do not lubricate satisfactorily due to their breakdown in a vacuum environment, a preferred approach for space application is to use a vacuum-tight seal around the moving parts to minimize exposure of the contact area and to maintain positive pressure through the use of relatively high-vapor-pressure oils or greases on the order of 10^{-2}mm-Hg. Magnetic drives are feasible for high-speed, low-load combinations; these will eliminate some of the friction problems of sliding surfaces. Solid lubricants generally have a low vapor pressure, and they may suffer less from evaporation than low-vapor-pressure oils and greases. However, the evaporated material is not replaced, as in the case of fluid lubricants where reservoirs can be utilized. Graphite is useless in a vacuum. Molybdenum disulphide, silver, and various other platings are effective in selected applications. Due to critical performance specifications, the selection of materials is occasionally restricted to the non-magnetic variety to avoid possible interference with electronic components or instruments. This could be a severe constraint, as it rules out the use of the very common 300-series, cold-worked stainless steels. Of all the stainless steels, the 300 series would otherwise be used most commonly for nut-and-bolt applications. Generally speaking, an A-286 material is substituted for the 300 series in such applications because of its nonmagnetic quality.

STRUCTURAL CONCEPTS

Another phase of mechanical-design philosophy that is of major importance is the selection of the type of fabrication to be used for the structure. There are several distinct types of structural-fabrication techniques that have been used successfully in satellites These include skeletal framing of tubes; extrusions with channels, angle, or *I* sections; stressed skins, or monocoque; combinations (semi-monocoque); and cast, forged, or machined bases. Each technique may be particularly advantageous for one area of application: for example, to optimize structural efficiency for weight or size or both, or to provide the necessary dynamic environments for subsystem components, or to favor integration requirements. It should be noted that although aluminum has been used in the majority of our existing satellite structures, magnesium is being used increasingly in current designs, generally in the form of machined or cast elements. Since magnesium presents distinct weight, machinability, and dynamic-damping advantages, in spacecraft design its use produces very efficient structures of low structure-to-payload weight ratio.

Present design experience involving total payload weights of 150 to 400 pounds has produced a number of structures of combined construction, such as the Tiros and Ranger payloads depicted in Figs. 1 and 2. The skeletal concept was used in the design of the Relay communications satellite shown in Fig. 3, to provide a *cruciform*, or framed, structure. This structure incorporates the inherent strengths of a number of the subsystem components into the stability of the overall structure. The Relay structure also provides for soft mounting of the honeycomb solar panels to allow attenuation under critical dynamic-load conditions. The structure of a space "capsule," Sert, utilizes the machined-baseplate configuration, fabricated from a magnesium forging. The machined-baseplate approach has also been advanced in proposed designs for lunar orbiter satellites. The machined baseplate is distinguished from previous RCA designs in that riveted skeletal frames are combined with the machined elements.

An integrated structure, when not restricted by equipment assembly requirements, can be used very effectively to reduce critical payload weight. The black boxes are treated as structural elements and provide for accessibility, interchangeability, redundancy, and the like. If mission requirements should change, the affected black boxes could be replaced by structurally equivalent boxes, probably of less weight. Other selective means for satellite-weight reduction include using the launch vehicle to perform a required function; for example, a despin system may not be required on the satellite if the launch vehicle's final spin rate can fulfill satellite's requirement.

STRUCTURAL DESIGN CRITERIA

Once the physical configuration of the total payload has been established under the above considerations, the stress levels of the structure under launch conditions must then be analyzed. A further analysis is made to determine the amount of rigidity necessary to performance of the system components aloft. Currently, the load levels in most satellites tend to be less critical for higher total weights; this is true of both steady-state or thrust loads and vibration loads. Therefore, the design and analysis of smaller payloads and structures of low weight ratios are considered to be more critical in many aspects than those of a larger and heavier structure. In other words, a finite degree of redundancy or conservatism is more penalizing to a smaller and lighter structure. This can be extremely important in discontinuities and concentration of stress.

At the present time, steady-state load levels are about 10 g with vibration inputs simultaneously applied in combinations, such as 7 g-RMS, sinusoidal plus "white-noise" at densities of approximately 0.05 g^2 per cps, over the range of 20 to 2,000 cps. Structural rigidity and alignment problems must also be considered to avoid yielding of the basic structure during the launch period. Therefore, a thorough analysis of the combined rocket and spacecraft loads in conjunction with a complete investigation of the natural frequencies of the structure and components are required for proper estimates of transmissibility. The relationship of natural frequencies to vibratory loads must be carefully evaluated to avoid critical coupling of these frequencies; each structural member must be analyzed to determine the peak load for each condition set, to verify that the stress will not be above yield or above some selected limit.

In addition to the above stress considerations, the structure must be analyzed to ensure that failure due to shock and cumulative fatigue will not occur. The peak stress for each structural member under the load condition set must then be evaluated as a function of the number of cycles accumulated in the life expectancy of the payload, to assure that the combination of stress level and total cycles does not cause premature failure due to fatigue.

Present design philosophy considers that the life expectancy in total cycles of the satellite in space is set at two to three times its life expectancy under the environmental conditions established for qualification testing.

Thermal stresses are also analyzed where they are deemed critical to the satellite's orbital mission; however, these are generally minor compared to the over-all load conditions of launch. Thermal deflections can be considered more critical to a particular subsystem or component, such as in a telescope where these deflections are a function of its specific design rather than of the structural design.

MANUFACTURING, ASSEMBLY, AND TEST

In order to produce structures of high reliability and consistant performance, the manufacturing inspections and assembly operations must be conducted with an appropriate degree of precision and control. Obviously, structures that have been optimized with respect to volume, weight, safety factors, and fatigue must incorporate a high degree of process control.

The test and development phases of the structure and payload must also receive critical consideration during the over-all design. Once again, alterations in development are more critical in the low-weight-ratio structures, with the nature of such alterations being a direct function of permissible schedule time and design latitude. Such alterations should be treated with the same regard as are those in the basic design, to avoid the introduction of latent problems relative to weight, stress, stabilization, or dynamic loads.

CONCLUSION

In this paper, the authors have attempted to establish the relative importance of most of the factors of normal structural creative design. The importance of each factor in its own right, however, should not be minimized. As the state of the art advances in the satellite field, there will undoubtedly be demands for a higher degree of optimization and greater creativeness in generating more refined structural designs. The number of experiments or functions required of a particular satellite is constantly increasing, with particular emphasis on the efficient integration of these components relative to volume and weight. The trend towards more integral packaging on a module basis is also increasing, and it is ideally possible that the structure itself may replace the numerous covers, plates, brackets, etc., which are common to present-day methods of component and subsystem integration. It is reasonable to assume that many changes such as this will be introduced into design philosophy, in order that design keep pace with the increasing demands of space technology.

ANALYTICAL APPROACHES TO THE STRUCTURAL DESIGN OF SPACECRAFT

In the mechanical design of spacecraft, theoretical analysis is used to: 1) verify the ability to achieve the design objectives (usually in relation to the launch and space environments), and 2) optimize the verified design in relation to weight, volume, and strength. Specific analyses include methods for determining the layout of equipment on a spin-stabilized satellite, and a method for performing the stress analysis of a typical built-up sheet-metal structure, such as the baseplate of a TIROS satellite.

R. GOLDBERG

Mechanical Analysis Group, Astro-Electronics Division, DEP, Princeton, N.J.

A PRIMARY purpose of mechanical analysis of a satellite structure is to ensure that the satellite can satisfactorily withstand exposure to environmental conditions which it is expected to encounter; some possible environmental conditions are:

1) A constant thrust acceleration at a level of 30 g.
2) Sinusoidal vibrations at levels of 10-g peak at frequencies ranging from 20 to 2000 cps at a rate of 0.5 octave per minute.
3) Random noise in the frequency band from 20 to 2,000 cps at a spectral density of 0.1 g^2/cps.
4) A shock load at a level of 40 g for a period of 13 msec.
5) A pressure of 14.7 psi such as for a pressurized container, and
6) Extreme high temperatures such as from a radio-active isotope heat generator.

PRELIMINARY ANALYSIS

A structural design should be analysed in the preliminary stages to insure feasibility of the design. Preliminary concepts from the design group should be reviewed to be sure there are no obvious reasons why the structure would not withstand exposure to any of the environmental conditions specified. At this time, a preliminary layout may be made to ascertain whether or not the satellite components can be located within the geometrical confines of the satellite and, if the satellite is to be spin stabilized, whether or not a balanced weight distribution can be achieved. The design should be flexible so that changes in weight, size, and location of the components of the satellite can be made. A mechanical analysis of a new design should be made early enough so that required changes in the design may be suggested before the changes would require costly and time consuming design effort.

Since there is usually more than one proposed design configuration, a preliminary analytical check of the various design possibilities will usually reveal the merits of each. For example, a weight comparison was made between supporting solar cells by a honeycomb structure or by a built-up sheet-metal structure. An analysis indicated that the use of the honeycomb structure would save 10 pounds for a total weight of 60 pounds.

Once the general configuration has been chosen, a detailed stress analysis is performed to optimize the design with regard to weight. Minimum sizes for structural members are calculated as well as their margins of safety under the specified load conditions.

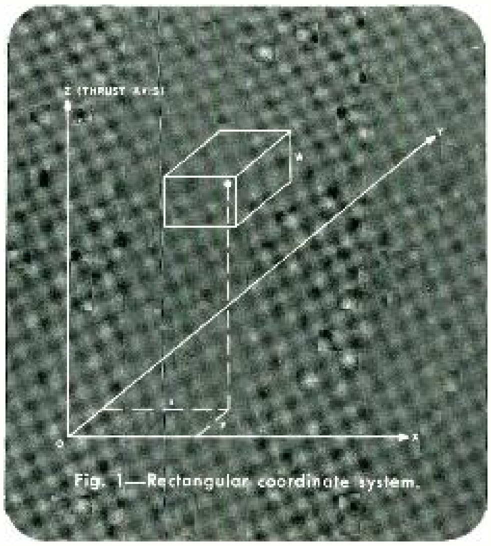


Fig. 1—Rectangular coordinate system.

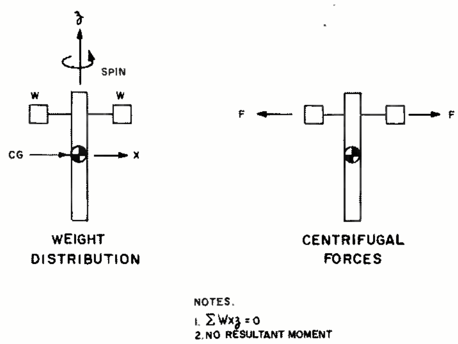


Fig. 2—Dynamic-balance conditions.

Since it is impossible to accurately determine the vibration responses of some of the more complicated structures, a mechanical test model is usually subjected to vibration surveys at an early stage in the design. This survey is performed to confirm the initial assumptions made. Modification in the design can be accomplished, if required, and the analysis is then updated. The results of these studies, in turn, provide a basis for analysis of future designs. The TIROS baseplate was used successfully with a minimum of structural modification for seven different component configurations based on the application of the above techniques.

COMPONENT LOCATION

After a configuration for the satellite has been selected, the problem of locating specific components and stress analyzing the structure next comes into consideration. To help locate components on the structure a simple mockup may be made from a scale drawing of the mounting surface of the structure and from cardboard or paper cutouts of the component outlines cut to scale. The name, weight, and center of gravity of each item is noted on the cutout. Various arrangements of the components can then be made and checked easily. The mockup is also useful when the shapes of components are changed and when equipment is added or removed.

The mounting surfaces of some satellite structures are not simple, and interference of components may be hard to visualize with only a two-dimensional model. Under these circumstances a three-dimensional mockup of the components and structure should be made. This three-dimensional mockup is used also to help determine the location of the components to insure proper weight distribution. Satisfactory placement of the components within the complicated structure of the RELAY satellite would have been extremely difficult without the three-dimensional mockup.

STATIC BALANCE

In order that no forces act to disturb the flight path of the satellite/launch-vehicle combination, the center of gravity of the satellite should coincide with the geometric thrust axis within very close tolerances. This static-balance condition can be defined by:

$$\Sigma Wx = 0 \text{ AND } \Sigma Wy = 0 \qquad (1)$$

Where W is the weight of each component of the satellite and x and y are the respective components of the position of each satellite component in the rectangular coordinate system shown in Fig. 1. The z axis of this system is the thrust axis of the satellite. and the origin of the system is at any convenient point.

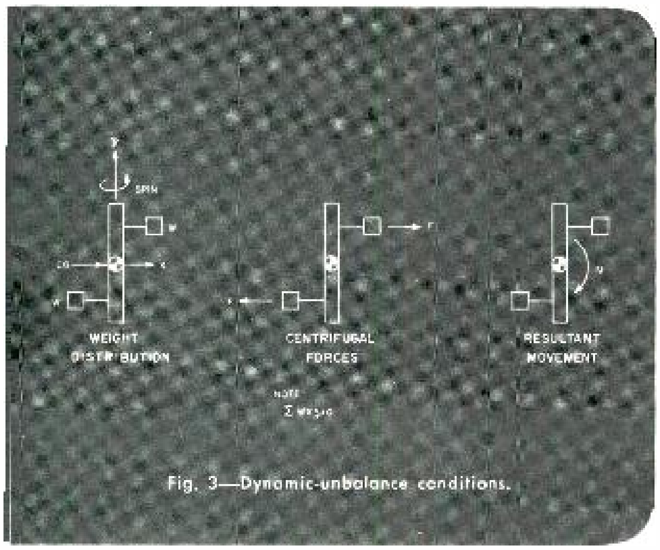


Fig. 3—Dynamic-unbalance conditions.

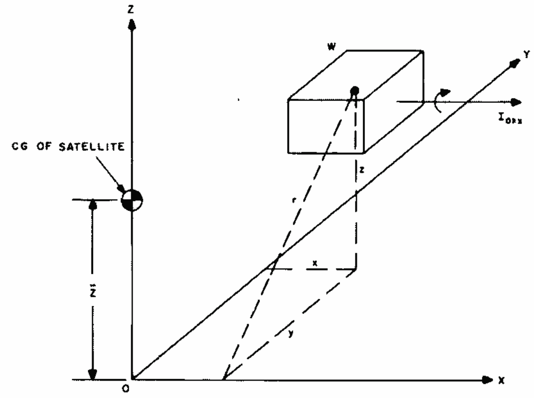


Fig. 4—Parameters for the determination of I_p.

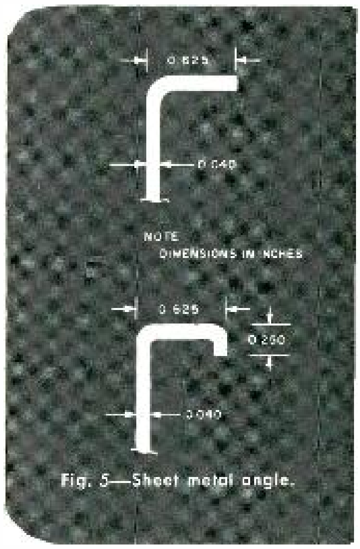


Fig. 5—Sheet metal angle.

DYNAMIC BALANCE

In order to achieve proper attitudes in orbit, many satellites are rotated about the thrust axis (with the last propulsion stage). Therefore, in order to prevent wobble, the satellite must be dynamically balanced about the thrust axis (in addition to static balance). This dynamic-balance condition is defined by:

$$\Sigma Wxz = 0 \text{ AND } \Sigma Wyz = 0 \qquad (2)$$

Where z is measured from each unit to the center of gravity of the satellite. Illustrations of dynamic balance and unbalance conditions with the resultant forces and moment are presented in Figs. 2 and 3, respectively.

The specified requirements for static and dynamic balance are of such a low order of magniture (the 270-pound TIROS had to be balanced to within 4 ounce-inches) that the final balancing of the satellite is done experimentally on a balancing machine. Small weights are added until balance is obtained.

ATTITUDE STABILITY

A spinning satellite tends to rotate about an axis in the direction of the maximum mass moment of inertia. Therefore, if the orientation of a satellite is to be maintained (to keep the cameras pointed in the right direction as for the TIROS satellite or to maintain a directional antenna pointed in the proper direction as for the Relay satellite) the mass moment of inertia about the spin axis I_s must be greater than the maximum mass moment of inertia along a pitch axis through the satellite center of gravity in any other direction in a plane perpendicular to the spin axis.

To find the maximum pitch mass moment of inertia I_p the mass moments of inertia about the x and y axis are first determined. For the component shown in Fig. 4:

$$\Delta I_{xx} = Wr^2 + \Delta I_{o_{xx}} \qquad (3)$$

Or:

$$\Delta I_{xx} = Wy^2 + Wz^2 + \Delta I_{o_{xx}} \qquad (4)$$

Where: ΔI_{xx} is the mass movement of inertia of a component of the satellite about the reference axis and $\Delta I_{o_{xx}}$ is the mass movement of inertia of the component about an axis parallel to the x axis and through the center of gravity of the component.

The total mass movement of inertia of the satellite about the x axis (I_{xx}) is the sum of the mass movements of inertia of the components:

$$I_{xx} = \Sigma \Delta I_{xx} \qquad (5)$$

The mass movement of inertia of the satellite about an axis parallel to the x axis and through the center of gravity of the satellite ($\bar{I}_{xx}$) is obtained using the transfer relationship:

$$I_{xx} = I_{xx} - W\bar{z}^2 \qquad (6)$$

Where: $\bar{z}$ is the distance from the reference axis to the center of gravity of the satellite as shown in Fig. 4.

The mass moment of inertia of the satellite about an axis parallel to the y axis and through the center of gravity of the satellite ($\bar{I}_{yy}$) is found in a similar manner.

The maximum pitch mass moment of inertia I_p is found by expanding the following determinant and solving for I_p.

$$\begin{vmatrix} (\bar{I}_{xx} - I_p), (-I_{xy}) \\ (-I_{xy}), (\bar{I}_{yy} - I_p) \end{vmatrix} = 0 \qquad (7)$$

The term I_{xy} in the determinant is the product moment of inertia of components of the satellite about the reference $x - y$ plane and is defined by:

$$I_{xy} = \Sigma Wxy \qquad (8)$$

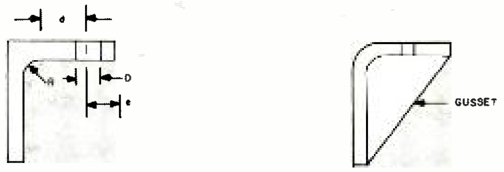
The RELAY satellite had a ratio of I_p to I_s of 0.96. This ratio was very critical for the design. Therefore, constant analytical checks of the mass moments of inertia were kept throughout the design stages and the original ratio was maintained. The final mass moments of inertia were checked experimentally by the use of a bifilar pendulum with results to an accuracy of 0.1%.

STRUCTURAL STRESSES

After locating the components on the structure, a stress analysis should be performed. All loads should be considered. These may be from vibration, shock, and acceleration. Each of these dynamic loads can be replaced by an equivalent static load. For example, for sinusoidal vibration loads the natural frequency of vibration of the structure


A. BUTT JOINT (AVOID)   B. JOGGLED JOINT (PREFERED)

Fig. 6—Methods of joining sheet metal structural parts.



A. EXTRUDED   B. SHEET METAL

Fig. 7—Proper fitting design.

f, in cps, may be found approximately from:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{y_{st}}} \qquad (9)$$

Where: y_{st} is the maximum static deflection and g is the gravitational constant.

The specified environmental input at this natural frequency is then multiplied by an amplification factor Q, which is either known from experience with similar type structures or is estimated to obtain the maximum output load which occurs at the point of maximum deflection. The loading at other places on the structure is estimated to be roughly proportional to the static deflection. The static load is then multiplied by the appropriate factors at each point on the structure. A similar type of treatment can be applied to loads caused by shock, random vibration, or acceleration.

Once the equivalent static loads are known they are applied to the structure and reacted at the point of support of the satellite (the interface with the last stage rocket). A main-loading-path structure to transfer the local loads to the point of support has to be designed. For example, the structures which provide the main loading path in the TIROS and SERT satellites are composed of a series of radial ribs connected to a central hub which, in turn, are attached to the last stage rockets by separation rings. Appreciable weight can be saved if this structure is designed so that the most critical loading conditions are taken in the most direct path to the point of support with efficient use of materials. The most efficient way for the structure to be loaded is in tension with compression, shear, bending, and torsion loads being less efficient in the stated order.

Light-weight structures (such as are used in the TIROS baseplate and the Relay and Ranger structures) are made of built-up sheet-metal construction. In these structures a thin web of sheet metal carries the shear loads and either a bent-up sheet-metal section or an extruded section carries the bending loads in direct compression or tension. In this type of construction the elements carrying tension loads can withstand loads up to the yield strength of the material without permanent damage. The exception to this is when the structure is under vibration loads that can cause fatigue failure at lower allowable stresses. The elements under compression and shear must be designed for stability. Lack of stability can be illustrated by taking a small sheet of paper and applying a compression or sheer load to it and noting how it ripples or buckles under the load. When the edge of the paper parallel to the direction of the compression load is turned up, the paper is stabilized for the compression load. The lip on a 2024-T4 aluminum-alloy-sheet angle as shown in Fig. 5 increases the allowable stress on the angle from 20,000 to 45,750 psi.

Although sheet metal structures are light in weight, certain good design practices are required to avoid failures due to local instability. Concentrated compression loads should not be applied to unsupported thin webs because the loads could cause buckling of the structure at the point of application. Vertical stiffeners on the webs react the loads and transfer them to the rest of the structure. When parts of a sheet metal structure are attached to each other, axial load-carrying members should be joined by joggling them or using gusset plates rather than by a straight butt joint so that a compressive load is not placed on the web. Examples of a simple butt joint and a joggled joint are shown in Fig. 6.

Mechanical analysis of the strength of a structure and good design practice always go together hand-in-hand. This is illustrated in the proper design of fittings as shown in Fig. 7.

The first consideration is the use of the proper material. For example, the yield strengths in tension of two aluminum alloys are 36,000 psi for 6061-T6 alloy and 51,000 psi for 2024-T3 alloy. Aluminum alloy 6061-T6 has good welding properties. However, if no welds are required, the use of 2024-T3 alloy instead of 6061-T6 alloy give added strength with no additional weight.

The addition of an adequate fillet of radius R to a fitting, as shown in Fig. 7, avoids stress concentrations and increases the bending and fatigue stress allowables with a negligible increase in weight. For example, the bending fatigue stress allowable in the 6061-T6 aluminum alloy specimen for 10^5 reversals of load are 17,000 psi for a sharply notched specimen and 31,060 psi for a smooth specimen. Stress concentrations due to abrupt changes of section are to be avoided at all times.

The location of attachments is very important. Eccentricities of loading should be avoided. For example, the bolts should be put as close to the load carrying member as possible. As the dimension d (Fig. 7) increases, so does the local bending moment due to a tension load in the bolt. However, an adequate edge distance (dimension e, Fig. 7) must be maintained especially in sheet metal design. For example, the bearing shear load allowable from a bolt for 2024-T3 aluminum alloy is 71,000 psi for an edge-distance-to-diameter (e/d) ratio of 1.5 and 82,000 psi for a ratio of 2.0. Finally, this example also illustrates the preceding statement about an efficient way to take loads. For large loads on sheet metal fittings, the use of a gusset as shown in Fig. 7 enables the load to be reacted as a truss by axial loads. Increasing the gage of the material to react the load on the bend by bending stress would be highly inefficient and may not be adequate.

The use of structural bolts properly torqued to prevent reversals of load and fatigue during vibration should also be specified where needed.

CONCLUSION

An engineer experienced in mechanical analysis should be consulted from the early stages of any structural design until its final concept so that costly and time-consuming design errors can be avoided and a more reliable structure result.

ROBERT GOLDBERG received an AB in Mathematics from Brooklyn College in 1941, and an MS in Aeronautical Engineering from New York University in 1945. From 1943 to 1946, he worked for the Curtiss-Wright Aeronautical Corporation as a vibration engineer performing flutter analysis studies of the P-40 and C-47 airplanes. During 1946 and 1947, Mr. Goldberg worked for Republic Aviation as a stress engineer in vibration and flutter analysis. At the Chase Aircraft Company from 1948 to 1957, he worked on stress, vibration and mathematical problems, the design of new aircraft structures, and had general engineering responsibilities. Mr. Goldberg joined RCA in 1957, and worked in Camden as an engineer in the Project Coordination group. He also set up test specifications for equipment and worked on the development of a fire control system for the Avro-Arrow aircraft. At the Astro-Electronics Division, Mr. Goldberg performs dynamic and structural analysis on such projects as TIROS, RELAY, SERT, and RANGER. He is a member of the AIAA.

EFFECT OF STRUCTURAL FATIGUE ON MECHANICAL DESIGN OF SPACECRAFT

In the mechanical design of spacecraft, it is very important that the fatigue effects on the structure be thoroughly considered during the design process. This paper briefly discusses input loadings and responses (including construction of an experience table), theoretical analysis of fatigue stresses, and then presents a practical satellite design problem to illustrate the design process followed.

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

The effects of structural fatigue on the design of machines have been considered in a general way for many years. However, new and specialized problems have been posed in the field of modern transportation. For example, in the design of aircraft structures up to the end of World War II, the problem of structural fatigue was minor and could, in general, be ignored. However, with the advent of higher-speed aircraft, i.e., jets and later rockets, this problem assumed considerable importance.

This high-speed aircraft fatigue was induced primarily by wing flutter, by conductive vibration due to the uneven burning of rocket fuel, and by convective vibration (acoustic noise) due to the exhaust velocity of jet engines and rockets. This problem is aggravated by the high, fluctuating stress involved.

The fatigue analysis problem is generally considered during the initial stages of a design, when the allowable fatigue stress is to be determined. Another problem occurs when the life expectancy for a structure of known or assumed dynamic response is to be established. Since the one analysis is the inverse of the other, the problem will be discussed in the terms of the first: the initial design. The following salient mechanical design features (some of which are interdependent) are usually considered when the allowable fatigue stress is to be calculated:

TABLE I — Definition of Symbols

D, specific damping energy, in-lb/in^3
C_d, η, material's damping constants, where $C_d = D/S^{\eta}$
S, stress, psi
N, total number of cycles to failure
n, actual number of cycles
K, allowable stress per g of acceleration
α_i, S_i, material's fatigue constants, where $S_i = SN^{1/\alpha_i}$
g, acceleration, in/sec^2
g_r, acceleration response, in/sec^2
g_o, acceleration input, in/sec^2
ω_n, natural frequency, cps
ω_f, final frequency of sweep, cps
ω_o, initial frequency of sweep, cps
Q, magnification at resonance
T_g, duration of Gaussian noise acceleration, seconds
T_s, duration of sinusoidal acceleration sweep, seconds
z, x, dimensionless parameters

1) loading history of structure
2) structural materials
3) design-style of configuration and method of construction (and compatibility of estimated stress levels with these)
4) natural frequency and damping of the structure
5) number of degrees of freedom
6) stress concentration
7) required safety factors
8) ambient temperature of fatiguing
9) accumulation of fatigue stresses from different types and directions of loading.

INPUT LOADING AND RESPONSES

The loading history, i.e., the input acceleration level (and, hence, stress level) versus the number of fluctuations (or cycles) evaluated at discrete frequencies is basic to any analysis. These programmed input loads cause a definite pattern of response loads, the summation of whose effects determine the allowable fatigue stress for a given material.

The most elementary response pattern is one occurring at constant frequency with a constant amplitude reversal. This may fluctuate about a finite mean or zero. A more complex pattern is due to the response of a constant-amplitude reversal occurring during a logarithmic sinusoidal frequency sweep input. This is often specified in satellite testing to simulate a portion of a rocket environment.

Another useful response pattern is that caused by a Gaussian amplitude-distribution input over a broad bandwidth. This is useful to describe *white noise* effects. These loading patterns may have been applied to the satellite in one of two ways; i.e., by conduction through an interface or by convection through the medium surrounding the structure.

FATIGUE STRESSES

Preliminary values of an allowable fatigue stress may be approximated from previous experience to facilitate selection of design-style and construction materials. A typical "experience table" for satellites is shown in Table II.

JOSEPH J. FRANK received a BSME from the Drexel Institute of Technology in 1950 and an MSME from the University of Delaware in 1958. From 1950 to 1954 and from 1956 to 1957, Mr. Frank was employed by the Hercules Powder Company. Mr. Frank specialized in machine design for the explosives and ordnance departments. As a machine designer and then a project engineer, he was responsible for the preparation of estimates, specifications and orders for chemical plant equipment. From 1958 to 1961, Mr. Frank was employed by RCA in Moorestown, New Jersey. He performed vibration and stress analysis for MIPIR Radar Pedestal; packaged BTL and BMEWS radar control panels, packaged TRADEX noise, power and phase measuring equipments. In 1961, Mr. Frank joined the Astro-Electronics Division as a vibration and structures analyst. He is responsible for the fatigue, vibration, and stress analysis of structures. In addition, he performs thermal analysis and is the liaison between the metallurgical groups. Mr. Frank has worked on RANGER, NIMBUS, SERT, and several classified projects.

In Table II the *actual maximum stress* value is the maximum attained for the given (typical) test program; it is not the operating value for the total number of *test cycles* required by the test specification. Also, the *number of direction* column states the number of vibration directions involved in arriving at the calculated fatigue stress; in some instances it is one or two, in others it is all three. When vibrations from two or three different directions cause the same type and direction of stress at a given point in the structure, the effects must be combined inasmuch as fatiguing is cumulative; this is done by proportioning the accelerative damage effects according to the ratios of the dynamic stresses caused by a 1-g acceleration response in each of the three directions.

TRIAL WORKING STRESS AND STRUCTURAL LOADING

From an experience table, a trial working stress can be selected to allow the preliminary design to proceed. From this trial working stress and knowledge of the S vs. N curves for several materials (at the ambient temperature involved during fatiguing), the material selection can be made. (S is the stress at failure, and N is the corresponding number of cycles to cause this failure.) Also taken into consideration is the method of fabrication (i.e. casting, welding, riveting or machining). In all these decisions, cost and time enter as parameters. Frequently, two or more alternate design styles are roughed out before the cost and time elements are considered.

The structure's loading is determined not only by the input acceleration but also by the damping. Damping is both a function of the material used and the method of fabrication. In general, riveted structures exhibit more damping than machined ones. The additional damping of a riveted structure is of the Coulomb (or sliding) type, while the inherent measure of a material's damping characteristic is the specific damping energy at resonance; this is, of course, caused by hysteresis in the material. When additional damping is required, it is introduced by artificial means (e.g., fluid dashpots, coulomb sliders, and visco-elastic-rigid structures).

It has been found that the material's specific-damping energy D is a function of the stress level S of the material, and can be expressed as $D = C_d S^{\eta}$, where C_d and η are the material's damping constants. A typical set of values is listed in Table III.

It is important to be able to determine the natural frequencies of the system in order to estimate the magnifications and the number of fatigue cycles for each mass. In this connection, being able to determine the number of degrees of freedom of the structure is necessary.

THEORETICAL ANALYSIS OF STRESSES AND FATIGUE

To proceed with the analytical effort, the method of fabrication and the construction used will determine the general or average degree of stress concentration that the structure will generally experience.

TABLE II — Experience Table

Project	Structure Section	Satellite Dominant Dimensions diam x ht (inches)	Structural Material	Satellite Weight (lbs)	Loading Direction	Behavior Under Loading	Resonant Acceleration Input (g's)		Natural Freq. (cps)	Resonant Amplification	No. of Directions of Loading	Total Cycles Required by Test Specification (x 10^4)	Actual Max. Stress (psi)	Cycles to Failure atzMax. Stress (x 10^4)	Max. Allowable Fatigue Stress‡ (psi)
							Sinusoidal (peak)	Gaussian (rms)							
X	Main	24 x 18	Al	103	Long.	Flat Plate	—	25	200†	20†	1	29.6	25,600	1.5"	25,600††,§
SERT*	Main	30 x 24	Mg	320	Long.	Flat Plate	10.7	11.82	100†	5.82†	1	2,973	25,400	4.0	30,500§§
	Support Col.	9 x 7	Al	—	Lat.	Cantilever	2.1	11.82	55†	6.62†	1	2,914	14,650	35	27,000§
TIROS	Main	42 x 16	Al	270	Long.	Flat Plate	—	21	59†	10†	3	42.6	32,400	0.24	34,000§,**
RANGER	Main	25 x 60	Al	370	Long.	Cantilever	1.25	2.11	40‡	10¶	1	23.7	31,800	0.26	31.800§,**
	Main	25 x 60	Al	—	Lat.	Flat Plate	2.45	6.0	80‡	10¶	1	18,06	32.200	0.24	32,200§,**
	Main	25 x 60	Al	—	All	Cantilever & Flat Plate	2.45	30	40 & 80‡	10¶	3	41.8	31,800	0.26	31,800§,**
Y	Main	33 x 166	Al	855	Lat.	Cantilever	3.5	30	93‡	10¶	1	16.7	22,300	3.0	22,300§,**

X,Y—Classified projects

*SERT structure is a machined forging; all others are riveted.

†Measured

‡Calculated

¶Assumed

§For a mildly notched structure

§§For smooth structure

**For three complete sets of tests.

††For two complete sets of tests.

From Ref. 1

TABLE III — Typical Damping Constants

Material	*Yield Strength psi*	*Damping Constant, C_d*	*Average Exponent, η*
Rubber		2×10^{-2}	2
Methyl-methacrylate	6×10^3	390×10^{-12}	3
Bakelite, grade X	6×10^3	65×10^{-12}	3
Plywood, brick	5×10^3	16×10^{-12}	3
Magnesium-alloy M	9×10^3	1×10^{-12}	3
SAE 1025 S'M'L'S Steel	64×10^3	0.05×10^{-12}	3
Cast Iron	—	494×10^{-12}	2.4
Titanium RC 130B	—	274×10^{-12}	2.0

When the S-N curve is determined for the method of fabrication (e.g. mildly notched for riveted structures), any local deviations of higher stress concentration can be taken care of individually. When calculation of the fatigue stress is started, an important consideration is the factor of safety desired. The criterion of failure favored is Miner's (Palmgren's) Hypothesis[2], which states that failure occurs when $\Sigma(n/N) = 1$, where n = the actual number of cycles at a discrete stress level, and N = the total number of cycles at this stress level that just causes failure (taken from the S-N curve).

To be capable of having a "life-to-failure" ratio of 2, the proportion is set as $\Sigma(n/N) = (1/2)$, etc. The problem of determining the allowable fatigue strength for a probable life expectancy is then one of matching the programmed response stress to the S-N curve, such that Miner's Hypothesis holds.

Because the usual parameter of vibration tests is the acceleration in g's, the author has found it convenient to work in this domain mathematically. Then, at any discrete point A, the stress S_A is K_A times the response acceleration at point B (linear structures) or $S_A = K_A g_{rB}$.

In addition, the S-N curve can be analytically expressed in increments as $N_i = (S_i/S)^{\alpha_i}$, where S_i and α_i are material constants for any given region, a to b, such that $S_a < S < S_b$.

TABLE IV — Test Specifications

Test	*Input Acceleration, g*	*Frequency Range, cps*	*No. of Sweeps*	*Duration per Sweep, sec.*
Gaussian Noise	3 (RMS)	15 to 1,500	1	180
Sinusoidal Sweep	2 (peak)	15 to 1,500	3	120

Usually, one region is sufficient to define the entire S-N curve. It can be shown that for Gaussian noise and sinusoidal sweep, (the two usual conductive vibration tests for satellites) the following expressions for fatigue life expectancy are true.

Gaussian noise:

$$\sum \frac{n}{N} =$$

$$\frac{\omega_n T_G}{\sqrt{2\pi}} \left(\frac{K}{S_1}\right)^{\alpha} \sigma^{\alpha} \int_{x=o}^{\infty} x^{\alpha} \exp\,(-x^2/2)\; dx$$

Where: $\sigma = (\tfrac{1}{2}\pi\omega_n Q G_o)^{1/2}$, and $x = g_r/\sigma$.

Sinusoidal Sweep:

$$\sum \frac{n}{N} =$$

$$\frac{\omega_n T_S}{\ln \frac{\omega_f}{\omega_o}} \left(\frac{K}{S_1}\right)^{\alpha} g_o^{\,\alpha} \int_{z=z_a}^{z_b} \frac{dz}{\left\{(1-z^2)^2 + \left(\frac{z}{Q}\right)^2\right\}^{\alpha/2}}$$

Where: $z = \omega/\omega_n$.

A PRACTICAL DESIGN PROBLEM

To illustrate a typical fatigue design problem, a satellite will be considered to be essentially a single-degree-of-freedom system, with a natural frequency of 40 cps in the direction of vibration. It is desired to build into the satellite a double life-expectancy capability, in order to permit two complete sets of tests. Preliminary designs indicate that a riveted structure of 2024-T4 aluminum is feasible. The structure is columnar; and it is expected that the magnification at resonance will be 10. Assume that the test specification comprises the information of Table IV, separately, and that tests in orthogonal directions do not cause the same type of stress at discrete locations. The sinusoidal sweep shall be performed at a rate proportional to frequency. Evaluating the necessary parameters, the problem's solution is:

Gaussian Noise

$$G_o = \frac{g^2}{\Delta\omega} = \frac{3^2}{1500 - 15} = 0.00606$$

$$\sigma = \left(\frac{\pi}{2} \times 40 \times 10 \times 0.00606\right)^{1/2}$$

$$= 1.948 \text{ g's}$$

From the S-N curve for mildly notched 2024-T4, we find $\alpha = 4.24$ and $S_1 = 10^5$ psi. Evaluating the integral:

$$F(\alpha) = \int_o^{\infty} x^{4.24} \exp\,(-x^2/2)\; dx = 4.60$$

Sinusoidal Sweep

$Z_a = 15/40 = 0.375$

$Z_b = 1500/40 = 37.5$

Evaluating the integral:

$$I(z, \alpha, Q) = \int_{0.375}^{37.5} \frac{dz}{\{(1-z^2)^2 + (z/10)^2\}^{2.12}}$$

$$= 1307.30$$

Combining the two fatigue effects (Gaussian $\Sigma[n/N]$ + sinusoidal $\Sigma[n/N]$) gives:

$$\sum \frac{n}{N} = \frac{1}{2}$$

$$= 40 \left(\frac{K}{10^5}\right)^{4.24} \left\{ \frac{180\,(1.948)^{4.24}}{(2\pi)^{1/2}} \left[4.60\right] + \frac{(3 \times 120)\, 2^{4.24}}{\ln\,(1500/15)} \left[1307.3\right] \right\}$$

Solving: $K = 1278$ psi/g

The maximum acceleration (in g's) is one of the following:

$g_{r\text{-max}} = Q g_o = 10 \times 2 = 20$ (sinusoidal)

$g_{r\text{-max}} = 3\sigma = 3 \times 1.948 = 5.844$ (Gaussian)

Therefore, $g_{r\text{-max}}$ is taken as 20 g. (In the second expression, damping in the structure and practical testing machines tend to limit this acceleration to a 3σ value, even though theory indicates that maximum accelerations due to Gaussian noise are infinite.)

Allowable Fatigue Stress

From the above, the allowable fatigue stress $= K g_{r\text{-max}} = 1278 \times 20 = 25{,}500$ psi.

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SANDOR D. RUBENZ graduated with an AB degree from Columbia College in 1923 and received his degree in ME from Columbia University in 1925. He attended the Graduate School of George Washington University for work in theoretical physics and was elected to Sigma Pi Sigma in 1942. Mr. Rubenz was Senior Design Engineer at the Vertol Aircraft Corporation, Senior Marine Engineer for U.S. Maritime Commission, Marine Engineer for Sun Shipbuilding Co., and Mechanical Engineer in the Aeronautical Engine Laboratory, Naval Aircraft Factory. Mr. Rubenz's work with RCA concerns the mechanical engineering and design of communications equipment. He is a Registered Professional Engineer in Illinois and Pennsylvania.

DESIGN OF A VIBRATING TABLE FOR RELIABILITY TESTING

This paper describes how RCA mechanical engineers designed and built a "shaker table" which was to provide controlled vibration in a high-temperature chamber for the purpose of reliability tests on military communications equipment. The resultant equipment, completed in a very short time period and on a limited budget worked to specifications and is now in use as a permanent piece of capital equipment.

S. D. RUBENZ

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

For military communications equipment, one of the important ways to assess the degree of reliability that can be expected in actual service is for the contractor to subject it to tests that simulate the conditions of field use. One such simulated environment involves mechanical shock and vibration, varying in frequency and intensity and in mode of distribution in time and space. Another involves temperature, and a third may include variations on atmospheric pressure (to simulate altitude). Where equipment may be operated in more than one of these environments in the field, it is desirable to combine such tests—e.g., vibration while in a high-temperature environment.

Such a temperature-vibration test is one function of the vibrating platform (or "shaker table") discussed in this article, which the author and his group were asked to design and build in a minimum of time and on a small budget.

BASIC REQUIREMENTS

The reliability group provided the following design-parameter specifications:

1) The platform had to operate inside a standard Hotpak chamber with interior temperature variable between —65°C and 85°C. Chamber dimensions are 53 inches wide x 30 inches deep x 30 inches high.
2) The table had to vibrate at constant frequencies between 25 and 60 cps, without inducing resonance at any particular frequency, except that it could pass through resonance while accelerating up to the operating frequency.
3) It had to vibrate equipment weighing 300 pounds including fixtures.
4) Maximum force on a test load was to be 2g (equivalent to twice the equipment weight).
5) Oscillating motion had to be sinusoidal or a combination of harmonics.
6) The platform had to be spring-mounted to eliminate or minimize lateral motion in the horizontal plane, and as far as possible, allow only vertical motion.
7) The entire machine had to be designed, fabricated, and installed on a strictly limited budget—*and ready to operate only weeks from the start of design.*

The last requirement obviously imposed severe restrictions on any notions of elegance and sophistication. It had to be built in the simplest and quickest way possible to do its job efficiently, with relative freedom from modifications to clear up bugs and operational failures after completion.

The simplest way to drive such a table is by mechanical reaction, in which eccentric weight or weights rotate on a shaft supported in bearings on which the platform is mounted. The ideal arrangement is two counter-rotating shafts, each with identical eccentric weights, phased so that the bearing reactions of one shaft will cancel out those of the second in every direction except the vertical. However, this approach requires not only two shafts and their bearings and two sets of weights, but also an interconnecting gearing or belt drive to produce the phased counterrotation. To save money on this project, a simpler and less-

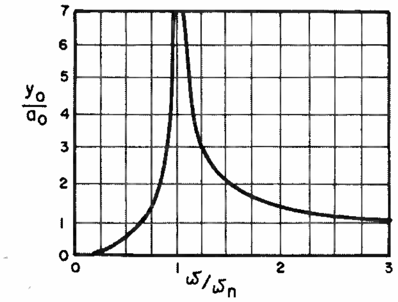


Fig. 1—Transmissibility curve of Eq. 3.

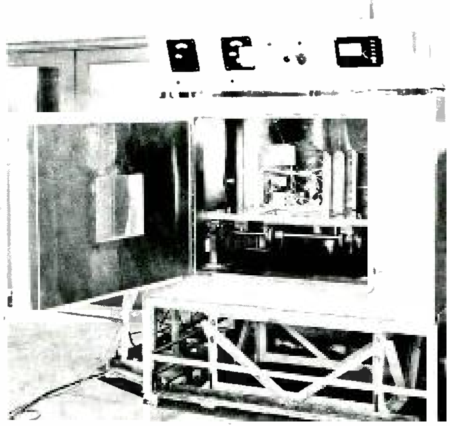
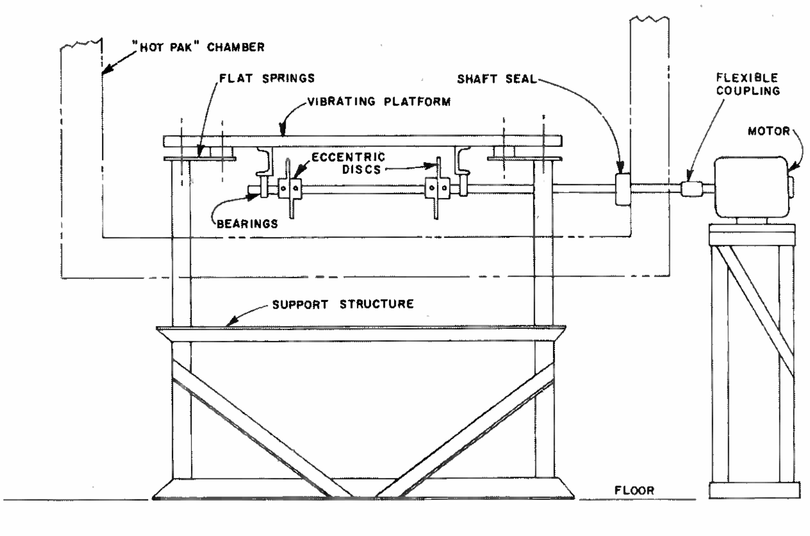


Fig. 2—Below: Shaker table and structure. Photo above: Shaker inside Hotpak chamber.



costly approach was taken: Two equal eccentric masses on a single shaft, equally spaced on the shaft from the center of mass of the platform—with a set of flat cantilever springs used to eliminate the unwanted lateral motion that would otherwise occur with only a single shaft. While lateral constraint could be provided by encasing the platform in a set of guides, such an approach was too costly — requiring precision shaft-guide fitting and elaborate structural bracing, and creating lubrication problems.

GENERAL DESIGN CONSIDERATIONS

The requirement for vertical motion only imposed restrictions on the kind of spring mounting to be used. The usual type of vibration isolator was unsuitable, since it is a cylindrical device which behaves like a helical coil spring, and is therefore highly susceptible to lateral motions of the platform induced by coupling effects in vibration.

It was decided to use springs with greater stiffness in the horizontal plane compared to the stiffness in the vertical direction, thus supplying a built-in restraint to lateral motion in the mounting itself. This is a characteristic of a beam or plate-type spring in which the lateral dimensions are large compared to thickness; it is also a characteristic of the torsion-bar spring if the axis of twist is properly oriented with respect to the direction of forces on the platform.

The flat, beam-type spring was selected instead of the torsion bar, on the basis of simplicity of mounting structure, available space, and overall cost. The effective length of the beam-type spring and point of application of the load are both uncertain, depending upon (among other things) rigidity of clamping arrangements. Consequently, the experience of the designer enters into the analysis of the spring performance.

THE PROCESS OF DESIGN

In this design, the input force is proportional to ω^2, where ω is the rotational frequency in radians/sec of the rotating weights. Every system capable of vibrating has a so-called *natural frequency*, the frequency at which the system will vibrate freely when it is not under the influence of any imposed forcing vibrations, but has been subjected only to an initial impulse. An oscillating system may be considered to act as a linear spring, and then its natural frequency f_n (in cps) is a function of the ratio of its stiffness to its mass; i.e., in the absence of damping:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}} \qquad (1)$$

Where: the mass M is found by using g in ft/sec^2, and K is the spring constant (or pounds of force per foot of deflection or any similar set of consistent units).

When the table is vibrated at frequency f, it will go through a periodic displacement about a midpoint; this displacement is dependent upon the square of the ratio of the forcing frequency to the natural frequency of the system. As the oscillation is assumed to be sinusoidal, it is more convenient to deal in terms of circular frequency ω, where $\omega = 2\pi f$ radians/second. Then the forced displacement is dependent upon $(\omega/\omega_n)^2$.

The basic equation for a simple harmonic motion leads to:

$$\ddot{x} = 4\pi^2 f^2 x_o \qquad (2)$$

Where: $\ddot{x}$ is the maximum acceleration reached in the cycle and x_o is the maximum displacement. Since the force exerted on the oscillating body at any given frequency is proportional to its maximum displacement in the cycle, if we know the effect of a forced vibration upon the displacement we also know its effect on the forces exerted on the vibrating body.

In dealing with these forces, it is convenient to make use of *transmissibility*—the ratio of magnitude of the force exerted on the body to that of the input force, which also is the ratio of the magnitudes of the respective amplitudes. If, then, y_o is the maximum amplitude caused by a forced vibration and a_o is the maximum amplitude of the input vibration, then:

$$\frac{y_o}{a_o} = \frac{(\omega/\omega_n)^2}{1-(\omega/\omega_n)^2} \qquad (3)$$

Eq. 3 shows that as ω approaches ω_n, in value the ratio y_o/a_o increases rapidly; and, when $\omega = \omega_n$, this ratio becomes infinitely large, in theory. In practice, some damping is always present and prevents infinitely large transmissibilities, but this factor can and often does become extremely large. This is the condition of *resonance*, and is obviously a dangerous one. The built-in damping of a mechanical reaction vibrator is made up almost entirely of bearing friction and windage friction opposing motion of the eccentric weights and the oscillating table. It is usually assumed to have a coefficient of 0.1.

With overall design of the vibrating platform established, the various detail parts were then investigated, starting with the mounting springs. The design of the springs depends upon whether we want *hard* or *soft* mounting, that is, a stiff spring with a very high natural frequency or a soft spring with a low natural frequency. The stiff spring should in theory allow the table to reach operating frequencies without passing through resonance. The soft spring will require acceleration through resonance on the way to operating frequency. On the other hand, the stiff spring will tend to transmit the table forces through the support structure and into the foundation. To avoid passing these vibrating forces into the building floor, the foundation would need to be a very heavy "seismic mass" suitably isolated from the floor. In practice, such seismic masses are made about ten times the total mass of the vibrating system. The soft spring tends to isolate the supporting structure and foundation from the oscillating forces on the platform, and is more desirable from this standpoint.

Another consideration favors the soft spring mounting. Fig. 1 shows a plot of transmissibility (y_o/a_o) *versus* ω/ω_n. Where $\omega = \omega_n$, transmissibility increases rapidly, approaching infinity. This plot neglects damping, the effect of which would be to decrease y_o/a_o to within finite limits; but it would still be very large depending upon the amount of damping. The value of ω_n where this peak occurs would not be affected appreciably by damping, and the resonance would still occur at $\omega = \omega_n$, i.e., the *critical frequency*.

Fig. 1 shows that the region of stable isolation occurs where $\omega/\omega_n \geq \sqrt{2}$. In fact, the transmissibility factor rapidly approaches unity as the ratio ω/ω_n increases beyond $\sqrt{2}$. In other words, such a spring system would be completely stable where its natural frequency was 1/2 or 1/3 the forcing frequency. On the other hand, in the region where $\omega/\omega_n < 1$, this stability is critical until a very low value of ω/ω_n is reached, approaching zero. Thus, in this region, a very stiff spring system would be needed, and the transmissibilities would approach zero.

The operation of this type of "shaker" depends upon the transfer of the energy of the eccentric weights to the table. From the principle of the equivalence of work and energy, it can be shown that if M = mass on the vibrating table (including that of the table itself), X = its single amplitude of oscillation, m = the mass of one eccentric disk, and K is its radius of gyration, then:

$$mk = \frac{MX}{y_o/a_o} \qquad (4)$$

In the region where y_o/a_o is close to unity, we take it as equal to one for simplicity and then $MX = mk$.

Obviously, from the standpoint of minimum loads on the shaft bearings and on the supporting structure, it is advantageous to use soft springs, preferably springs which would give $\omega/\omega_n = 3$ or more, where the amplification is substantially unity.

The next step in the design process, then, was to determine the excursion of the platform necessary to impose a 2-g load on the equipment at the operating frequencies. For a linear oscillator at any given frequency, the g load is a function of the maximum amplitude.

Substituting in Eq. 2, for 1 g (x = 386 in/sec^2), we find the maximum amplitude of oscillation $x_o = 9.778/f^2$. In general, then, $g = 0.1022\, x_o f^2$, since 1 g is equivalent to 386 in/sec^2. If D_A is the double amplitude of vibration, then g $= 0.0511\, D_A f^2$. Then, for a 2-g load and $f = 60$ cps, we find $x_o = 0.0054$ inch and $D_A = 0.0109$ inch. At $f = 25$ cps, we find $x_o = 0.0313$ inch and $D_A = 0.0626$ inch. These, then, are the limits between which the platform oscillates.

The table itself is 1-inch plywood, (40 x 26 inches) covered on top with a 1/8-inch-thick aluminum plate. Plywood was chosen for several reasons: 1) to provide a reasonably rigid flat platform without going to a heavy steel or aluminum plate; 2) to allow for quick and easy mounting of equipment and fixtures by use of simple straps and bolting thus avoiding elaborate holddown arrangements and hole patterns needed with a metal plate; and 3) fabrication costs. The rigidity of the plywood table was greatly increased by suitable ribbing and cross-bracing on the bottom surface using steel angles, channels and flat bars as needed. Channels were provided as attaching members for the pillow block ball bearings supporting the rotating weight shaft. Fig. 2 shows a simplified section through the structure. The vibrating platform with reinforcement and components weighs 50 pounds.

If the heaviest equipment to be mounted is 300 pounds, the total weight to be shaken is 350 pounds, or 88 pounds per spring. The maximum loading condition occurs when this total weight is vibrated at 25 cps for 2-g load. In this case, $MX = 350 \times 0.0313 = 10.96$ lb-in. This immediately gives us the maximum mk condition for the eccentric masses.

For any frequency greater than 25 cps or weight less than 350 pounds, this factor will obviously be reduced. In these calculations actual weights are used instead of mass because the acceleration due to gravity occurs on both sides of the equation relating MX to mk.

If the springs are sufficiently soft, that is, with a natural frequency low enough so that they work in the region of $\omega/\omega_n = 3$, Fig. 1 shows that mk need be no larger than 10.96 lb-in. The amplification factor is never less than one on the "soft" side of resonance. However, if stiff springs are used so that they are working on the "hard" side of resonance where $\omega/\omega_n < 1$, then mk will have to be larger than 10.96 lb-in. As already noted this will result in greatly increased loading on the shaft bearings and structure.

In deciding to use flat cantilever springs designed for soft mounting, the natural frequency of the springs had to be less than $f/\sqrt{2}$ and preferably less than $f/3$ to avoid resonance effects. Thus, for 60 cps, the desired spring needed to have a natural frequency of about 20 cps. At 25-cps operation, this spring would be critically close to resonance. Using the criteria of $f/3$ results in too soft a spring. The desired natural frequency is then taken as 18 cps.

Design considerations indicated that the cantilever springs should have a free length of 4 inches from point of support

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APPENDIX: DESIGNING THE SPRINGS AND DRIVE SYSTEM

The natural frequency f_c of any spring with a single degree of freedom is:

$$f_c = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} \text{ cps} \tag{5}$$

The deflection δ of a statically-loaded cantilever beam (i.e., in this case the flat spring) is:

$$\delta = Wl^3/3EI \tag{6}$$

Where: W is the total load on each spring, pounds; l is the length of spring, inches; and E is Young's modulus = 30×10^6 psi for steel. Also, I, the section moment of inertia, is:

$$I = 1/12\ (bh^3) \tag{7}$$

Where: b = the width and h = thickness of the rectangular section through the spring (inches).

Substituting Eq. 6 in Eq. 5, and taking $l = 4$ inches and $W = 88$ pounds, then for $f_c = 20$ cps we find the required $I = 0.00256$ in.^{4} (Actually, in a thin spring where $h << b$, Eq. 6 should be multiplied by $(1 - \nu^2)$, where ν is Poisson's ratio. Since ν is usually around 0.3, actual deflections may be 10% *less* than the above approach indicates.) Physical considerations suggested springs 3 inches wide.

Initial utilization of the table was for equipment weighing about 50 pounds; adding 90 pounds for fixtures plus table gives $W = 35$ pounds per spring. For this loading at $f_c = 20$ cps, we need $I = 0.00102$ in.^{4} With $b = 3$ inches and trying $h = 0.156$ inch, the actual $I = 0.00096$ in.^{4} For this I, and $W = 35$ pounds, we find the actual natural frequency from Eq. 5 and 6 as $f_c = 19.4$ cps, which is acceptable for the aforementioned 50-pound equipment to be tested at 60 cps.

The next step is to check stresses in the springs. The oscillating spring is subjected to two superimposed stress components: from static load, and from dynamic loading.

For the static components at $W = 35$ pounds, and $I = 0.00096$, we substitute in Eq. 6 and find $\delta = 0.026$ inch. The static stress σ_S is:

$$\sigma_S = \frac{3E\,(h/2)\delta}{l^2} = 11{,}400 \text{ psi} \tag{8}$$

The dynamic-stress component is found by using Eq. 5, to calculate $a \pm \delta$, taking f_c as the operating frequency of 60 cps. From Eq. 8, the fluctuating dynamic stress $\sigma_D = \pm 2390$ psi. Therefore, the stress in the springs ranges between 9,000 and 13,179 psi ($\sigma_S \pm \sigma_D$), a fluctuating stress that is, of course, fatigue loading.

For the maximum equipment loading of 300 pounds, we use $W = 88$ pounds per spring, and try $h = 0.250$-inch-thick springs. Following the above calculation steps gives for 60-cps operation a fluctuating stress of 14,500 to 19,290 psi.

Note that for the same material frequency f_c at various equipment weights, the static deflection δ is constant; in this case about 0.024 to 0.026 inch —which follows from Eq. 5. But for a *constant deflection*, the thinner the beam the lower the maximum stress because the distance from the neutral axis to the extreme fiber decreases. Therefore, it is advisable to use the thinnest spring consistent with the f_c and the maximum stress desired. O course, the value of I must be maintained, and if the thickness is reduced, the width must be increased considerably (since b is inversely proportional to h^3). Obviously, this approach has practical limitations because b increases rapidly and the beam will no longer act according to theory.

For the initial operating requirements of this table, the springs chosen were:

1) *Light Loads;* 0.156 inch thick by 3 inches wide.
2) *Heavy Loads;* 0.188 inch thick by 3 inches wide.

For the second spring at 300 pounds of equipment, $f_c = 16$ cps. This spring is adequate for the heavier loads but at lighter loads may result in resonance effects at 25-cps operation.

Materials procurement dictated that the actual spring (2) be 0.176×3 inches. Then, $I = 0.00136$ in^4, and at 88 pounds per spring, $f_c = 14.7$ cps (which is acceptable for all ranges of frequencies, 25 to 60 cps, at 300 pounds). Then, $\delta = 0.046$ inch, and $\sigma_S = 25{,}800$ psi. At 25 cps, the amplitude of vibration is ± 0.03 inch. Then, $\sigma_D = \pm 16{,}800$ psi, so that the fluctuating stress in the spring is 9,000 to 42,600 psi. At 60 cps, the $\sigma_D = \pm 2{,}800$ psi, and the fluctuating stress is 23,800 to 28,600 psi.

Using 0.156-inch springs with 300-pound equipment load, $\delta = 0.063$ inch, and $\sigma_S = 27{,}600$ psi.

The stresses developed in the spring by the foregoing loads, while high for fatigue loading, are not unduly high for properly heat-treated spring steel such as SAE1070, specified for this design. Nevertheless, for practical reasons in a piece of capital equipment such as this, the maximum static stress

Fig. 3—Spring capabilities.

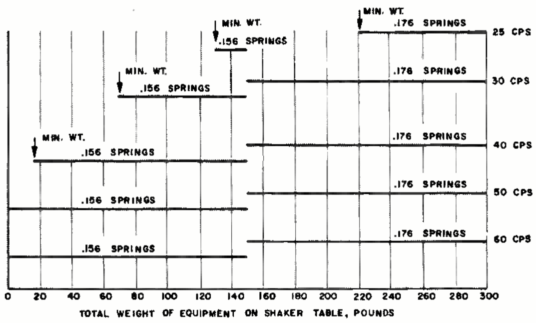


Fig. 4—Eccentric discs.

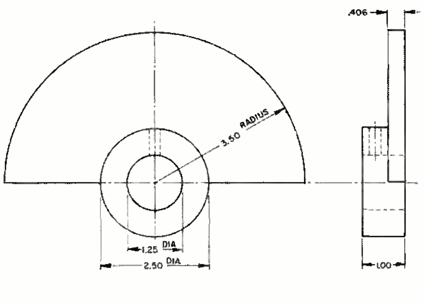
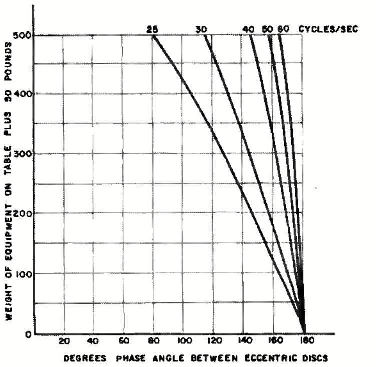


Fig. 5—Phasing between eccentrics (0.156 and 0.176 inch thick springs only).



to center of load application. Although in actual construction there may be considerable overhang from the point of load to the free end of the spring, for purposes of analysis, the center of load is taken as the free end (a convenient and allowable simplification, especially since precise built-in conditions are not known at this stage of design).

Detailed analysis of the springs and drive system are presented in the accompanying *Appendix.*

The final step in the design is to plan a way of anchoring the vibrating table to a foundation so that the shaking forces are not transmitted to the floor.

Some help has been obtained by using soft springs but these are of little help when passing through resonance. The principle of the "seismic mass" can be used here. The supporting structure is securely bolted to a heavy foundation of sufficient mass to result in very small movement of the foundation. The foundation itself is isolated from the floor, the isolating material absorbing the motion of the foundation. The motor stand must be completely isolated from the vibration table foundation so that no vibrations are induced into the motor through this means. However, the shaft carrying the eccentric discs will oscillate with the table and thus will impose its cyclic motion on the motor shaft. To minimize this, a flexible coupling is placed between the motor and the drive shaft. The coupling, of course, must be able to absorb the maximum translational misalignment due to normal oscillation of the table, in this case ± 0.031 in. No coupling can take care of the excessive translations which occur during resonance and the only things that can be done are to pass through resonance as quickly as possible, and to load the springs so that resonance occurs at as low a frequency as possible.

OPERATIONAL EXPERIENCE

The machine was used in regular operation on a variety of equipments at the New Castle, Delaware, Engineering Facility since it was first assembled in the spring of 1963. It has now been transferred to the Environmental Engineering Laboratory in Camden.

Barring fatigue failure of the springs, the vibrator should last indefinitely. The bearings which are oversized for the load should have an almost infinite life with proper care. With careful selection of springs to suit the weight-frequency combinations, fatigue failure of the springs should be no problem.

Commercially, a shaker to meet the specific requirements of this job could not be bought as an off-the-shelf item but would have to be designed and built as a custom item, especially as it had to fit inside the Hotpak chamber. The machine described herein was designed and fabricated for a total in the neighborhood of the cost of a purchased item of standard design for which the support structure would need considerable modification in order to fit into the Hotpak chamber. It has to be remembered that the need to meet a schedule was a strong factor in deciding to build the machine here.

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will be arbitrarily limited to 16,000 psi. The maximum allowable static deflection will be $\delta = (16{,}000/11{,}400) \times 0.026 = 0.036$ inch, and the maximum load will be $35 \times (0.036/0.026) = 49$ pounds, say 50 pounds per spring.

Thus, for the four springs, the maximum load for the 0.156-inch springs will be 200 pounds total, or 150 pounds of equipment plus fixtures. Using these criteria of maximum stress and critical frequency (to be such that $f/f_c = \sqrt{2}$ as a minimum) a chart of spring capabilities can be drawn up specifying the load and frequency ranges in which the 0.156-inch and 0.176-inch springs can be used. Such a chart is shown in Fig. 3. Thus, according to Fig. 3, for equipment weights greater than 150 pounds, the 0.176-inch springs should be used, *except* that at 25-cps operation, the load on these springs should not be less than 220 pounds. (Loads below this are likely to lead to resonance in the table.) For the 0.156-inch spring the minimum equipment weights to be used to avoid resonance are: *at 25 cps*, 130 pounds; *at 30 cps*, 70 pounds; and *at 40 cps*, 15 pounds. At 50 and 60 cps, equipment weights down to zero should be capable of vibrating on these springs without resonance.

It will be noted that with the machine as described with the two sets of springs, there is a gap in the weight range for recommended operation of 25 cps. The maximum recommended equipment weight for the 0.156-inch spring is still 150 pounds, but the minimum recommended for the 0.176-inch spring is 220 pounds. Neither spring is considered suitable for the range of weights between. For this gap a new spring will have to be designed.

The oscillations of the table are induced by a pair of eccentric discs which set up bearing reactions in the shaft bearings due to centrifugal force of the displaced weights. As we intend to work in the region where x_0/a_0 is close to unity, we assume it equal to 1 for simplicity so that, as we saw in the foregoing, MX = *mk*. The design of the forcing system has to be made flexible enough so that the effect of a number of simplifications adopted in design will be absorbed by suitable adjustments. This has been done by splitting each eccentric disc into two equal parts which can be symmetrically phased with respect to each other. Thus, when the c.g.'s of the two discs are in line, we have the maximum effect of the eccentric masses. When the two c.g.'s are 180° apart, the effect is zero. In between the effective mass is obtained as the resultant of a vector diagram.

At 60 cps and 350 pounds total weight to be shaken, we found the total excursion for 2 g to be 0.0109 inch, double amplitude. In this case, $MX = 1/2 \times 0.011 \times 350 = 1.75$ lb-in.

At 25 cps and 350 pounds, the total excursion for 2 g is 0.0626 inch. Then $MX = 1/2 \times 0.063 \times 350 = 11.0$ lb-in. As we have taken the amplification factor to be unity, the maximum mk needed in the eccentric weights is 11.0 lb-in or 5.50 lb-in per each of the two sets. As we have divided each set into two separate *but equal* discs, each one needs $5.5/2 = 2.75$ lb-in.

The design chosen for the eccentric disc is that of a semicircular sector on a suitable hub. From considerations of design and bearing loads, the bearings chosen were pillow-block ball bearings of 1¼-inch bore, the series called by SKF, "SY-104". The design of the disc is shown in Fig. 4. The hub bore is 1.25 inches. The O.D. of the hub is 2½ inches. The outside radius of the sector is 3.50 inches. The length of the hub is made 1.0 inch to allow for set screws. The width of the sector, *a*, is to be determined from the *mk* value needed.

By the method of elementary mechanics we find the polar moment of inertia of a circular sector to be:

$$J_P = \frac{Mr^2}{2} \text{ lb-in-sec}^2$$

Where: r is the outside radius and M is the mass of the sector. This is the J_P of *any* circular sector regardless of its included angle so that it holds for a semicircular sector as well as for the full circular cylinder. By definition, $J_P = Mk^2$, so that $k^2 = J_P/M = r^2/2$. Whence, the radius of gyration of the sector $= k = r/\sqrt{2}$.

As the hub is symmetrical about the axis of rotation, its effect is neglected and we need to deal only with the semicircular disc. Each of the phasing discs has been designed to a value of $mk = 3.0$ lb-in, which allows for a certain margin of error in meeting the force requirements of the table. Such a margin is advisable because, as already noted, the design analysis is highly simplified—especially in relation to the behavior of the springs. (A more refined analysis was not in the writer's opinion justified on the grounds of cost and time, and a number of assumptions would still have had to be made.)

For an outside radius $r = 3.50$ inches, $k = 3.5/\sqrt{2} = 2.48$ inches. At $Wk = 3.0$ lb-in, $W = 3/2.48 = 1.21$ lb.

Knowing the weight of the disc, it remains to find the thickness a,' and this comes out to be 0.298 inch. From production considerations, a was made 0.406 inch. The resulting weight of the sector is 1.92 pounds. With all four discs lined up in phase for maximum input to the table, the input energy is $1.92 \times 2.48 \times 4 \times 2 = 38$ lb-in. This is far more than it is expected will be needed to impose a 2g load on the 300-pound equipment at 25 cps, so that the discs will always be operated at some relative phasing angle.

As an example, suppose we set the two discs a each bearing 90° apart. Then, per set, $Wk = 2 \times 1.92 \times 2.48 = 10$ lb-in. By the parallelogram of forces, the resultant *Wk* effecting input to the table is $10 \times \sqrt{2} = 14.14$ lb-in. For the two sets, then total *Wk* on the table is 28 lb-in.

Similar calculations can be made for other angular displacements and a chart drawn up as Fig. 5, giving angular phasing relations against resultant *Wk* acting on the platform. Of course, the set of discs at each of the two bearings must line up correctly with the set at the other bearing, so that the resultants of both are exactly in phase. Otherwise, an unwanted rocking action will be induced in the table.

There remains the problem of powering the table. An oscillating spring system, once it has been accelerated to operating frequency is self-powered to a large extent. The work which has been put into deflecting the springs by the table is fed back to the table by the springs on the return cycle. Of course, there are losses: friction in the bearings, windage and hysteresis damping in the springs. These can be quite small. The only other load on the driving system will be the inertia torque reactions to acceleration of the vibrating mass.

The motor chosen to drive the table is a DC variable speed motor from 1,500 to 3,600 rpm (equivalent to 25 cps to 60 cps). In this range of speed, its output torque is constant and as it is rated at ½ hp at 3,600 rpm, the torque is $(5{,}250 \times 1/2)/3600 = 8.8$ in-lb, at output shaft. Torque of acceleration involves only the acceleration of the eccentric masses. For each of these discs, $J_P = 0.0304$ slug-in.² For four discs, $J_P = 0.122$ slug-in.² At 3600 rpm, $\omega = 2\pi \times 60 = 378$ radians/sec. Then, the energy required to reach 3600 rpm $= E = \frac{1}{2} J_P \omega^2 = 8{,}750$ in-lb.

A ½-hp motor with an output shaft ⅝ inch in diameter will develop 55 in-lb of work per revolution. To reach 8,750 in-lb of energy will take 159 revolutions of the motor. In view of the almost negligible friction and windage torques, acceleration should be limited only by the rotating inertia reaction. But even if the motor reached 3,600 rpm in the minimum possible time, it would still take $159/60 = 2.65$ seconds to do so. Thus in coming up to 3,600 rpm, average acceleration would be $378/2.65 = 142$ radians/sec². The torque required for this acceleration would be $T = J_P \sigma = 0.122 \times 142 = 17$ in-lb. This is about twice the torque available at the motor, so that it would not be able to accelerate the machine at this rate. This does not mean that the motor is underpowered or inadequate, but that acceleration will take twice as long as calculated, or about 5 seconds. Actually, the motor is brought up to operating speed in discrete steps by the rheostat control so that fully adequate torque is always available.

MECHANICAL FIELD MAINTENANCE OF EDP EQUIPMENT

Modern electronic data processing installations must operate at peak efficiency and with minimum down-time for servicing if the best return on the large dollar investment in them is to be realized. An important activity of the RCA Service Company is the maintenance of many installed RCA computer systems, an activity performed in the field by Computer Service Representatives. To support their work is an important responsibility of the EDP Service Engineering group of the RCA Service Company, where electrical and mechanical engineers perform important analyses of service problems. This paper discusses approaches used to some of the mechanical maintenance problems encountered.

E. J. CROALL, JR.

EDP Service Engineering
RCA Service Co.
Cherry Hill, N. J.

THERE are a number of mechanical aspects of an electronic data processing installation that affect its maintenance and, thus, ultimately affect its efficiency of operation.

Field needs are indicated in many ways, such as engineering data requests, service hints, suggestions, memos, phone calls, formal meetings, and part-usage data. Such information from many sources must all be carefully analyzed to determine if any given problem or suggestion for improvement is or could be common to all computer installations. Questionnaires are frequently used to obtain data on the extent or severity of a given problem. Solutions to one-of-a-kind problems are given to field service personnel by phone or letter, while solutions common to all sites are relayed by the more formal *Service Letter.*

Some titles of recent Service Letters will illustrate the broad scope of the information supplied to the field: "Air Conditioning," "Removing Excessive Gear Train Play by Shimming," and "Fan Bearing Replacement for the RCA 501 System."

SERVICE TOOL EVALUATION

To do a repair or maintenance job efficiently, proper tools are imperative. This is especially true on computer equipment, since repair and maintenance time is at a premium. Tools required for maintaining EDP equipment can be classed as "commercial" or "special." Commercially available tools (screwdrivers, wrenches, etc.) usually present no problems. However, care must be taken to prevent the possibility of duplicating similar tools that may be specified by different equipment vendors. This is possible since equipment manufacturers usually specify the necessary maintenance tools and RCA EDP systems utilize equipment made by many manufacturers. Manufacturer-recommended special tools such as gages, jigs, fixtures etc. must first be analyzed to determine if they are absolutely necessary to maintain the equipment. The design of a special tool must be checked to insure that it will aid rather than hinder the service man, that the specified tolerances are justified, and that the cost is reasonable. Special tools must also be accurately inspected before they are released to the field.

Similarly, it is important that the service representative have available to him the best in operating supplies, such as lubricants, along with clearly outlined procedures on how to use them. For example, as equipments are added to the RCA EDP product line, the list of specified lubricants multiplies, and in many cases four or five lubricant products from different manufacturers may be listed, even though all do essentially the same job—a maintenance problem that results from the fact that RCA EDP equipment may utilize components made by several manufacturers. In one case, a lubricant list that had grown to some 25 different types was cut to just 5 by consultation with the manufacturers—thus materially easing the supplies problem and the written procedures. This is very significant when it is realized that lubricating greases have a short shelf life because they are nonhomogeneous and will separate in time. Thus, quantities of grease stocked at a computer site must be such that it is used up before shelf life is exceeded. Similarly, warehouse stocks must be controlled.

In selecting cleaning agents, not just their cleaning ability must be considered, but also potential deleterious effects on machine parts, detrimental health effects, etc.

PARTS EVALUATION

The equipment in a typical field installation is composed of hundreds of thousands of component parts. Some of the parts have a long life expectancy while others have a relatively short life expectancy. Every installation must therefore stock a sufficient supply of parts to meet everyday needs. This requires making a recommended site spares list for every piece of RCA EDP equipment. The two big problems in making such a list is *what* and *how many.* If too many items are stocked at an installation it will tie up too much capital in inventory, but if too few are stocked it could result in excessive downtime and subsequent loss of computer rental fees. For new equipments that are introduced to the field, the lists are based on past experience and educated guesses. All lists are then updated quarterly based on actual parts usage to insure that sufficient quantities of the required parts are stocked.

There are many assemblies and subassemblies utilized in the various equipments that malfunction as parts wear or break. The majority of these assemblies may be repaired, but *who will perform the repair, is it economically feasible,* and *are the replacement parts available?* Some assemblies may be repaired in the field using procedures developed by EDPS Engineering, since special tools are not required and the assembly realignment is not critical.

Switchlight assemblies used in the 301 and 501 equipments are good examples of field-repairable assemblies. Malfunctioning microswitches cause a majority

EDWARD CROALL received the BSME from Drexel Institute of Technology in 1958. He was employed at the Burrough's Research Laboratories as an Assistant Development Engineer working on new ledger and check transports, where he spent extensive time in the design and development of high speed magnetic and electrostatic inkers. In 1960, he joined the Beloit Eastern Corporation where he was responsible for the design of new paper handling equipment and the redesign of obsolete equipment for useful service. In 1961 he joined the RCA Service Company, EDPS Engineering activity, where he has been responsible for all phases of mechanical service engineering from developing new test and alignment procedures to evaluating the feasibility of repairing a defective assembly.

of switchlight failures. Switch replacement was thought impractical because the assembly was riveted, and a popular misconception is that riveting involves very special skills and is used to gain precise parts alignment. Actually, rivets are used for production economies. (Precision would have called for pins, shoulder screws, keys, etc.) In this case, using a #2-56 panhead screw, nut, and lock washer made it possible to replace a defective microswitch in the field. Applying Loctite-D to the nut prevents vibration loosening.

Assemblies which are economically repairable but require remachining and then readjustment using special tools are sent to a depot where they are farmed out for repair. Once an assembly has been repaired, it is required to meet a set of test specifications developed by EDPS Engineering before it is shipped back to the field.

There are also many components used throughout the various equipments which fail rather rapidly. Constant evaluation, life tests, and experiments are being performed in an effort to find better more reliable parts or a method to prolong life of presently used parts.

A good example of increased parts reliability is replacement of the 328 lamp used to excite photocells in the 381 tape station with a GE381 lamp. Their prices are about the same, yet the 381 has a life of 45,000 hours, compared to 350 hours for the 328 lamp.

An evaluation is presently being conducted into the use of shims in the 573 printer clutch-brake to obtain the desired running gap. End play in the armature shaft cannot be tolerated: therefore, the center portion of the armature must be in contact with the flanged oilite bushings of the clutch and brake. Experiments have proven that the surface of the flanged oilite bushing wears at a much faster rate than the brake material on the armature. To maintain the desired gaps between the friction surfaces of the clutch, brake and armature, shims must be added on the armature shaft. The shim material must be capable of resisting wear as there will always be relative motion between the center portion of the armature and one of the two oilite bushings.

Life tests to determine the interrelationship of horizontal versus vertical mounting, speed, and shielded vs sealed bearings have been in operation since early 1963. The results of these tests are helpful in setting up preventive maintenance programs such as the fan bearing replacement program for the RCA 501.

Many experiments are conducted to determine if hints and suggestions submitted by field personnel are workable. An experiment conducted recently proved that by modifying the shape of a leaf spring on a pressure pad assembly, its life could be extended by a factor of 100. Also, by making the spring field replaceable, the replacement cost would be reduced from $10.00 to $0.50 and the time required for installation reduced from 30 minutes to 10 minutes.

SOLVING PARTS FAILURES

Inspection of parts which have prematurely failed coupled with exact knowledge of their machine function helps determine the cause of the failure and suggests what remedial measures must be taken to prolong part life. Premature failure of the 581 tape station pressure roller assemblies will be used to illustrate this point.

Hundreds of malfunctioning pressure roller assemblies were inspected to determine what type of failures were occurring; 52% of the failures were due to the separation of the rubber tire from the aluminum hub. This problem was caused by attempting to mold rubber onto an aluminum hub which had a 32 or better microfinish. Due to the smooth surface on the hub, the rubber tire could work loose during normal operation. This condition was overcome by specifying that the hub surface should be sandblasted or fine knurled prior to installation of the rubber tire.

Also, 29% of the failures were caused by bad bearings. Bearing failure was caused by damage upon initial installation and tape oxide and fretting corrosion dust which had worked past the shields into the bearings. Bearing damage at initial installation was minimized by providing field personnel with the proper installation procedure and installation tools. The oxide dust from the tape could not be eliminated but it could be minimized by periodic cleaning and lubrication. Dust caused by fretting corrosion is caused when two mating surfaces creep or oscillate relative to one another at a high rate of frequency. This type of motion did exist between the pressure roller shaft and the inside diameter of the bearing, because shaft tolerances were chosen to insure that there would always be a clearance fit. Relative motion between the two parts was eliminated by adding a very small drop of Loctite grade E to the shaft where it enters the bearing. Of the failures, 9% were caused by elongated shaft holes in the fork. The holes were elongated by the repetitive actuation of the pressure roller assembly against the capstan roller. Loctite grade D was applied to the shaft to prevent movement of the shaft within the fork. The application of Loctite also stops lateral shaft movement thereby preventing the shaft from damaging the pressure roller housing.

Many fans used to circulate air through 301 and 501 equipments fail because of bad motor bearings. If the fan could be removed before the motor windings overheat and subsequently burn, the bad bearings could be replaced. At the present time, the first indication of a bad fan is usually smoke or the odor of burnt enamel. When a motor is allowed to overheat to this extent, the windings are usually destroyed. EDPS Engineering is presently engaged in a program to find an economically feasible method to warn the operator that a fan is not performing properly long before it burns out. One method which was evaluated was fusing. This method was found to be impractical because the difference between full load current (0.75 amp) and the locked rotor current (0.85 amp) was too small. A 0.75-amp instrument fuse will pass 0.85 amp for two or more hours before it will blow. A fan motor winding will be completely burnt in this period of time. Another method which was evaluated was reduced air flow detection utilizing air flow switches. Air flow switches may be effectively used in laminar air flow not in turbulent air flow. The delivered air from the subject fans approaches laminar flow, but, there is not enough clearance available above the fans to mount the switch. Air motion on the intake side of the fan is very turbulent, therefore, the switch would not operate reliably. A third method is presently under investigation. This method employs a temperature sensitive switch fastened directly to the motor. It was proven by experimentation that the average motor case temperature of 85°F when running at full load is increased to 120°F in a 5 minute period when the rotor is locked. When an inexpensive reliable temperature sensitive switch is found, this method of fan motor and rack protection will be employed.

CONCLUSION

These problems and many others of a similar nature will continue to make the work of this mechanical engineer in the EDPS Engineering activity challenging though hectic. The wide array of problems encountered in a service organization require the full use of one's resources and promise many demanding but interesting experiences.

The David Sarnoff

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The 1964 Individual Awards for Science and Engineering

Dr. Alfred H. Sommer

Jack Breckman

. . . About the Awards

RCA's highest technical honors, the four annual David Sarnoff Outstanding Achievement Awards, have been announced by Dr. George H. Brown, Vice President, Research and Engineering. The 1964 Awards will be conferred on two individuals and two science and engineering teams for major contributions to the fields of color television, space technology, integrated circuitry, and electron tubes. David Sarnoff, RCA Board Chairman, and Dr. Elmer W. Engstrom, RCA President, will present the awards which consist of a gold medal, a bronze replica citation, and a cash prize for each.

The Awards for individual accomplishment in science and in engineering were established in 1956 to commemorate the fiftieth anniversary in radio, television, and electronics of David Sarnoff, RCA Board Chairman. The two awards for team performance were initiated in 1961. All engineering activities of RCA divisions and subsidiary companies are eligible for the Engineering Awards; the Chief Engineers in each location present nominations annually. Members of both the RCA engineering and research staffs are eligible for the Science Awards. Final selections are made by a committee of RCA executives, of which the Vice President, Research and Engineering, serves as Chairman.

Dr. Alfred H. Sommer, RCA Laboratories, Princeton, N. J., recipient of the 1964 David Sarnoff Outstanding Achievement Award in Science . . . *"for meritorious contributions in the field of electron-emission phenomena leading to new emitter materials for electron tubes."*

Dr. Sommer, winner of the Individual Award in Science, has gained world-wide recognition in the field of photoemission for his contributions not only to the practical development of photocathodes, but also to the theoretical semiconductor physics of these emitters. He has been on the technical staff of the RCA Laboratories since 1953 and is probably unique in being the only scientist to have discovered *three* entirely different photocathodes, materials that produce electric current when exposed to visible light. Two of his cathodes widely used in RCA light-sensitive products are the S10, a bismuth-silver-cesium photocathode, and the S20, a multialkali photocathode. The S10 is used in all commercial image orthicons, and the S20, the most sensitive photoemitter known, is used in special photomultipliers, image intensifiers, and super-sensitive camera tubes. Dr. Sommer's work has led to a great increase in our theoretical and practical understanding of photoemission. His more recent work on solar-blind, ultraviolet-sensitive cathodes for space applications has also been of significance. In 1963 he developed a new cathode which is of considerable value in nuclear detection devices (scintillation counters). It is a potassium-cesium-antimonide semiconductor with high sensitivity to blue light and low thermionic emission.

Mr. Jack Breckman, Systems Engineering Evaluation and Research (SEER), Defense Engineering, RCA Defense Electronic Products, Moorestown, N. J., recipient of the 1964 David Sarnoff Outstanding Achievement Award in Engineering . . . *"for far-reaching contributions to space technology by means of the Breckman Projection and the comprehensive simulation of the earth-space environment."*

Mr. Breckman, recipient of the individual engineering award, has demonstrated unusual competence and creativity in conceiving and developing original approaches to critical data analysis problems in space technology. Shortly after joining the Radio Corporation of America in 1954, he designed in detail all the logical circuitry for the central control equipment, and supervised its construction, for the BIZMAC computer installation at the Army Ordnance depot in Detroit. More recently, he has formulated and written the entire mathematics for the PAGE computer programs which can handle performance analysis of any ground-station network working in space surveillance, and for the complementary EAST program, which can generate moment-by-moment details of all passes of a possibly long-lived satellite over a network of 100 observing stations. Perhaps Mr. Breckman's most important achievement, however, is the Breckman Projection (also called B-Chart), which does for space and satellite problems what the Mercator Projection did for earth charting and ship navigation centuries ago. Just as the Mercator renders a ship's course as a straight line, so the Breckman Projection makes it possible to render a satellite track in a straight line. For the first time, it puts into the hands of the field operator a tool which makes manageable all the complex relations of celestial mechanics and earth geography.

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Joseph A. Briggs


Steven R. Hofstein


Thomas O. Stanley


Dr. J. Torkel Wallmark

MESSRS. BRIGGS, HEIMAN, HOFSTEIN and **STANLEY,** and **DR. WALLMARK,** winners of the Team Award in Science, are members of a group which originated and established the concept of integrated logic nets as a major innovation in silicon-based integrated electronics. This concept has become a reality through the development of the MOS or metal-oxide semiconductor transistor, also an achievement by members of this group. In early 1961, this group undertook to fabricate "junctionless" silicon transistors by exploiting an effect that had been observed in diode structures—a nonlinear capacitance attributed to conductivity modulation in silicon. The same effect, they reasoned, should make possible an MOS transistor. Late in 1961 the first successful array of MOS transistors was made. Basic studies conducted by members of this group revealed much about the role of surface states in MOS devices and the electrical properties of silicon dioxide, leading to experimental MOS transistors with much greater speed, improved stability, and simpler production techniques. A concurrent program leading to several interconnection and insulation techniques was also carried out, with consultation on memory and logic applications within RCA Laboratories and on apparatus design with systems groups in DEP and EDP. Although the long-term impact of integrated logic nets may prove to be greatest for data processing equipment, their present success is contributing significantly to RCA's stature in the field of military microelectronics.


n E. Hardy

MRS. PHYLLIS B. BRANIN, and **MESSRS. AUSTIN E. HARDY, A. M. MORRELL, THEODORE A. SAULNIER, TERRY M. SHRADER,** and **MORRIS R. WEINGARTEN,** Television Picture Tube Division, RCA Electronics Components and Devices, Lancaster, Pennsylvania, recipients of the 1964 David Sarnoff Outstanding Team Award in Engineering . . . *"for team performance in making many important contributions to the development of the shadow-mask design and screen application techniques which made possible the commercial success of the RCA color picture tube."*


re A. Saulnier


Terry M. Shrader


Morris R. Weingarten

MRS. BRANIN, and **MESSRS. HARDY, MORRELL, SAULNIER, SHRADER,** and **WEINGARTEN,** winners of the Team Award in Engineering, have individually and collectively contributed numerous technical innovations to the evolution of color television tube manufacturing and to the development of the highly successful RCA shadow-mask picture tube. One of their noteworthy accomplishments has been an unique method for reconstituting the phosphor slurry necessary to the development of a practical process for applying an all-sulfide screen. Wide public acceptance of color TV is due in major part to performance features provided by this all-sulfide screen. This group also developed a highly successful filming method for color picture tubes and an automatic color screening machine, both of which proved to be important in reducing costs as well as eliminating hazards to operators and overcoming critical control problems. Another vital contribution made by members of this group was a method for accurate removal and replacement of the shadow-mask-frame assembly, a major difficulty in mass-producing high-volume, high-quality, low-cost color tubes. Through these, and other innovations too numerous to mention, this group has not only contributed significantly to RCA's present leadership in color television, but has also provided a basis for continuation of this leadership.

The introduction of the air-bearing panel for use with RCA TV tape recorders was a major step in improving the performance of this equipment. Advantages made possible by floating the motor shaft on a film of air are freedom from vibration, uniformity of rotational velocity, and greatly extended bearing life.

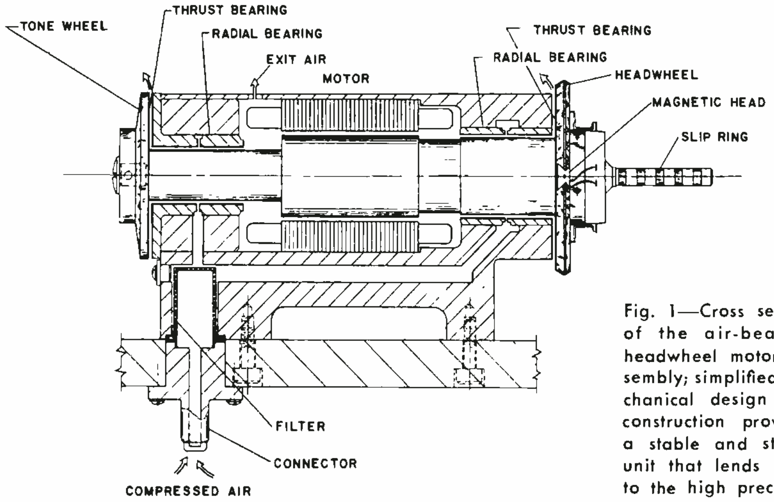


Fig. 1—Cross section of the air-bearing headwheel motor assembly; simplified mechanical design and construction provides a stable and sturdy unit that lends itself to the high precision required.

AIR-BEARING DESIGN FOR IMPROVED VIDEO TAPE RECORDING

F. M. JOHNSON

Audio, Projector, Magnetic Head,
and Scientific Equipment Engineering
Broadcast and Communications
Products Division
Camden, N. J.

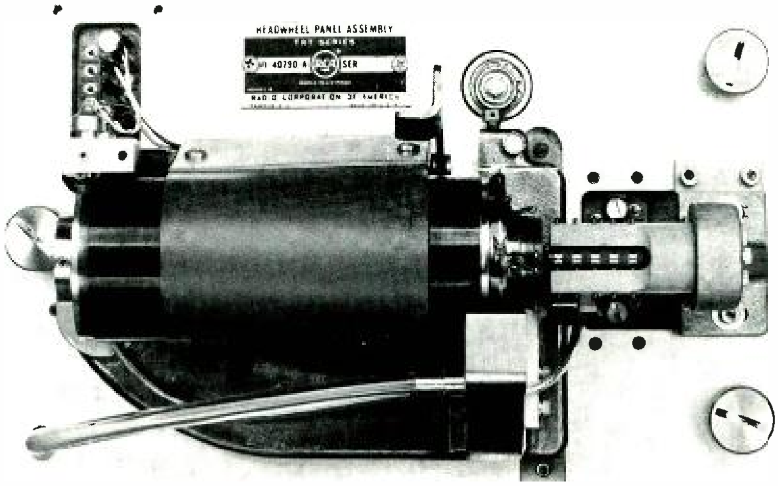


Fig. 2—The completed air-bearing headwheel motor assembly as it appears ready for installation in the RCA video tape recorder deck.

Applied Research, DEP. Camden, built the first air-bearing video panel for broadcasting and demonstrated its performance possibilities. The job of designing an economically producible, commercially reliable unit was then performed by Broadcast Engineering. The first three units were designed as "add-ons" to existing motor housings; to do this, one air bearing was fitted to each ball-bearing seat and a special shaft with headwheel was installed.

Subsequent production units were built without this conversion feature for simplicity and economy (Figs. 1 and 2). In the new production model, the housing was bored to hold the motor stator, and an air bearing was shrink-fitted into each end; air ducting was formed by grooves and drilled holes. The shaft was fitted with the motor rotor, headwheel, and tonewheel to complete a sturdy, simplified assembly.

A PRECISE MECHANICAL DESIGN

The rotating shaft is the key part of the air-bearing assembly. It is made of nitride-hardened nitraloy steel for gall resistance and stability of dimension; its hardness is Rockwell 15N-90 and it is finished to a *micro-four* surface, similar to the hardness and smoothness of a razor blade, two journal surfaces and the two pilot diameters (for tonewheel and for headwheel centering) are concentric within 0.00005 inch; the diameter tolerance of the journals is 0.0001 inch. Even the shoulder dimensions at each end of the shaft must be precise; such dimensions locate the tonewheel and headwheel so that thrust journal surfaces are formed square to the radial journal sur-

TABLE I—Glossary of Terms

bearing: the part in which a shaft rotates and is supported.

journal: the shaft surface that is supported by the bearing.

air bearing: a bearing and its journal which uses air as a lubricant in lieu of oil, commonly used.

hydrodynamic bearing: a bearing designed to float its journal on a film of lubricant (gas or other fluid) by the motion of the journal itself; no other pressure source is present.

hydrostatic bearing: a bearing designed to float its journal on a film of lubricant whether the journal is still or moving; a pump or pressure source for the lubricant (gas or other fluid) is required.

whirl: an instability characterized by rotation of the axis of the shaft as it rotates; usually occurs at some fraction of the journal speed (half-speed whirl, etc.). Lightly-loaded and large-clearance bearings are more prone to this.

pad bearing: the bearing may be broken into sectors, each having its pressure supply and exhaust grooves or each may be pivoted to act individually, as in a *Kingsbury* thrust bearing; the journal need not be completely surrounded with a multiplicity of pads.

pool bearing: a hydrostatic bearing having a recess about each inlet orifice; the area and depth of each pool is suited to the job. Characteristically, a higher load, higher cost and less stable design.

headwheel: a disc with holding surfaces to which the magnetic heads are attached for the transverse recording of signals on magnetic tape.

tonewheel: a disc of soft permeable material having a notch in its rim; it operates with the magnetic head to produce a signal (once each revolution) for servo or timing purposes.

gall: a transfer of metal from one surface to another as the two surfaces rub together. Galling is characterized by a roughening of the surface, powdering of the metal, and in tight-fitting bearings by a cessation of rotation.

faces; tolerances are held within 0.0001 inch-TIR (*t*otal *i*ndicated *r*eading, dial indicator) at the outer wheel diameter.

When these tolerances are met and the stator bearings are within specifications, the shaft may be operated safely after a complete pressured-air failure from 14,400 rpm to standstill; such operation may be repeated many times without serious galling and the air bearing still remains capable of excellent broadcast performance when air pressure is returned. However, constant rubbing together of the shaft and bearings during air failures results in galling; this proved to be the first obstacle to reliability that the air-bearing design had to overcome.

The housing, motor, two radial bearings with thrust surfaces, and the required air ducts comprise an assembly of many parts; the combination must be nearly as precise in dimension as the shaft itself. The necessity for such precision arises from the use of an air-film thickness of 0.0007 inch. For such an unusually thin air film to act properly, bearing surfaces must be round and coaxially in alignment with one another; alignment tolerances are held within 0.0001 inch.

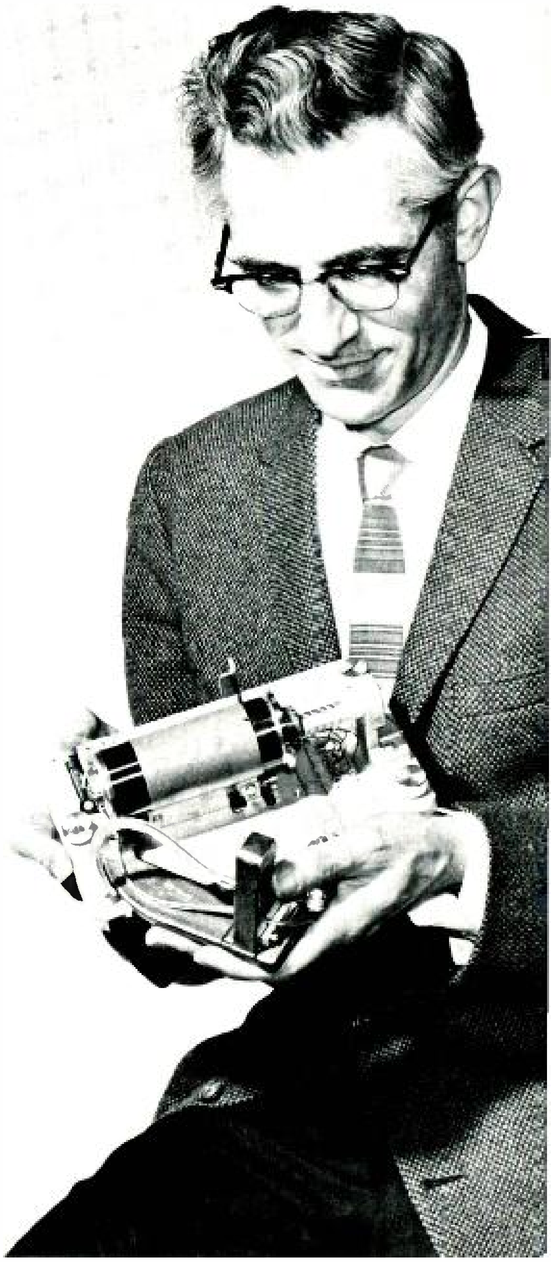
THE AIR-BEARING ASSEMBLY

Both radial-bearing shells are of nitrided steel; at each bearing shell midlength, six 0.015-inch diameter orifices are drilled radially and spaced equally about the diameter. Each radial-bearing shell is force-fitted to an aluminum mount, grooved to form appropriate air ducting. Air under pressure is fed to the six radial orifices by way of an annular duct, connecting ducts, and a connector nipple to mate with the air-supply connector on the tape transport. This connector is located as near as possible to a panel clamping screw to reduce the panel deformation which might arise from air pressure and from the force of the connector shut-off valve actuating spring. An air filter catches any particles greater than 10 microns in size which might get into the ducts during shipment or handling.

AIR-BEARING FLOTATION

The air-bearing assembly requires an airflow of 0.5 cfm at a pressure of 40 psi. Air enters each radial bearing through the six throttling orifices so that the shaft is held equidistant from each orifice by the pressure of the air. If the shaft is pushed toward one side, the bearing clearance is reduced; to correct this, the exit (flow) of air from the bearing in this area is then automatically reduced, resulting in an increase of the air pressure in this bearing area. Meanwhile, on the opposite side of the shaft, the reverse situation has occurred; an increased clearance and a greater exit of air produces a low-pressure area. This pressure differential creates a force opposing the shaft movement whether the shaft is stationary or rotating.

The thrust bearings are lubricated by the exhaust air from one-half of each of the radial bearings; originally, mechani-



F. M. JOHNSON received his BSME degree from Pennsylvania State College in 1938. He was employed until 1948 by the Universal Camera Corporation in the design of cameras, projectors and lens-building machines for binocular optics. From 1948 to 1950, Mr. Johnson did engineering design of automotive replacement switches at the Ideal Corporation, Brooklyn, N.Y. At the International Resistance Corporation he was engaged in the design of deposited carbon resistors, and machines and tools for metal-film resistor production until 1957. During that year he joined RCA in the Airborne Fire Control section from which he transferred late in 1957 to the Magnetic Head Engineering group. Here he participated in the design and development of the headwheel panel for the TV tape recorder and is presently assisting in the production engineering phase of the same unit.

cal design incorporated separate ducts and orifices centered about the thrust bearings; but, tests indicated that equal performance was obtained without these orifices. An additional load requirement of the thrust bearing results from the long "coast-down" time (after the headwheel is turned off) which is much too long for studio timing; the tonewheel serves as a very convenient braking surface; operators simply stop the shaft by finger pressure. When the thrust bearing cannot support this finger pressure, a metal-to-metal contact occurs and galling of the thrust bearings results eventually.

ECONOMY AND STABILITY

As designed and constructed, this precision motor is economical when compared with a commercial grinding spindle of equal precision; such a spindle would cost about $750. Cost of the air-bearing panel is substantially less and provides a precise rotating mount for the magnetic heads; speed of rotation is 14,400 rpm. The 2-inch-wide magnetic tape moves in a direction parallel to the rotation axis of the headwheel; the tape is held widthwise in an arc that makes precise contact with the rotating heads. Each head traverses parallel-pitched paths, sequentially from edge-to-edge of the tape. This arrangement allows high head-to-tape speed while maintaining low tape speed and good tape handling. Any variations in the velocity of the heads cause signal errors, just as tape-speed variations do in the conventional tape recorders. Thus, headwheel bearing vibrations convert to high-frequency signal flutter; bearing drag variations become low-frequency signal flutter.

The absence of such vibrations in the air-bearing panel can be attributed directly to air flotation; there is no metal-to-metal contact. The bearing air-film and the motor's magnetic field are the only connecting media between the housing and the shaft. However, the motor's magnetic field alternates with the driving voltage and causes the motor rotor to vibrate as it rotates; the effect of this vibration on the tape heads may be reduced by lessening bearing drag, reducing the strength of field required, and by selecting a "safe" electrical frequency.

It is possible for the bearing air-film to become turbulent and cause a "whirl" (half-speed gyration of the shaft as it rotates); this is uncommon below 50,000 rpm and may be controlled in design. Another effect which may be transmitted to the tape heads, is the motion of the shaft due to dynamic unbalance; this is corrected by balance weights comprised of four radially-threaded set screws arranged in quadrature on both the headwheel and the tonewheel. Using sensitive balance indicators as a guide, these screws are adjusted to provide a near-perfect balance; since there is no distributing vibration from the bearing, this is done easily and precisely.

LONG BEARING LIFE

Long bearing life also results from this air film; with no metal contact, there is no wearing surface. So long as clean, dry air is supplied, the bearing will continue to operate, as new. An interruption in bearing life may be caused by dirt accumulation on the bearing surfaces; however, dirt may be washed away easily by an injection of cleaning fluid into the air ducts. Rusting of the shaft and orifices by the water in the air supply may be expected when high-humidity air is compressed. The rust problem presented a serious obstacle to long bearing life; oily rust inhibitors were found to coagulate dust particles small enough to pass the fine filters; eventually, such an accumulation of mud would jam the shaft. This condition, of course, could be corrected easily by a cleaning fluid wash as mentioned above; but, the oil protection against rust would be also washed away. Vapor Phase Inhibitor was tried, but it evaporated while the units were in the warehouse. Finally, it was observed that rusting became a problem only at the highest humidity condition; thus, the air from the compressor was stabilized in a tank to allow supersaturated moisture to separate and collect in the tank. The saturated air then enters a regulator where it is allowed to expand to five pounds less pressure. Such an isothermal expansion provides air having a relative humidity of approximately 93%—and dry enough to avoid rusting of the bearing parts and of the motor laminations. A mysterious jamming of the shafts occurred when the saturated air regulator was adjusted for less pressure drop. After jamming occurred due to coagulated dirt particles, the panel would be removed and set aside where the water would evaporate; when tried again, the panel would work well until water and dust again would jam the shaft.

UNIFORM SPEED

Uniformity of rotational velocity is another important feature of the air bearing. There is nothing present to give velocity variations other than air turbulence. This may be illustrated by applying air to a panel with the slip-ring brushes removed and the motor degaussed to remove static magnetic fields; turn the shaft slowly and it continues to turn for many minutes. The air bearing has demonstrated its superiority in use with Pixlock operation (an advanced servo system synchronizes the output picture signal from the headwheel with the local sync generator by comparing horizontal sync pulses). Consistent lock-in and greater stability in operation are advantages of this air-bearing panel and can be readily displayed with this equipment.

HYDROSTATIC AND HYDRODYNAMIC AIR BEARINGS

The type of air bearing just described may be classified as *hydrostatic;* the shaft floats while the bearing is at rest, and the bearing must be supplied with compressed air. The other major type of air bearing is the *hydrodynamic*, which floats the shaft only when it is rotating fast enough to wipe a film of air into the bearing by its own motion. Variations are made by using these combinations: 1) a hydrodynamic bearing with a pressured air supply or a fluid (alcohol, etc.) applied during *start* and *stop* only; 2) a small-pad hydrostatic bearing mounted adjacent to the hydrodynamic bearing for *start* use, or for continuous use, when the attitude of the bearing is constant; and 3) ball bearings mounted on each side of a hydrodynamic bearing pair allowing it to acquire speed until the ball bearings are lifted from their outer seats; in this case, the bearings freewheel until the shaft slows down.

All such design variations require the higher precision of the hydrodynamic bearing, which has one-third of the clearance provided by the more desirable hydrostatic design—and require at least twice the area to support the same load. By far the most reliable and least expensive bearing to design and build, because of the wider tolerances permitted, the hydrostatic self-compensated type is used in the air-bearing headwheel panel.

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SEPARABLE MULTI-CONTACT CONNECTORS FOR HIGH-SPEED COMPUTER CIRCUITS

Periodically, in the normal improvement of any technology, particular problems arise which require solutions utilizing novel and at times not completely orthodox techniques. Such a problem instigated the development described by this paper —a development which ultimately produced a separable multi-contact connector suitable for use with miniature coaxial cable in ultra-high-speed computer circuits.

M. E. ECKER, H. R. KAUPP, and D. P. SCHNORR
*Computer Advanced Development**
Electronic Data Processing
Camden 2, New Jersey

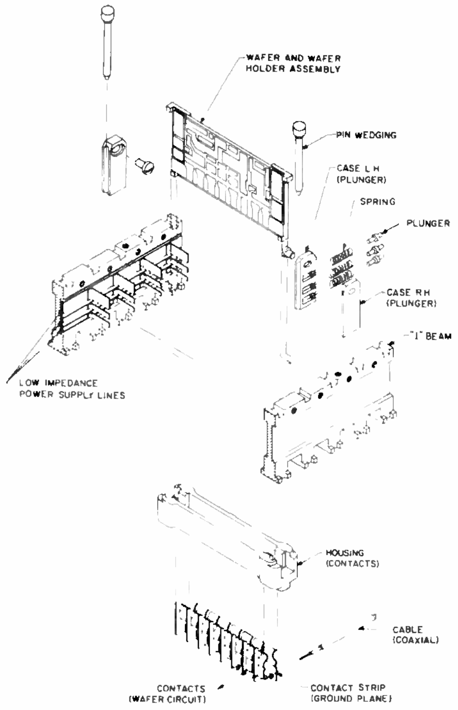

Fig. 2—Exploded view of wafer connector.

Recognizing the need for an extension of the computer state-of-the-art to include high-speed digital equipment, the Government began a program several years ago to develop nanosecond computer techniques and circuitry. RCA was one of the companies selected to participate in this activity. The project goal was 3 to 4 logic levels per nanosecond (nsec), 10 nsec per memory *read-regenerate* cycle, and a shift rate of about 6 to 8 bits per memory cycle. At these speeds problems occur in packaging density, crosstalk, and wiring delays. At the expected rate of propagation, an interconnecting transmission line, 1½ inches in length corresponds to a delay of one logic level. The crosstalk tendency in high-speed computers necessitates the use of a well shielded transmission media. The problem, therefore, resolves itself into one of techniques aimed towards dense packaging[2] and the use of coaxial cable as well as associated connectors.

DISCUSSION

Signal transmission, at gigacycle computing rates, introduces a number of new problems in packaging; in addition, the extremely low voltages and delay minimization demanded for proper operation of the tunnel-diode computer circuits led to careful consideration of the following design criteria:

1) Use of transmission line is necessary; line lengths must be kept as short as possible because of propagation delay.
2) Since point-to-point cabling is desirable to minimize delays, it is imperative that coaxial cable be used for this application. This is the best connection method permitting wiring crossover without the danger of crosstalk at high frequencies.
3) Serious discontinuities in the transmission system will cause reflections which can have an undesirable affect on the operation of the circuits.
4) In a feasibility study machine, the basic logic gate circuit should be a plug-in, since circuit components must be readily available for testing and/or replacement.
5) Due to noise sensitivity of the high-speed circuits, filtered low impedance power supply distribution lines are required.
6) Any connection method used should be open enough to provide ample room for air passage between the circuits; dissipation of heat is essential to proper operation of this equipment.

After examination of many alternatives, a test unit was constructed. This structure, as illustrated in Fig. 1, contains 34 logic gates disposed in three columns, with the logic gate wafers spaced 0.350 inch apart. The basic wafer is 0.7 inch by 1.5 inches, and is composed of a 0.040-inch-thick brass ground plane, with a 0.030-inch-thick glass-filled teflon circuit board. The circuit board is notched along both sides to accept power supply filtering elements, consisting of silvered segments of barium titanate. The signal input connection tabs are located along the bottom edge

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* Since this paper was written, the authors have transferred to Defense Electronic Products. The Computer Advanced Development group is now part of DEP Applied Research, Camden.

Fig. 1—Logic test unit.

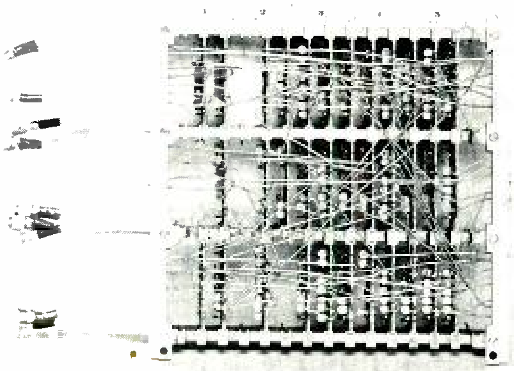
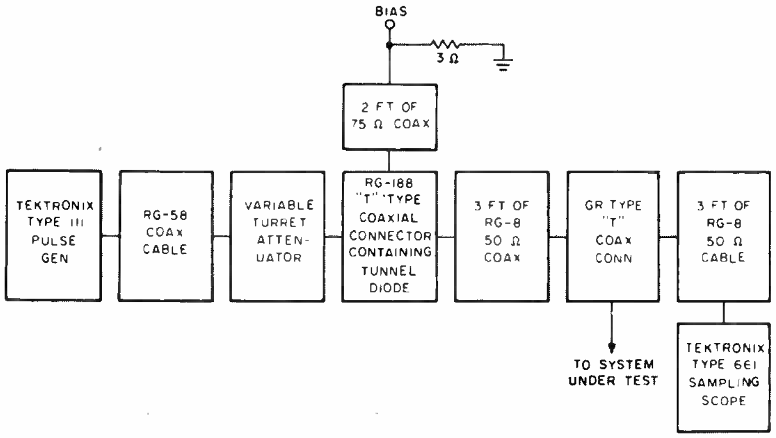


Fig. 3—Test setup for observing pulse response of coaxial connectors.



of the wafer. The wafer and wafer holder assembly fits between two *I* beams which, in addition to providing structural support, also serve as guides for the low-impedance power supply lines feeding the individual wafers. The low-impedance power supply lines were silvered strips of barium titanate 0.010 inch thick by 0.300 inch wide by 5.5 inches long. Miniature solid-jacketed coaxial cable was used extensively in making interwafer connections and a wide range of this type of transmission line was developed for the project; i.e., cables having an outside diameter of 0.039 inch and characteristic impedance of 4.5 to 100 ohms. The cables are connected to the wafers by soldering—the outer jacket was soldered to the wafer ground plane and the center conductor was soldered to appropriate pads on the wafer.

CONNECTOR DEVELOPMENT

Initial designs of the connector considered primarily a means of connecting to the signal tabs of the wafer, with the power connection as a secondary issue. The connector was originally visualized as a combination of individual contact pins, shielded from each other by a metal partition which would be part of the corresponding ground contacts. These ground contacts were to be connected together to make a common interconnected grounding shield. Due to the expedient nature of the project, it was decided to use the basic edge-board connector idea, with modifications to adapt such a device for use with coaxial cable together with a ground plane wafer.

The method of power distribution down the *I* beams presented some problems to the connector designer. The lines were constructed of silvered barium titanate strips which are very fragile; therefore, any connection scheme forcing connecting tabs onto wafer power tabs must use limited pressure. This pressure should be such that it will not crack the barium titanate, yet be sufficient to establish good electrical contact. The presence of hairline cracks in the 0.010-inch-thick barium titanate power lines could present the possibility of silver migration from both silvered surfaces and could result in a shorted line.

In order to prove out the design, the connector concept had to be modified to accept a wafer which was being used in a systems feasibility study machine. Since the *I* beam and wafer design was already finalized and oriented toward soldered connections, the connector philosophy had to be changed considerably. Fig. 2 shows an exploded view of the connection system for this type of wafer. With the slight modifications made, the base portion of the connector assembly was adapted to the subsystem frame structure. Power distribution was accomplished by means of a beam containing a number of small spring-loaded plungers, as shown on Fig. 2. The beam is mounted to the *I* beams so as to permit its displacement toward the circuit face of the wafer. A wedging pin is inserted between the grooved edge of the beam and the rear face of an adjacent wafer. The spring-loaded plungers are oriented in the beams so that they press the tabs of the low-impedance power supply against the pads on the wafer with sufficient force to insure good electrical contact.

MISMATCH—SIGNAL REFLECTIONS

Independent of mechanical design considerations and reliability, it is important to know how a connector behaves as a circuit element. An impedance mismatch in a transmission line system will cause part of a signal incident to the electrical discontinuity (which, in this case, is the connector) to be reflected back toward the source.

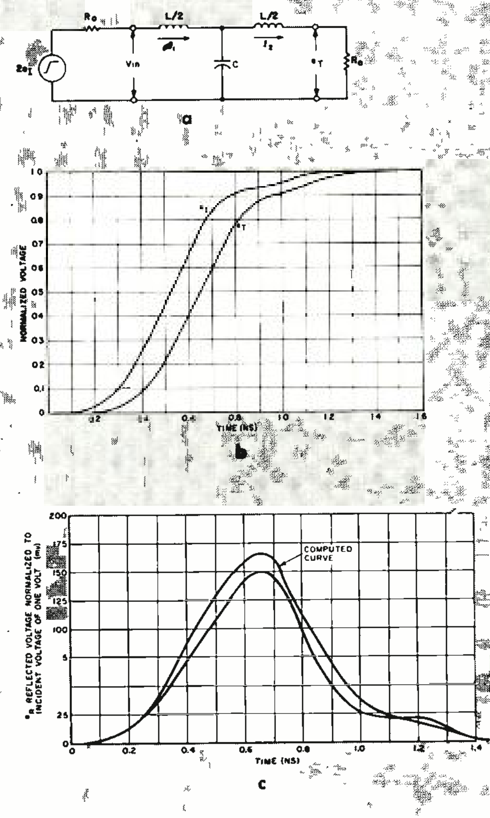
The test arrangement used to measure the connector reflections is shown in Fig. 3. Since the connector is used in conjunction with circuits having risetimes on the order of 0.2 nsec, it is desirable that the risetime of the pulse used to test the connector response be at least as fast. Two problems limit the accuracy of these measurements. First, the fastest pulses presently available are generated by tunnel diodes; but, since tunnel diodes are used in the logic system itself, the test system cannot use much faster pulses. Secondly, it is necessary to use miniature coaxial cable to separate and make distinguishable reflections in the system under test. Because the loss of these cables is on the order of 1 db per foot at 1 Gc, long cables will significantly distort the fast risetime pulses.

The heart of the test system is a very fast tunnel-diode pulser. The tunnel diode has no leads, and is held against the unbroken center conductor of an RG-188 coaxial *T* connector. The tunnel diode, which has a peak current of 50 mamp and a capacity of 5.7 pf, is used in a bistable mode and is biased close to the peak. The diode is triggered by an external pulse generator. Resetting of the diode is aided by the negative reflection caused by the termination of the 75-ohm coax in 3 ohms, as shown in Fig. 3. Thus, by locally generating the fast pulse, it is feasible to use a relatively slow pulse-generator and the long lengths of coax delay cables associated with the timing of sampling oscilloscopes. The risetime of the pulse generator, as seen on the oscilloscope using vertical amplifiers of 0.35 and 0.1 nsec, is 0.4 and 0.17 nsec, respectively.

Coaxial cable is used to terminate the wafer side of the connector, since it virtually eliminates stray parameters from the setup. To make this connection, a hole is drilled through the wafer at a signal tab. The coaxial cable center conductor is then passed through the hole and soldered onto the tab. The cable's outer conductor is soldered to the ground plane of the wafer. To observe the connector reflections, a 1-foot length of coaxial cable was used as a termination and another identical length was used on the conventional end of the connector. Thus, the discontinuity in the coaxial line is in the connector and its associated wafer tab. The wafer tab must be considered as part of the connector characteristic.

The extent of the discontinuity presented to the pulse by the connector is implicit in the reflection ratio. The reflection ratio here is defined as the ratio of the maximum voltage amplitude of the pulse reflected from the connector

Fig. 4—Plug-in connector circuit model and computer waveforms. a) equivalent circuit; b) incident and transmitted voltage waveforms for $R_o = 25$ ohms, $L = 5.5$ nh, $C = 1.8$ pf; c) comparison of computer and experimental reflected waveforms for $R_o = 25$ ohms, $L = 5.5$ nh, $C = 1.8$ pf.



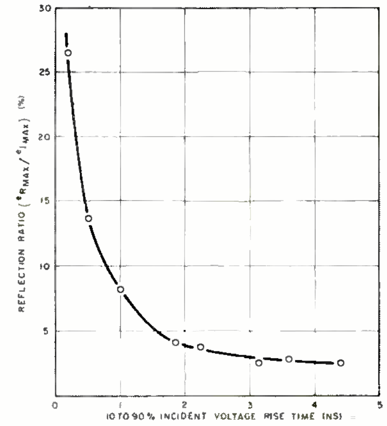


Fig. 5—Reflection ratio of plug-in comnnector as a function of incident voltage risetime with 25-ohm cable terminations.

to the steady state voltage level of the pulse incident to the connector. A negative sign in the reflection ratio indicates that the reflected and the incident pulses are of opposite polarity.

The incident voltage signal is observed on the scope as the voltage reflected from an open-circuited connector. Table 1 indicates some experimental voltage reflection ratios of the connector as used with coaxial cable having different characteristic impedances. For comparison purposes, the reflection ratio of an RG-188, 50-ohm coaxial cable-to-cable connector was observed to be 2.8%.

EQUIVALENT CIRCUIT

From a qualitative standpoint, it is convenient to think of the connector as a short piece of lossless transmission line. Consequently, since it is short, the connector can be adequately represented by a constant-K filter section,[1] as illustrated in Fig. 4a. Under matched conditions, the characteristic or image impedance and delay of this equivalent circuit are, approximately:

$$R_I = \sqrt{\frac{L}{C}} \qquad T = \sqrt{LC}$$

Where: R_o is the characteristic impedance of the cable, and R_I is the image impedance of the connector. Referring to Fig. 4a,

$$e_R = e_I - R_o i_I$$

$$e_T = i_2 R_o$$

TABLE 1—Reflection Ratio of Miniature Plug-in Wafer Connector for Various Characteristic Impedance Cables

Type of Cable	*Characteristic Impedance, ohms*	*Voltage Reflection Ratio, %*
Solid Copper Jacket (20-mil O.D.)	6.5	23.2
Solid Copper Jacket (35-mil O.D.)	25	9.1
Solid Copper Jacket (20-mil O.D.)	54	1.8
Microdot	75	—2.7

The terms e_I, e_T, and e_R are respectively, the incident, transmitted, and reflected voltages of the connector. The incident, as well as reflected waveforms for a cable characteristic impedance of 25 ohms, were observed on the oscilloscope and are shown in Fig. 4b. The reflected waveform was then computed, with the aid of an RCA 301 computer, using the observed incident voltage in numerical form. Values for R_I and T as indicated by experimental results were used. Computation runs were made, adjusting R_I and T, until the computed and experimental waveforms coincided, as shown in Fig. 4c. The parameters used to compute the waveforms in Fig. 4 yielded a matched image impedance of 55 ohms, and a delay of 0.1 ηsec. This checks closely with the measured delay of 0.11 nsec observed with the 54-ohm terminated connector. Also, the computed and measured connector delay both equal 0.13 nsec for the connector terminated in 25 ohms.

A plot of reflection ratio versus incident voltage risetime for the connector terminated in 25 ohms is shown in Fig. 5. This curve was obtained using the 0.1-nsec oscilloscope unit. For risetimes greater than 20 times the connector delay, the reflection ratio is less than 5%. However, for signals with risetimes on the order of 0.2 nsec, the reflection ratio is close to 25%. When the connector is used in conjunction with a circuit wafer, the connector reflection might be insignificant in comparison to the reflection caused by the nonlinear impedance of the switching circuit. However, if the connector is used to interconnect cables, a reflection of 25% could be significant.

It should be noted that the reflections shown in Fig. 5 were caused by a discontinuity less than 0.25 inch long. Making the ground path 1 inch longer than the signal path—even when using a 1.5-inch-wide copper bus—caused the reflections to *more than double* in amplitude.

CROSSTALK

Perhaps more important than signal reflections caused by the connector is the connector crosstalk problem; i.e., the signal induced in a cable, through its connector, by the signal passing through an adjacent connector. The setup used to observe the crosstalk between two adjacent connectors is shown schematically in Fig. 6a. This setup replaces the GR type T connector in the test system of Fig. 3. The voltage incident to point 1 of Fig. 6a, observed using the 0.35-nsec oscilloscope plug-in unit, is shown in Fig. 6b. The corresponding transmitted and cross-pulse waveforms, as defined in Fig. 6a, are shown in Fig. 7.

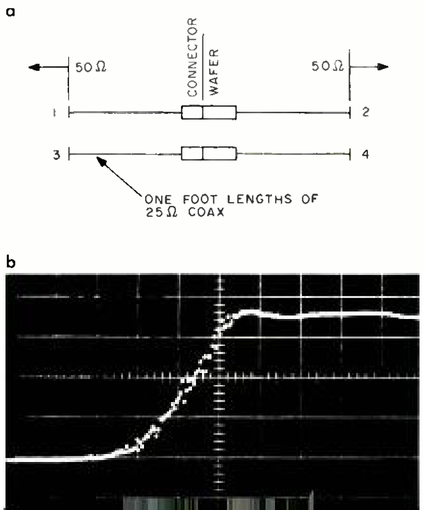
By referring to Fig. 7, it can be seen that the backward cross-pulse has the same polarity as the incident pulse while the forward cross-pulse is of opposite polarity. The difference between the incident and transmitted waveforms is primarily due to skin effect losses in the two feet of coaxial cable. It is not caused by the connector, as verified by the computation of the transmitted waveform illustrated in Fig. 4b. The cross-pulse ratio here is defined as the ratio of the steady state incident voltage level to the maximum value of the cross-pulse signals. Fig. 8 shows plots of this ratio versus the risetime for solid-jacketed coaxial cables having characteristic impedances of 25, 54, and 75 ohms. The data used to plot these curves were obtained using the 0.1-nsec oscilloscope plug-in unit, hence the curves are accurate down to 0.4-nsec input risetime. Below 0.4 nsec, the curves are optimistic because the narrow pulses are attenuated by the scope and the incident voltage level is not. When the cables were soldered directly to the wafers, the cross-pulses were approximately 15 db further down. Cross-pulses induced into one connector further removed are about 12 db further down than the adjacent cross-pulse.

CONTACT RESISTANCE

The pulse evaluation previously discussed indicates the response of the connector as a dynamic circuit element. However, it is also important to understand how the connectors will behave in typical circuit use, as well as what variations exist between individual connectors. The DC contact resistance, therefore, was used to index the dependability of the connector.

In the test setup used, the contact resistance of two connectors at a time was measured. The resistance measured is the contact point at the junction of the signal spring and the wafer pad. Contact resistance was measured as a function of current and was found to be quite uniform. It averaged about 4 milliohms for

Fig. 6—a) Method of observing cross-pulses (1, cident pulse; 2, transmitted pulse; 3, back cross-pulse; 4, forward cross-pulse) b) Output of tunnel-diode pulser.



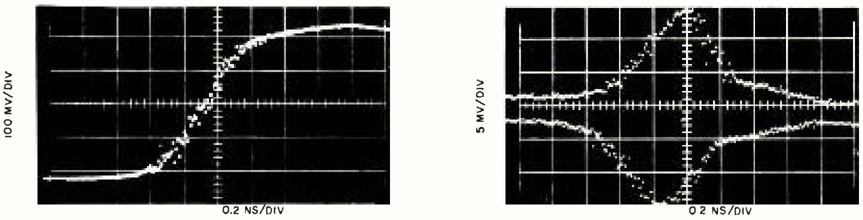


Fig. 7—Response of coaxial connector measuring setup to incident pulse (Z_0 = 25 ohms). a) transmitted pulse; b) cross-pulses at adjacent connector: upper trace, back cross pulse, ratio = 37; lower trace, forward cross-pulse, ratio = 35.

current over 5 mamp. The contact resistance was also observed as a function of the number of times a wafer is inserted into the connector bank. As expected. the contact resistance decreased with the number of insertions.

CONTINUOUS PERFORMANCE TESTS

Other tests were run to check contact resistance as a function of time. This was done to determine the effect of dirt or oxide film on the contact resistance. As in the insertion test. the current was maintained at 5 mamp. and the wafer tabs were milled flat. Wafers 0.080 inch thick were used. Of the connectors tested, half were continuously supplied with current, while the other half were supplied with current only during the resistance measurement.

Measurements continued on 32 connections for a period of 19 days. Each day the contact resistance had substantially increased. but. after applying pressure to the wafer, the resistance was decreased to about 10 milliohms. It is believed that the increase in resistance was caused by some imperceptible movement of the wafer in its connector due to handling of the connector supporting frame, or by slight vibrations caused by moving the frame on the lab bench. This motion or vibration could have permitted dust particles to work down between the contact surfaces or a shifting of the wafer might have resulted in the displacement of the contact onto an oxide film surface.

Next, test data were taken for wafers rigidly held in their connectors so that no movement of the signal spring on the wafer tab could occur. The procedure was identical to that of the previous test except that 64 connections, instead of 32. were used. This test was run over a period of one month. The contact resistance values stayed between 3 and 5 milliohms during this period.

Finally, a test was run that simulated actual subsystem conditions. A fan, forcing air in the direction of the connector. was used to cool the wafers. A total of 64 connections were tested. The other test conditions were as noted above.

At the end of the two-month test, all 64 connectors exhibited a contact resistance of 3 to 5 milliohms despite the fact that the connector bases were completely fouled with dirt from the cooling system.

Therefore, among the conclusions of the above tests are:

1) In this low-voltage application. it makes no difference whether the connectors are continuously supplied with current.
2) Circuit wafers should be tightly secured in the connector so that mechanical disturbances cannot cause the signal spring to move onto an oxide film that opens the circuit. If this is not practical. a contact protectant. such as "Cramolin," should be used.
3) In order to maintain flat wafer tabs of uniform thickness and omit oxide deposits. it was decided to put gold plating on future printed copper wafer tabs.

MODIFICATIONS OF ORIGINAL DESIGN

The development of improved logic circuits and a new power distribution concept necessitated further refinements in the original connection scheme. The new connectors were developed for a 40-gate subsystem. having logic circuits with reduced delays and power dissipation. increased repetition rate, increased fan-in and fan-out. and considerably smaller electrical components. These new logic circuits made it possible to utilize the 0.7-by-1.5-inch wafer size previously used but required additional signal connections on the base connector; i.e.. 12 instead of 8. Thus, closer spacing of connectors was required using contact centers of 0.100 inch instead of 0.150 in.

The new connector design incorporated:

1) A shorter electrical path.
2) A spring contact configuration designed to permit heat treatment.
3) Higher contact forces.
4) A 12-contact-pair connector per logic wafer unit.
5) A 20-db reduction in crosstalk due to better shielding.
6) Effective characteristic impedance of 40 ohms.
7) Overall reduction in physical size, thereby improving packaging density capability.

Figs. 9a and 9b illustrate the front and rear surfaces of the basic circuit wafer. The circuit wafer is comprised of three basic parts properly registered and bonded together. The first part carries the actual circuit; this is a 0.005-inch-thick cementable teflon substrate clad with 1 ounce of copper for printed wiring. This circuit element is bonded to the second part, which is a 0.015-inch-

MARIO E. ECKER received the BSME from Indiana Institute of Technology in 1956. He joined RCA in that year—and actively engaged in the design of 16mm motion picture projection equipment. He was responsible for the introduction of several new and improved projector equipments supplementing the product line and eventually became project engineer. He was assigned to the Airborne Systems Group where he provided design support on airborne equipment as well as ground support equipment. Since January of 1961, Mr. Ecker has been a member of the Computer Advanced Development Group conducting studies of packaging and interconnecting techniques for high-speed logic circuits with stage delays of tenths of a nanosecond.

HERBERT R. KAUPP was born on September 26, 1932 in Bristol, Pennsylvania. He received the BSEE from the Pennsylvania State University in 1959. He then joined the RCA Electronic Data Processing Division in Camden, New Jersey and, under the auspices of the RCA Graduate Study Program, received the MSEE from the University of Pennsylvania in 1961. Since joining RCA, he has done research on nanosecond circuit and interconnection techniques for digital computers. Some of this work is documented in a paper he co-authored which appears in the January, 1961, issue of the Proceedings of the IRE. At present, he is concerned with the development of tunnel diode-transistor hybrid circuits for nanosecond computers. Mr. Kaupp is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Tau.

DONALD P. SCHNORR graduated from Purdue University with a BSME in 1952. Employed upon graduation by Westinghouse Electric Corporation, he completed a study course at the Westinghouse Mechanical Design School, operated in conjunction with the University of Pittsburgh. After two years with the Westinghouse Steam Division in Philadelphia, he entered the Armed Forces and served from 1954 to 1956 in the United States Army Signal Corps. In 1956 he joined the Burroughs Corporation at the Paoli, Pennsylvania Research Laboratories where he engaged in packaging of military computers and mechanical design of servo mechanism systems. Joining RCA in 1960, Mr. Schnorr has been involved in development of computer peripheral equipment, and also design and development of packaging techniques for high-speed computer systems. Presently, he is with the Design Standards activity of DEP Central Engineering. He is a member of the American Society of Mechanical Engineers.

M. E. Ecker

H. R. Kaupp

D. P. Schnorr

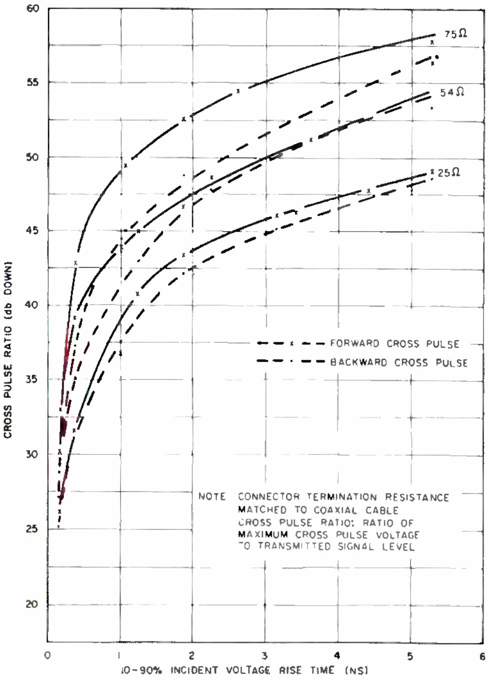


Fig. 8—Cross-pulse ratios of plug-in coax-wafer connector versus incident voltage rise-time for 25-, 54-, and 85-ohm coax.

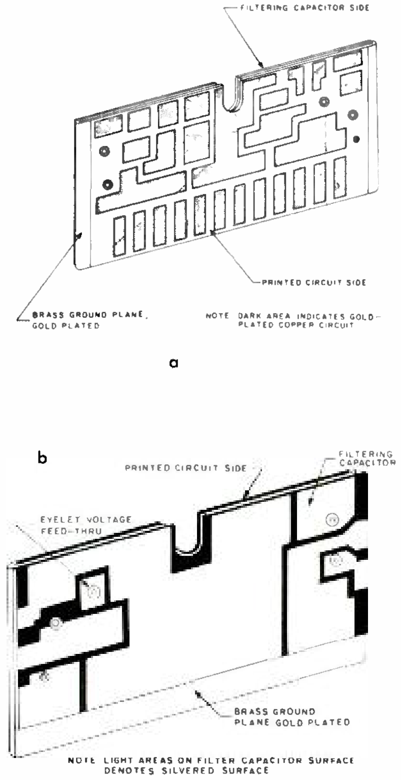


Fig. 9—Details of wafer for test subsystem; a) printed circuit side; b) filter capacitor side.

thick gold-plated brass ground plane, which also serves as a rigid support plate. The third part is composed of barium titanate, 0.010 inch thick, which is soldered onto the brass ground plane. This barium titanate element is completely silvered on one side and on the other side is silvered by a screened pattern as indicated in Fig. 9b. These silvered areas serve as filtering capacitors that absorbs transient switching signals, thereby reducing power supply noise. The circuit element is smaller than the ground plane to allow lands on both edges of the circuit side to be exposed for ground plane connection.

Because of the increased high-frequency filtering capability on the rear of the wafer, it was possible to relax requirements; i.e., the power distribution lines need only be comprised of double copper-clad teflon. These new considerations are illustrated in Fig. 10. The power-carrying *I* beam was fabricated from four sections of an acrylic thermoplastic material designed to have suitable apertures and channels to contain horizontal power distribution lines with attached contact springs when stacked together. The lower segment had a steel reinforcing member running its full length for structural support.

The lower section also contained removable inserts to permit the removal of several of the *I* beam power distribution individual base connector members after assembly and wiring operations had been performed. Repairability of the *I* beam was made possible by holding the entire assembly together with clips at each end and a leaf-spring across the top of the beam which was locked by the clips. Fig. 11 is a close-up view of a portion of the 40-gate subsystem showing the connector-wafer relationship. This subsystem was designed to accommodate 48 logic gates and measures 7.25 x 3.25 x 0.9 inches. It has been operated for over 1,000 hours without a contact failure. An oxide film problem occurred with the silvered surfaces of the filter capacitors on the back of the logic wafers. This problem will be solved in future wafer construction by glazing the contact surface with gold.

CONCLUSION

The feasibility of interconnecting high-speed circuits by means of a flat-spring connector with "coax-like" behavior was proven. The development and subsequent testing of at least two different connector types gave encouraging results, and at the present time, these connectors are in actual operation in the 40-gate subsystem mentioned.

ACKNOWLEDGMENT

The authors wish to express their appreciation to D. R. Crosby and S. T. Jolly for their guidance during this development.

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Fig. 10—Sectional view of subsystem frame assembly.

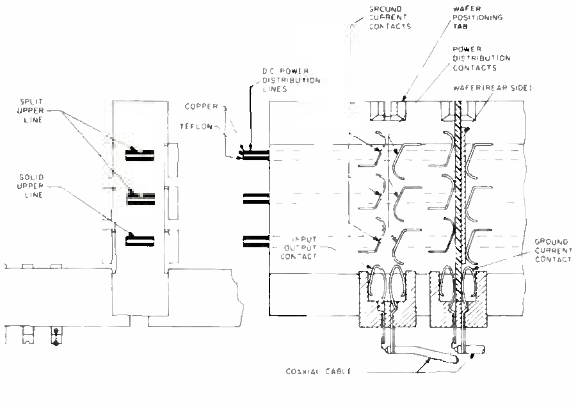
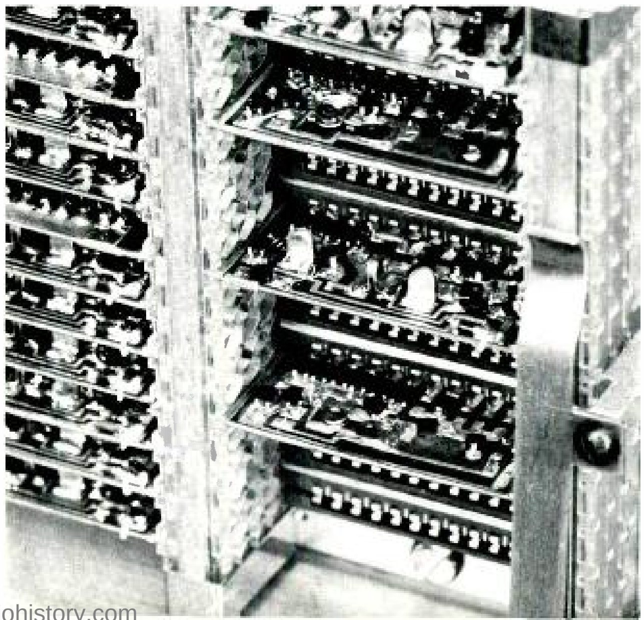


Fig. 11—Feasibility subsystem.



A COMPARISON STUDY OF ELECTRICAL CONNECTION TECHNIQUES

Electrical interconnections are an integral part of every electronic equipment. Yet, much confusion exists relative to their reliability and performance capabilities. This paper covers some of the important factors affecting the reliability of solder, welded, wrapped, crimped, screw-down and slip-fit (separable) methods of electrical connections. Individual contact forms are defined and common application problems discussed; specific interconnection forms are evaluated on a comparative basis in accordance with reliability, maintainability, producibility, ability to make engineering changes for prototype equipment, and cost objectives.

N. B. SHAIN and B. R. SCHWARTZ, Ldr.

Central Engineering

DEP, Camden, N.J.

Electrical interconnections are an integral part of most all electronic equipment; however, little specific reliability information is available. This is true for solder, welded or wrapped joints, mechanical terminations, and multi-pin connectors. This paper focuses attention on factors affecting the reliability of the various methods of making electrical interconnections.

GENERAL RELIABILITY CONSIDERATIONS

In discussing the subject from the reliability viewpoint, the following three basic considerations are important:

1) Electrical interconnections are the largest among the so-called "high population" parts groups. Therefore, by sheer force of numbers, they are potentially the greatest contributor to equipment unreliability.
2) The selection of optimum interconnection techniques is highly dependent upon design trade offs, involving packaging, production capabilities, cost objectives and maintenance philosophies.
3) The costs associated with providing interconnections represent one-third to one-half of total equipment cost.

As an example, the number of interconnection requirements for a large military digital communication system were:

mechanical dip solder joints	2,300,000
hand solder joints	125,000
wire wrap connections	1,750,000
crimp terminations	175,000
crimp-on, snap-in pin and socket contacts	150,000

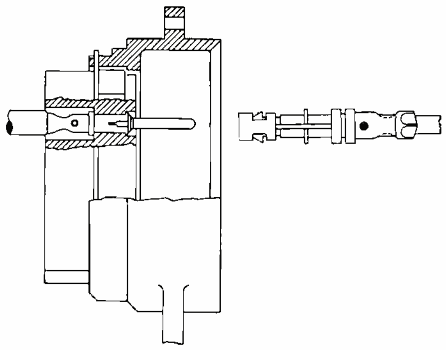
This total of 4,500,000 connections is responsible for approximately 35% of the allocated failure rate in the reliability model calculations. The interconnection selection process was based on the end-product reliability considerations primarily; but, attention was also given to maintainability, ability to test, producibility, and "value" criteria.

BACKGROUND

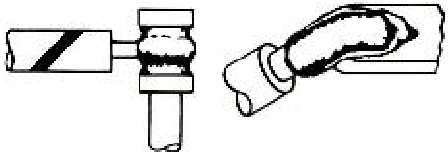
An understanding of the interconnection problem is gained by reviewing past experiences in constructing electronic equipment. Prior to World War II, the separable connector was rarely used in the design and fabrication of electronic subassemblies. Chassis were soldered using hand-wiring techniques and screw-type or soldered terminal boards were the prime methods for connecting subassemblies. The power input plug was the only removable connector device required.

World War II created a new environment where emphasis was placed on ease of maintenance for quick replacement of equipment in the field. Modules

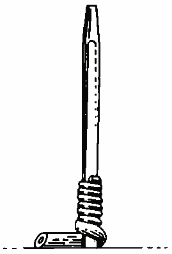
Fig. 1—Six interconnection methods.



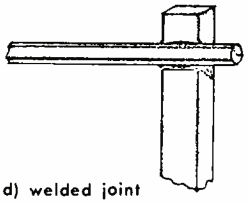
a) pin and socket connector



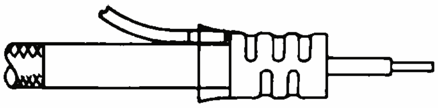
b) solder joint



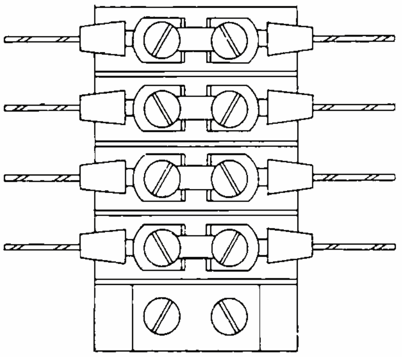
c) wire wrap joint



d) welded joint



e) crimp connection



f) screw-type terminal board

TABLE I—Comparison of Six Types of Interconnections

1) CRIMP TERMINATIONS

(As used in taper pins, terminals and crimp type, snap-in contacts in multi-pin connectors).

(a) Assets:

1. Good process reproducibility due to the development of a fully repeatable single-cycle tool which limits the human factors to the predress of the wire and terminal. Hand squeeze tools are available for field or factory use; semi-automatic tools are available for production only.
2. A well-developed tool history with data to substantiate the connection performance.
3. The electrical connection is made through direct contact with base metal caused by surface distortion at the material's combined interface.
4. A tight joint provides good shelf-life characteristics as well as environmental protection.
5. Crimping allows stranded wire to be used for high shock and vibration applications.

(b) Liabilities:

1. Mechanical disturbance of the wire affects its ability to withstand tension and flexing abuse.
2. The degree of effective joint tightness is unknown after crimping. Sufficient disturbances to plated surfaces within the crimp barrel may expose base metal to contamination. (This problem is predominately one of appearance rather than technical.)
3. The requirement for special tools in the field provides lesser repair flexibility.
4. Reuse of crimp junctions impractical, if not impossible.
5. The layout of crimp-fabricated assemblies must permit considerable clearance to facilitate the manipulation of the crimp tool. Easy access to the area to be crimped is necessary so that other adjacent terminations and insulated runs of wire are not scored or destroyed.
6. Note that the type of tool motion in the crimping operation requires considerably more service loop than the wire wrap tool.

2) SOLDER TERMINATIONS

(a) Assets:

1. Considerable data and history in the application of the technique (50 years).
2. Use of a generally available tool known and used by a wide variety of service personnel.
3. A well-protected junction area, free of exposure type contamination. (This process basically tin-lead plates the electrical junction area.)
4. A rigid junction is provided by the addition of a third material, the tin-lead solder. Solder provides a bridging between the two conductors being joined together.
5. A high degree of automation of assembly is possible in printed circuit boards which lend themselves to dip soldering.

(b) Liabilities:

1. Poor electrical joint inspection capabilities.
2. Human variables exists with each operation involved (pre-cleaning, fluxing, soldering, post-cleaning).
3. Variable contamination conditions due to the shifting of work from one bench to another; this reflects not only human differences but also variables of solder and soldering iron tips.
4. Corrosion of junctions and surrounding material possible due to the use of fluxing and precleaning solutions.
5. Poor mechanical environmental protection for wire termination at the sharp transition from the flexible state into a high-mass cross-section where the wire enters into the connection. This mass may contribute to flexing damage. Further, solder is inherently weak in withstanding ordinary mechanical stresses resulting from handling.
6. The application of heat causes damage to the wires being terminated as well as to adjacent parts and materials.
7. The use of materials which liquefy during processing allows droplets of solder to be separated and dropped within the work cavity area, thus endangering other parts or operating personnel.
8. In critical high-heat applications, solder softening can occur due to insufficient system cooling. Solder is prone to this condition because of its use of low-melting-temperature materials.

3) SCREW TERMINALS

(a) Assets:

1. The operator must be visually aware of junction condition while making the connection. There is a considerable amount of visual and manual agility associated with this operation which forces the inspection of the termination and its detailed parts.
2. Screw terminals offer optimum field service capabilities due to the general availability of screw drivers.
3. Screw terminals permit instant reuse of the parts involved without the loss of lead length. If the screw is captivated at the end of travel, even the danger of a lost screw is minimized. Circuit modifications and in-line circuit revisions can be made immediately due to the extreme flexibility of screw-type terminations.
4. Screw terminals may be staked in an infinite number of positions compared to other multiple-junction techniques.
5. Considerable data and varied experience were accumulated during World War II manufacturing era on this type of termination, all of which reflected the excellent reliability of this technique's performance.
6. Mechanical (impact) screw drivers are available for limited semi-automatic factory applications.

(b) Liabilities:

1. The lock position of the screw is under the sole control of the operator of the screw driver and his opinion of sufficient torque.
2. If an additional component is added such as a lock washer to prevent installation back-off, there is always a possibility of sacrificing contact pressure; lock-washer interference often gives a false sense of security of the contact function. Also, high-torque security pressure normally results in plating degradation which is a function of contact friction and the surface irregularities of the lock washer. This condition exposes base metal to corrosion both on the shelf and in the field. Without careful material selection, this condition can result in a noisy junction because of dissimilar metals problems. Appearance difficulties occur due to the same reason.
3. Most screw terminals are applied to areas which have been terminated with ring, fork, or spade-type terminals. Inasmuch as these terminals must be crimped and/or soldered to the wire prior to final screw termination, the number of terminations is increased over that associated with solder or wire wrap configurations.
4. The use of ring or closed-type terminals requires the screw to be removable rather than captivated. This requirement can result in the screw and its associated hardware being dropped within equipment areas where future circuit malfunction could occur.
5. The operator is performing tedious operations in trying to start the threaded screw in the terminal. This procedure, coupled with time-load pressures, can cause cross-threaded terminations and future circuit difficulties to occur.
6. In order to have a reliable termination, there is a limit to the effective screw size and head tip configuration. This factor, coupled to the minimum terminal creepage path condition, forces the space requirement to be higher than that associated with crimped connections and/or wire wrap terminal configurations, thereby creating a density problem.

4) WIRE WRAPPING TECHNIQUE

(a) Assets:

1. Very limited inputs due to human factors, especially if the automated wire wrap concept is used.
2. Spending and time-rate planning is highly controllable due to the full use of semi-automatic and fully automatic tools.
3. No unauthorized material is added to the junction area for cleaning or adherence purposes.
4. The resulting gas-tight junction provides long shelf life and field operational characteristics.
5. Electrical contacts are made without interim plating of the interface. Base material makes direct contact due to the elongation and corner-piercing characteristics of this type of joint. The finished product is professional in appearance with a uniform configuration highly standardized by the installation tool process.
6. Field maintenance has fewer human factors because tools fully control the operation. Further, the finished junction is capable of being soldered if the requirement occurs.
7. The speed and reproducibility of automated wire wrap reduces manual factory production operations to an absolute minimum. Self-maintenance is still possible since the terminals themselves are capable of rewrap. (This is the only connection process which offers any degree of factory automation for back-plane and internal drawer wiring.)
8. The number and quality of safety factors associated with the technique compensates for a high degree of unknowns in the process.
9. Correctly done, wire wrap will meet all ground, shipboard, and airborne equipment requirements for shock and vibration.
10. Wire wrap possesses tremendous operator appeal; the hand-type wire-wrap gun is preferred over a similar soldering iron or crimp tool.
11. A wire-wrap layout has the capability of making three or more connections on a single terminal.

(b) Liabilities:

1. This technique requires the use of solid wire which, in itself, has environmental limitations.
2. In very-high-frequency applications the maze and configuration of the connection must be taken into consideration. This is primarily a problem where distributed capacitance and inductance become design obstacles. Tests indicate that the problem area occurs above 100 megacycles.
3. Constant monitoring of tool performance is necessary to maintain connection reliability.
4. The present technique for testing a good wire-wrap joint is the unwrap and pull test, which establishes the minimum and maximum limitations for a good connection. These destructive tests obviously must be performed on a test connection basis and can not be applied on a live connection.
5. Termination reuseability is limited; the wire end can not be reused: the terminal can be re-wrapped up to 25 times.

5) SEPARABLE CONNECTORS

(a) Assets:

1. Removable-type connectors facilitate the assembly of individual components or subassemblies into electrical and electronic equipment and enable fast maintenance replacement of faulty units.
2. Connectors offer basic ease of interchangeability of sub-assemblies within equipment.
3. The use of a connector provides the basis for testing of complete units (debugging) or trouble-shooting in order to locate failed parts.
4. Within a unitized frame, a multi-pin connector assembly can demonstrate its versatility by servicing a variety of requirements, such as power requirements, and signal circuits which utilize conventional pin and socket or coaxial-type terminations. Further, a connector assembly can be adapted to meet specific environmental requirements for high temperature, pressurization, etc., applications.

(b) Liabilities:

1. A high susceptibility to mechanical damage either through faulty handling, design misapplication or through associated mechanical tolerance and alignment problems.
2. The use of the various rear-contact terminations provides a major source for trouble in multi-pin connectors; for example, when using solder, the problem of heat dissipation produces contact shorting and dielectric degradation; this is often a major consideration in multi-contact devices when more than 30 connections must be made in close proximity. In using crimp-on, snap-in type contacts other failure modes have been noted; the problems involve contact retention (back pin push-out), pin bending, and excessive float, creating registration problems. These conditions are indicated by intermittent or open circuit results.
3. The mechanical tolerance problem is a major consideration in the application of high-contact-density multi-pin connectors. Past experience indicates mating problems associated with pin bending, surface galling, or catastrophic failure to the retaining dielectric or retention member.
4. Other conditions directly associated with the operating configuration and the selection of the basic materials, processes, and surface finishes have contributed to the general picture of unreliability. To name a few, inadequate spring contact design, marginal limited entry (contact probe) provisions, high mechanical surface finishes, excessive individual contact float (alignment) characteristics, incompatible base material selections, and finish plating and processing problems.

6) WELDED

(a) Assets:

1. The joining of two metals through a fusion process produces an intermolecular exchange between these metals which is electrically stable and mechanically strong.
2. The resultant junction area is free from exposure type contamination, allowing for long life performance.
3. The joint is small and is relatively lightweight, thus allowing for a greater degree of miniaturization.
4. The connection is not affected by heat below the melting temperature of the parent metals.
5. The nature of the assembly tools limits the human-induced variables in making this connection.
6. Although the resultant connection is stronger than the parent metals, the connection is usually coated or encapsulated for support and will therefore meet all ground shipboard or aerospace environmental requirements.

(b) Liabilities:

1. Constant monitoring of production tools materials and personnel is necessary to insure production reliability.
2. Check of connection is dependent on visual examination of finished product. A destructive pull test of sample connections establishes the acceptability of the production process.
3. Where encapsulation is used, it limits maintenance and engineering change capabilities.
4. Lack of field tools make repair an impossibility and often requires a "throw away" maintenance philosophy.
5. Multiple tool configurations (shape and/or material of electrodes, electrode pressure, current rate and time duration) are required for different material combinations.
6. Material control prior to processing requires special pre-cleaning, storage and handling, which reflect in increased connection costs.

and subassemblies were designed for ease of replacement and interchangeability. The number of fixed connections increased and the need for separable connectors and connection devices created a field failure problem.

After World War II, developments in electronics were rapid and considerable. New computers, high-resolution radars and sophisticated communications equipments are but a few of the improvements in the field. These products have continually grown more complex and sophisticated. Today, the following trends are manifested:

1) The demand for miniaturization and greater efficiency contrasts with the demand for an increased number of the electronic functions required. Therefore, component part population and the number of required interconnections is growing.
2) The accent on end-product reliability is high, creating the need for circuit or part redundancies (multiplying interconnections requirements).
3) The accent on maintainability creates other problems, since the type of connections required to meet the goals of easy maintenance often compromise equipment reliability goals.
4) Prototype delivery requires that engineering changes must be made without compromising reliability and cost objectives.
5) Automation restricts interconnection and equipment maintainability. In general, the fixed or static connection offers less maintainability; yet, it is more economical and is more easily adapted to some degree of factory automation. On the other hand, the more easily maintainable connection costs more (3 to 10 times) and does not lend itself to automation.

CONNECTION SELECTION CRITERIA

Design review experience has provided the following criteria for optimum selection:

1) The connection technique must prevent either complete or partial disconnection when exposed to normal electrical and mechanical use.
2) The basic design features (including raw materials, manufacturing, and handling techniques) must guarantee long operational life and limited environmental or time-imposed degradation.
3) The basic design concept must withstand limited design misapplication without catastrophic implications. However, the connection technique should never be expected to substitute for the inadequacies imposed by either poor packaging concepts or disregard of proven standard design practices.
4) Junctions within a termination must be capable of inspection as part of the installation process.
5) Repeatability of the technique used to make the connection dictates that human influence should be minimized.

COMPARATIVE ANALYSIS

The various connection techniques used in the design of high-reliability equipment are of special interest to design engineers. Major characteristics of connection techniques may be classified as belonging to one of the following methods: 1) *crimp*, 2) *soldered*, 3) *screw-type*, 4) *wire-wrapped*, 5) *separable-types*, and 6) *welded*.

The desirability of the various interconnection methods listed above depends on the problems to be solved within the electronic equipment package. The major considerations are the number of interconnections, types of wire (size, stranded or solid type), the equipment maintenance philosophy, the test philosophy dictated by the system design, and the equipment electrical, mechanical and environmental requirements.

The current use of certain of these techniques is limited to preferred (standard) wire types, such as the use of wire wrap with solid wire and the use of crimp terminals with stranded wire.

The major points of comparison, assets and liabilities, between the six different methods of interconnection techniques are summarized separately from the general discussion in this paper (in Table I) to aid the readers in making evaluations.

INTERCONNECTIONS AND RELIABILITY

In much electronic equipment, the major reliability problem results from a compounding of human inadequacies, since all types of connections are employed in close proximity between the major contact points. In short, the fewer connections required between two points, the greater is the degree of reliability and the lesser is the need for new or different connection techniques.

Methods of Connection

The cheapest approach to reliability is through the use of continuous conductive

NORMAN B. SHAIN received his BA degree in General Science from Pennsylvania State Univ. in 1948 and has done graduate work for an MS in Mechanical Engineering at Southern Methodist University (1954-55). He was a design engineer at Chance-Vought Aircraft, Dallas, Texas, until 1956. He joined the technical staff of the Burroughs Corporation Research Center in 1956 as a Development Engineer. His major duties included component evaluation, reliability, system and failure analysis and the initiation of Non-Destructive Test Techniques related to the ATLAS Program. In 1960 he joined RCA as a consultant on Electrical Connection Techniques. He was responsible for the selection of electrical interconnection means used in the RCA portion of the MINUTEMAN equipment. His work included the implementation of the solderless wrap technique as a high reliability production technique into RCA plants in Camden, New Jersey and Cambridge, Ohio. Mr. Shain is a member of ASTM-B-4 Committee on Electrical Connections, SAE-A2C Committee on Electrical Connectors, EIA P7.5 Committee on Solderless Wrap Connections and the IEEE Professional Group on Production Engineering and Practices.

B. R. SCHWARTZ graduated from the College of the City of New York in June 1949 with a BEE degree; he received the MSEE from the Newark College of Engineering in June 1953. Mr. Schwartz has had over ten years experience as a resistive component specialist in the design, manufacture, test and evaluation aspects; he joined RCA in 1955 as Senior Resistive Components Engineer, with responsibilities for application and evaluation of linear and nonlinear resistive elements. In 1961 he was made Engineering Group Leader, Electromechanical Devices. He has been active in the MINUTEMAN, DYNA-SOAR, NIMBUS, RANGER and other high-reliability programs, especially in the development and implementation of technical plans on relays and connectors. He is a member of the RCA-DEP Value Improvement Council and Chairman of the Value Measurements and Standards Committee. He is a member of IEEE and was Chairman, Philadelphia Chapter of the Professional Group on Component Parts, 1959 to 1961. Mr. Schwartz has published papers in his specialty areas and has presided over a number of technical seminars.

wiring routed between as many points as possible. By removing all connectors from an electronic equipment, many of the variables which contribute a major portion to the system failure rate can be eliminated. However, when breaks in conductors are necessary, then the next best approach is to use terminal-board devices (screws, wire wrap, or similar terminations). Major opposition to this approach may result because terminal boards are not considered modern and sophisticated, but the long field history of the terminal board provides a better source of data than that derived from short-term life tests.

The demand for maintainability of subassemblies in electronic equipment has created a need for a rapid means for either module or cable replacement. The solution provided by multiservice, quick-disconnect connectors offers a serious compromise to reliability in that the connector is often expected to serve other than its basic function. For example, rack-and-panel connectors are often expected to act as aligning and guiding devices in the assembly of drawers into equipment racks. Circular-type metal-shell connectors have been used as counter balances and hand holders in some equipment. Thus, it is evident why connectors create reliability and maintenance problems.

Effects of Various Connection Methods

Central Engineering investigated the theoretical effect of using various electrical connection methods on the *mean time before failure* (MTBF) of a series of synthesized equipments. The reliability data in Table II indicates the results of this study.

Five systems of various sizes were used for model study purposes. A 100- to 200-hour MTBF closely represents that of a large size military or commercial computer. The 500-hour MTBF approximates the performance of an airborne fire control system. The 1.000-hour MTBF is similar to that expected of ground communications equipment, while the 10.000-hour MTBF is the goal of satellite type equipment. The typical component count involved in these systems is one component to four connections.

Reliability versus Type and Size of System

In the more complex component systems, Table II shows the nearly comparable performance obtainable with welding, wire wrap, or dip soldering. Even a reduction in the number of interconnections within the system provides little variation between these techniques.

However, large size computers require extensive maintenance procedures; therefore, much of the numerical advantages of the permanent connection must be comprised to obtain to the desired level of on-sight maintenance (connectors).

For smaller vehicular equipments where maintenance is usually conducted within a depot, the advantages associated with the fixed connections are even more apparent. However, the effect of a reduction in the number of interconnections within an equipment now becomes a significant factor. The controlled nature of maintenance in a depot should permit equipment designers to consider minimization of the use of separable connectors; these may be replaced by a more dependable joint, without experiencing additional equipment downtime.

The reliability table also indicates that in long-life satellite equipment, the number and type of connections used within the equipment can exhibit a heavy impact of its ultimate performance. Numerically, it is evident that the conventional electrical connector will impede the design objectives of this type equipment and offer no consolation in the area of replaceability because no maintenance is presently feasible.

SUMMARY

The selection and implementation of the various means of making electrical connections should be considered early in the system design phases, rather than as an afterthought. To do so, provides dividends in increased producibility, maintenance and logistic planning, lower unit installation costs, and a more accurate reliability planning position.

The *connection-population-versus-reliability* data of Table II separates the problems of reliability and maintainability; careful review will show the extent of their incompatibility. When both characteristics are sought, it is evident that the system designer must be prepared to trade-off either one of the two objectives. There is no universal solution to the multifaced problems in electrical interconnections; each equipment requires a design review to select distinctive criteria.

ACKNOWLEDGEMENT

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TABLE II—Effect of Connection Population on System Reliability (MTBF)

Type of Connections	Approx. Failure Rate*	MTBF, 100-hr system			MTBF, 200-hr system			MTBF, 500-hr system			MTBF, 1000-hr system			MTBF, 10,000-hr system		
		1,000,000 conn.	500.000 conn.	100,000 conn.	1,000,000 conn.	500,000 conn.	100,000 conn.	500,000 conn.	100,000 conn.	50,000 conn.	500.000 conn.	100,000 conn.	50,000 conn.	100,000 conn.	50,000 conn.	25,000 conn.
Weld	0.00002	98.0	99.0	99.8	192.3	196.1	199.2	476.2	495.0	497.5	909.1	980.4	990.1	8333.3	8909.1	9523.8
Wire-Wrap	0.00004	96.1	98.0	99.6	185.2	192.3	198.4	454.4	490.2	495.0	833.3	961.5	980.4	7142.8	8333.3	8901.9
Dip Solder #1	0.0001	90.9	95.2	99.0	166.7	181.8	196.1	400.0	476.2	487.8	666.7	909.1	952.4	5000.0	6666.7	8000.0
Dip Solder #2	0.00015	86.9	93.0	98.5	153.8	174.0	194.2	363.3	465.1	481.9	571.4	869.6	925.9	4000.0	5714.3	7272.7
Connector #1	0.0005	66.7	80.0	95.2	100.0	133.3	181.8	222.2	400.0	444.4	285.7	666.7	800.0	1666.7	2857.1	4444.4
Connector #2	0.001	50.0	66.7	91.0	66.7	100.0	166.7	142.9	333.3	400.0	166.7	500.0	666.7	909.1	1666.7	2857.1
Connector #3	0.003	25.0	40.0	76.9	28.6	50.0	125.0	58.5	200.0	285.7	62.5	250.0	400.0	322.6	625.0	1764.7
Hand Solder #1	0.01	9.0	16.7	50.0	9.5	18.2	66.7	9.8	83.3	142.9	9.9	90.9	166.7	99.0	196.1	846.2
Hand Solder #2	0.05	2.0	3.9	16.7	2.0	3.9	15.4	2.0	19.2	37.0	2.0	19.6	38.5	19.9	39.8	79.4

*The listed Failure Rates are unverified in many cases and represent approximation used by some reliability specialists for assessment purpose during preliminary model studies.

HIGH-PRECISION PHOTOMASKS FOR THE PRODUCTION OF SEMICONDUCTOR DEVICES

The development of new and improved high-precision production techniques has been an important catalyst to the dramatic progress in the technology of semiconductor devices—progress directly proportional to the ability of the industry to attain and precisely control very small dimensions (Fig. 1). The adaptation of the photoresist techniques to the production of semiconductor devices has played an important role in the extension of dimensional-control capabilities. Recent developments in the production of photomasks now permit highly complex geometric patterns to be exposed onto a photoresist-coated semiconductor wafer to a dimensional accuracy that as recently as a year ago was not considered either practical or possible. As a result, the photomask has become an increasingly important tool in the production of semiconductor devices. This paper discusses the historical development of the photoresist process, describes the meticulous care in the production of photomasks that is required to attain the high degree of dimensional accuracy now possible in semiconductor devices, and briefly explains the application of the photoresist process in the production of these devices.

G. L. FINNE, Ldr. and **H. V. KNAUF, Mgr.**
Photomask Laboratory *Equipment Development Engineering*

Electronic Components and Devices
Somerville, N.J.

THE basis for the use of a photosensitive resist dates back 2,000 years. Historical evidence indicates that this process was first employed by the ancient Egyptians who produced a material made from natural asphalt which was sensitive to ultraviolet light. The art developed by the Egyptians was lost for many centuries but was rediscovered by Niepce in France early in the 19th century. Niepce used the photosensitive-asphalt technique in a manner similar to present-day practice in the graphic-arts field. However, he kept his process secret and it again became lost to civilization upon his death in 1833.

Later in the 19th century, subsequent research again disclosed the Niepce technique, and Currier and Ives made advances in the process which enabled them to produce photoetched printing plates made of natural stone. Their process was subsequently extended to include the photoetching of metals, such as zinc, copper and iron. The photoetching technique was further developed and refined, later in the 19th century, by Max Levy of Philadelphia, who invented the halftone process in which optical principles were used for the first time.

ADAPTING THE PHOTOENGRAVER'S ART TO ELECTRONICS

Continuous evolutionary development over the years has refined the photoengraving process in the graphic-arts field to its present high standard of quality.

After World War II, the electronics industry began to adapt the photoengravers art to the production of electronic components and devices. Among others, these applications included the etching of printed-circuit boards, the shadow-mask and tricolor-phosphor-dot exposure of color-kinescope screens, and the chemical micro-milling of components. More recently, the process was adapted to the production of semiconductor, integrated-circuit, and other related types of devices. However, it became readily apparent that significant improvements in the state-of-the-art techniques for the production of photomasks would be required to realize fully the potential of the rapidly advancing semiconductor technology.

In early 1962, the Photomask Laboratory of the RCA Semiconductor Plant in Somerville, N. J. was established to meet the demands of the growing sophistications in semiconductor products. Prior to that time, all photomasks had been obtained from outside the company; however, the restrictions imposed on the production of semiconductor devices by the limitations of these masks indicated that an in-plant photomask development and production facility would be desirable. Consequently, during 1961, a comprehensive investigation was conducted to determine the facilities, equipment, and technical skills for a laboratory that would be capable of developing the new and improved photomask production

Fig. 1—Improvement in the stability and performance capabilities that has resulted from the increased control over dimensional accuracy achieved in recent years.

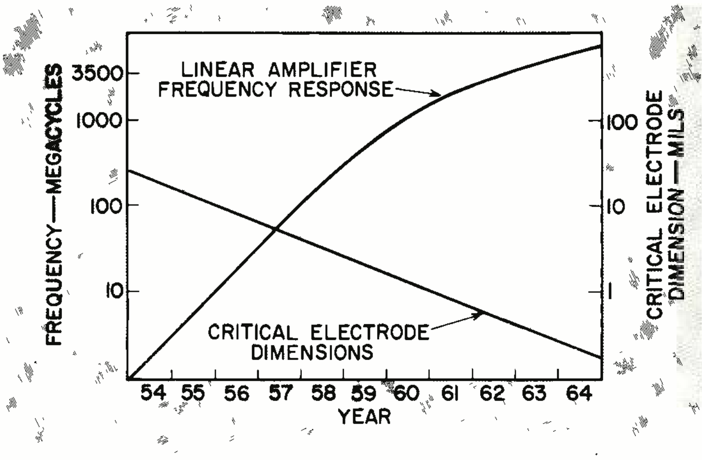
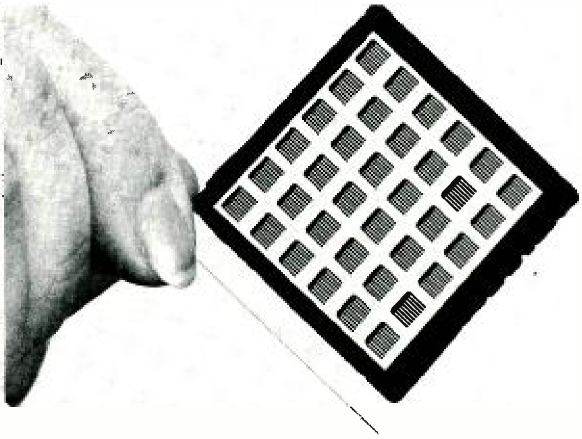


Fig. 2—Typical 2-inch-square glass photomask with 36 patterns for a relatively large device. Masks containing over 10,000 patterns for a very small device have been similarly produced.



processes and techniques required to keep pace with the ever-increasing requirements of the semiconductor industry.

The operation of the Photomask Laboratory was begun on a relatively small scale. Initially, the work was limited to the layout and checking of simple precision templates; only after satisfactory results with these templates could be consistently obtained were more complex mask geometries attempted. Each step in the over-all production process was carefully scrutinized by all personnel involved, and each new development approach was thoroughly analyzed and tested.

The growth in both the technical skills and the production capability of the Photomask Laboratory was exceedingly rapid. By the end of the first year of its operation, masks having highly complex geometries could be produced to a dimensional accuracy that previously had been considered impossible.

In the production of photomasks, the preparation of two-inch-square glass plates coated with a high-resolution emulsion and processed to very exacting standards has been reduced to a routine operation. Fig. 2 shows a photograph of a typical plate of this type. In special cases, masks have been produced, within a one-inch-square area, which appear completely free of foreign particles when viewed through a microscope at a magnification of 1000 and in which dimensional deviations are held to tolerances that approach the lower limit of physical measurement by visual means. In regular high-volume production, the requirements of the masks, however, are somewhat less stringent. Under such conditions, the masks may be permitted a few microscopic imperfections, and a tolerance limit of 0.000050 inch on dimensional deviations is considered adequate. Masks of this type can be produced on a more or less routine basis.

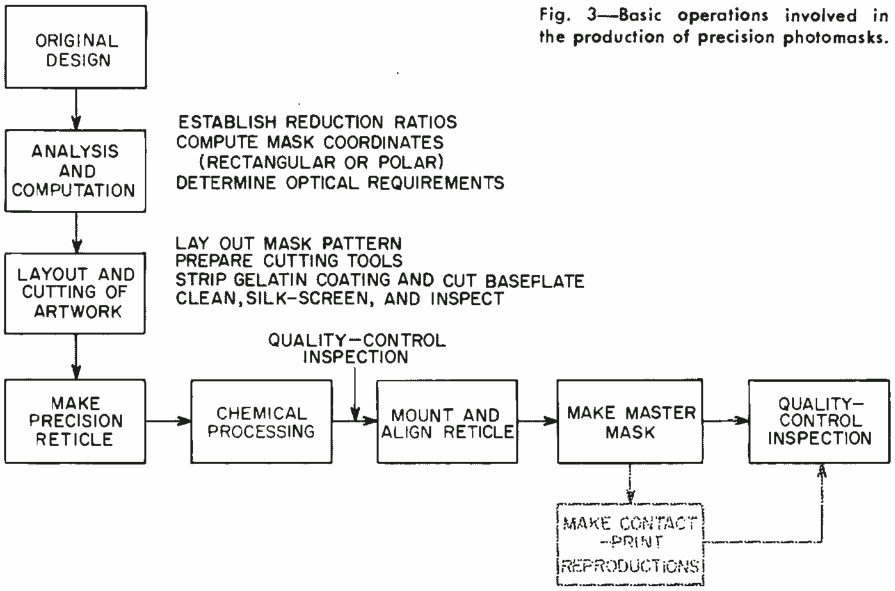


Fig. 3—Basic operations involved in the production of precision photomasks.

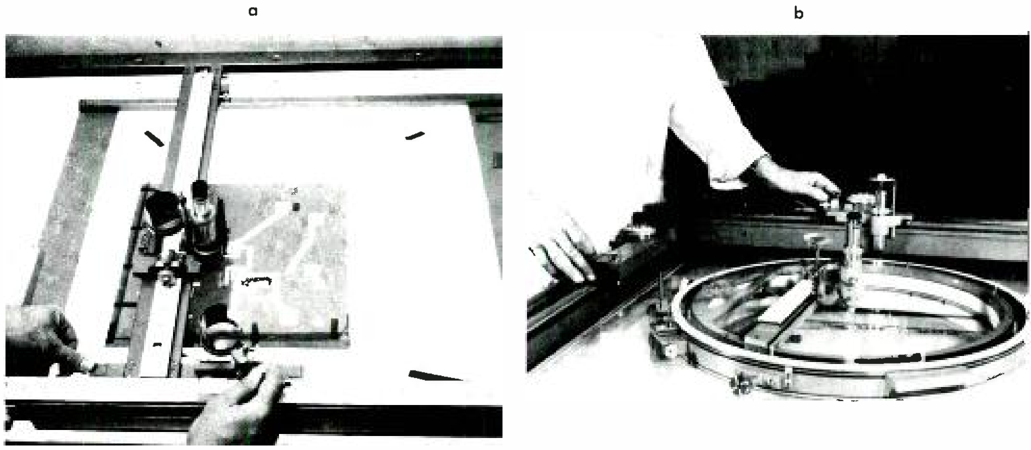


Fig. 4—Heig-Streit Coordinatograph used to enable precision layout and cutting of photomask patterns: a) Setup for plotting rectangular coordinates; b) Setup for plotting polar coordinates.

G. L. FINNE received the BS in Industrial Education from Trenton State College in 1941 and the EE and ME degrees from Rutgers University in 1952 and 1953, respectively. After graduating from Trenton State College, he served in the U.S. Navy, and then from 1946 to 1952, was engaged in engineering and design work for consulting firms. From 1952 to 1957, he was engaged by Air Reduction, Incorporated as a manufacturing engineer. He joined the RCA Electron Tube Division in 1957, and then transferred to the Equipment Development Activity of the Semiconductor and Materials Division, where he designed transistor fabricating equipment, specializing in cold welding, thermo-compression bonding, and photoresist processing equipment. In 1962, he was promoted to Engineering Leader in charge of the Photomask Lab. He is a registered professional engineer and a member of the NSPE, ASME, and the Plainfield Engineers Club. He is a former member of the Executive Board of ASME.

HARRY V. KNAUF started his career in February of 1926 as a radio test man with the Victor Talking Machine Company (taken over by RCA in 1930). Since 1930 he has acquired broad experience in all phases of manufacturing, process engineering, and tool and equipment development. He holds a number of patents and has patents pending. From 1926 to 1948, he held supervisory positions in Manufacturing, Process Engineering and Manufacturing Development. In 1953, he was promoted to Manager of Equipment Development Engineering at Harrison for the entire Tube Division. In November 1953, he was made Administrator, Equipment Development Engineering, Chief Engineer's Staff. In 1958, he was assigned to provide mechanical guidance on a special task force committee which resulted in the development of the Nuvistor Tube. Since 1961, he has held his present position as Manager, Equipment Development Engineering at Somerville for the Semiconductor Activities of Electronic Components and Devices.

G. L. Finne

H. V. Knauf

Fig. 5—Photomask cutting tip and holder. (Magnification about 10×.)

depending on the complexity of the geometric configuration and the size of the individual pattern. In general, regardless of the number of step-and-repeat operations that are to be performed, the simpler the geometry of the device and the smaller the pattern, the easier it is to maintain dimensional accuracy and to keep the mask free of imperfections.

PHOTOMASK PRODUCTION TECHNIQUES

The production of a photomask master is carried out in three basic stages: The first stage consists of preparing the art pattern to very precise, accurately controlled dimensions. This art pattern is then processed through a first-reduction step to produce a precision reticle. In the final stage, the step-and-repeat processes and final reduction required to obtain the final master are performed. The various production and processing steps must be performed to very exacting standards to assure that the quality and accuracy demanded of the final product will be achieved. Each step in the over-all operation is carefully and critically analyzed to ascertain that the master mask will be dimensionally accurate and free of surface imperfections within tolerance limitations. Fig. 3 shows a flow chart of the basic operations, from engineering conception of the semiconductor device through the final quality-control check.

Art Pattern—Analysis and Layout

The foundation of the photomask process is the artwork. During this stage, the reduction factors that will determine the final reduction accuracy are established and the detailed mathematical computations that will translate the geometry of a device into the required mask pattern are performed. This pattern is then laid out on a suitable baseplate, and the pattern is cut to form a stencil-like mask.

In the preparation of the artwork, it is necessary to first convert the pattern geometry, for a specific semiconductor device, to a mathematical language that is readily adapted to a rectilinear and polar-coordinate system. As the first step, the engineering drawings must be carefully analyzed in relation to mask requirements and subsequent operations. The tabulated mathematical computations are directly applied to the design layout and precise cutting of the artwork. The theoretical limits of accuracy within the practical limitations imposed by the Heig-Streit Coordinatograph, shown in Fig. 4, are determined by analyzing each design to arrive at an optimum multiplier to provide a final photomask to the required specifications.

Base Material

A number of materials that will form a suitable base for the artwork are available from several sources. The characteristics of these materials vary somewhat, however, because of the different approaches used by the various manufacturers. Although a satisfactory art pattern can be produced on each of these materials, their characteristics had to be evaluated in terms of the requirements of subsequent operations in the production of the photomasks. This evaluation resulted in the selection of Ulano Ruby Lith, Type M3, as the optimum base material. This gelatin-coated material can be used to form a very thin baseplate that will be dimensionally stable within tolerable limits. The surface characteristics of the Ruby Lith are such that precision cutting and stripping of the gelatin is a straightforward mechanical operation.

Cutting Operation

The cutting of the art pattern is performed on a precision "drawing board" (Coordinatograph) that enables a total tolerance of 0.001 inch to be maintained between any two points within the four-foot-square work area. A special cutting tool and holder, shown in Fig. 5, had to be developed to provide the high dimensional accuracy required for this operation because no commercially available devices would provide the precision cutting demanded. The angle and position of the cutting edge was determined experimentally using various basic materials, such as diamond, sapphire, tungsten carbide, and various grades of steel. For cutting the gelatin patterns, tips made of ordinary high-carbon steel readily available in drill blanks were found to be satisfactory. For cutting other materials, such as plastic or metal, diamond or sapphire tips must be used.

The accuracy of the cutting tool was dramatically illustrated by placing a Ruby Lith plate on the Coordinatograph and cutting a 0.001-inch square in the 0.001-inch-thick gelatin coating. *Only one-billionth cubic inch of material was removed in this operation.* A medium power microscope, precision tools, and a high degree of skill are required for this degree of precision. A high level of skill in cutting artwork was necessary to assure minimum distortion in subsequent optical reduction. The artwork should be cut as small as practical so that the

Fig. 6—D. W. Mann Reticle Camera used for making the precision reticle.

Fig. 7—D. W. Mann Photorepeater used for the step-and-repeat operations required for the production of the master photomask.

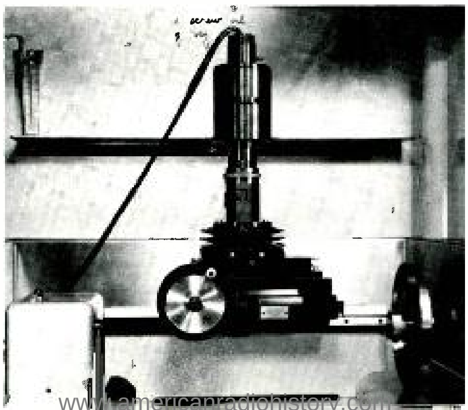
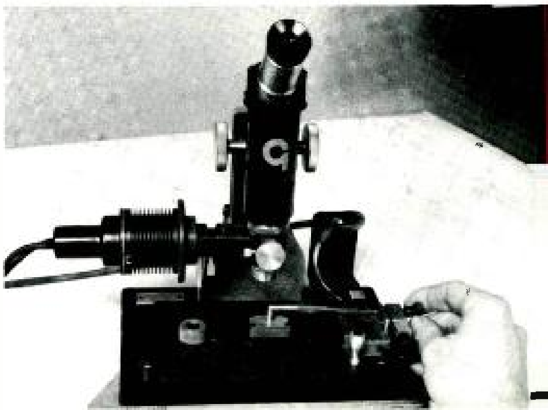


Fig. 8—Master reticle aligner used to assure that the optical center of the mask pattern will be coincident with that of the step-and-repeat process.



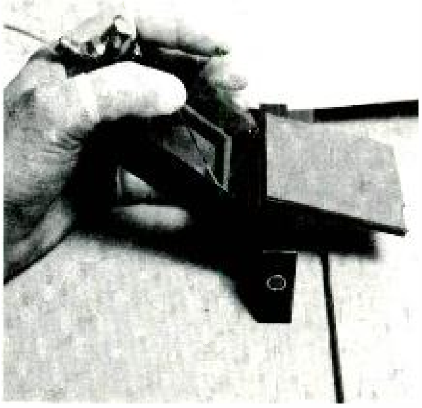


Fig. 9—Contact printer and special vacuum frame used for making reproductions of the master photomasks.

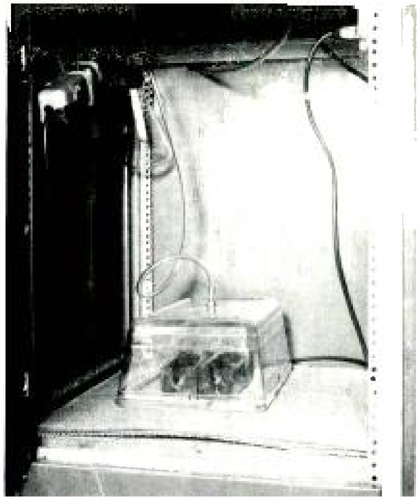


Fig. 10—Drying system for the photomasks.

Fig. 11—Stereomicroscope used to detect surface imperfection in the photomasks.

smallest optical cone can be used in the reduction processes.

Although the cutting of photomask artwork can now be accomplished with exceptional accuracy, a look into the future indicates that the speed of the process must be significantly increased to keep pace with the growing volume of semiconductor requirements. With the present manual techniques, as much as two weeks may be required, in some cases, to complete the cutting of complex mask patterns. The sheer volume of new devices indicates that the cutting art should be reduced to an automated science. In the future, it is anticipated that programmed, computer-controlled automatic machines will be used to reduce the cost and to increase the speed of the process.

Formation of the Precision Reticle

The first reduction, or precision reticle as it is termed in the mask industry, is produced photographically on a precision reduction camera. The equipment used for this purpose in the RCA Photomask Laboratory at Somerville is the D. W. Mann Reticle Camera shown in Fig. 6. This camera is fitted with a fixed-aperture Kodak microfile Ektar lens and will provide variable reduction ratios of 10 to 20. The use of micrometer focusing and a shock-mounted bed enables repeatable precision reduction within the limits of physical measurement. An Aristo cold grid light source, which has a very narrow band output, provides the back lighting for the artwork.

In the production of the precision reticle, either Kodak high-resolution plates or Ortho type 3 plates are used. The choice depends on the size of the pattern—For small patterns, the high-resolution plates are preferred; for large patterns, the Ortho plates are used. The chemical processing of either of these plates again is a function of the particular geometry. The relationship of the opaque to clear areas and the size of the largest and smallest geometric configurations are the determining factors. The greater the ratio of opaque to clear areas, the less active the developing chemicals should be.

Production of the Master Photomask

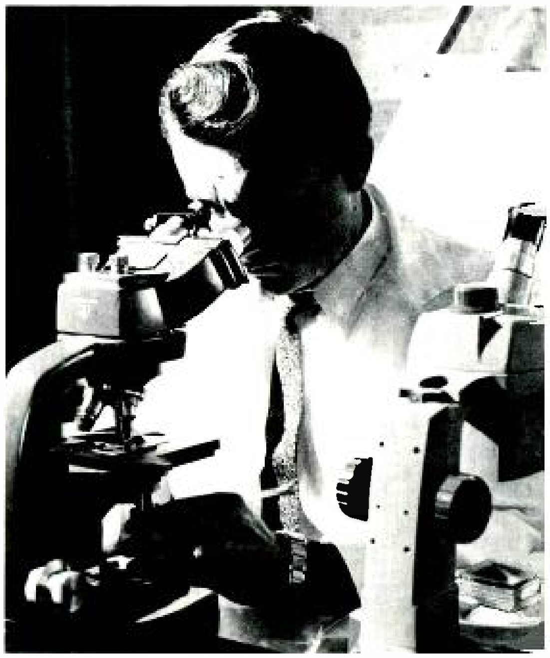
The final step in producing a master photomask is the step-and-repeat process. A D. W. Mann Photorepeater is used for this operation. This equipment, shown in Fig. 7, will precisely position a high-resolution photographic plate in the focal plane of a special projection type of reduction camera. This camera uses microscope objectives. First, the precision reticle must be mounted and properly aligned in a metal frame so that the optical center of the pattern is coincident with that of the step-and-repeat process. This alignment is accomplished on a master reticle aligner, shown in Fig. 8, supplied as part of the Photorepeater.

During the step-and-repeat process, the reduced-pattern image is projected and exposed at preset intervals. These center-to-center intervals are automatically controlled by an encoder and power supply, which pulses a high-voltage capacitor discharge in a precise relation to the carriage position. The carriage is traversed with a high-precision lead screw which is dial calibrated in 0.000050-inch increments. The lead screw is compensated to within 0.000005 inch. With this precision instrument, operation within the rated accuracy of the device itself is routine. However, some semiconductor devices, currently in design, require dimensional and repeatable center-to-center accuracy to a tolerance of only 0.000010 inch. This stretches the state-of-the-art beyond its present capabilities; however, a 0.000020-inch tolerance is practical on certain geometries and in the smaller-pattern range. As with the precision reticle, chemical processing of the master photomask is determined by the pattern geometry. In some cases, however, where extremely fine definition is necessary, special processes must be used.

Reproductions

For many devices, the requirements are such that a high volume with less stringent tolerances may be accepted. In such cases, reproductions can be made by contact-printing a negative master. This contact-printing is accomplished in a special vacuum frame, shown in Fig. 9, and with a controlled-frequency light source.

Fig. 12—High-power microscope used to observe edge definition in the photomasks.



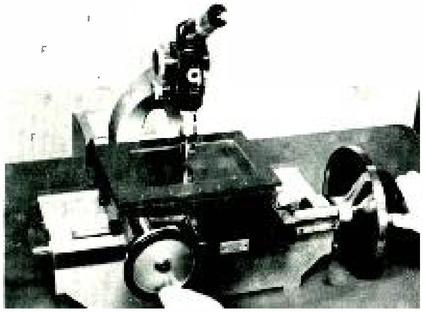


Fig. 13—D. W. Mann Comparator used for dimensional analyses of the photomasks.

Cleaning

In the processing of high-resolution photographic plates, extreme care is necessary to insure absolute cleanliness. The presence of residual and external foreign matter as small as ⅓ micron on a critical area will cause an imperfection in the final product and may render the device useless. Therefore, before each plate is processed, it is put through a static-generator field to deionize adhering particles. The plates are then vacuum-brushed for mechanical removal of the particles. These precautions provide a reasonable assurance that foreign matter on the surface of the masks will be held to a minimum. Other cleaning procedures are being evaluated.

Post-process cleaning requires meticulous handling care. The washing system is composed of a water still, storage tank, millipore filter, two chemical exchange columns for removing impurities, a constant circulation pump, a washing tank, and an ultrasonic generator. Additives are used in the system to further enhance the cleaning procedure. A plate, properly processed in this system, will have no visible particles of residual foreign matter.

To further insure the cleanliness of photomasks, a specially designed drying system (Fig. 10) is used that never allows a mask to be exposed to room atmosphere. The equipment consists of an outer cabinet which is pressurized with filtered air that is heated slightly above ambient temperature. Inside this controlled atmosphere, an inner chamber, used as the actual drying area, is flooded with dry nitrogen which has been filtered through a millipore filter. The dry masks are packed in individual clean plastic envelopes before they are removed from the drying system.

Quality-Control Techniques

To insure engineering acceptance, a tight visual and dimensional evaluation is made on a random sample from each lot of photomasks that are processed. Visual inspection is performed on a stereomicroscope (Fig. 11) at 30 power using transmitted light. Edge definition is observed using a 1000-power microscope (Fig. 12) using monochromatic light. Dimensional analysis is made on a D. W. Mann Comparator, calibrated in 0.000050-inch increments, and equipped with a high-power microscope (Fig. 13).

APPLICATION OF THE PHOTORESIST PROCESS

As mentioned previously, the adaptation of the photoresist process to the production of semiconductor devices has resulted in a production method that provides a dimensional accuracy that approaches the limit of physical measurement by visual means. The basis for this precision, of course, is the dimensional control that can now be imposed in the production of photomasks. Fig. 14 shows a flow chart of how a mask might be employed in the photoresist process for the production of semiconductor devices.

In the first step, a polished semiconductor wafer is coated with photosensitive material; a centrifugal type of coating machine (whirler) is used to apply this coating. The wafer is then placed in an oven and baked at an accurately controlled temperature for a short period to stabilize the coating. After the baking step is completed, the coated wafer and the precision photomask are carefully aligned in a vacuum frame so that their optical centers coincide; an ultraviolet light is used to expose the mask pattern onto the photoresist coating of the wafer. Next, the wafer pattern is developed according to a carefully prescribed schedule. The wafer is then subjected to a microscopic examination to insure its freedom from surface imperfections and irregularities in the pattern.

The preceding steps establish the geometric pattern that is etched into the wafer. The etching of the wafer is followed by a short period of accurately controlled high-temperature processing. At this point, another quality-control inspection of the wafer is made. When more than one pattern is to be etched into the wafer, it is again coated with photoresist after the quality-control check is completed, and the sequence of operations is repeated. As many as seven different etching cycles, which corresponds to a quadruple diffusion, may be performed on a single wafer. Upon completion of the final quality inspection, the wafer is subjected to a series of electrical tests. If it passes these tests, it is diced into individual pellets which are then processed into the completed final semiconductor package.

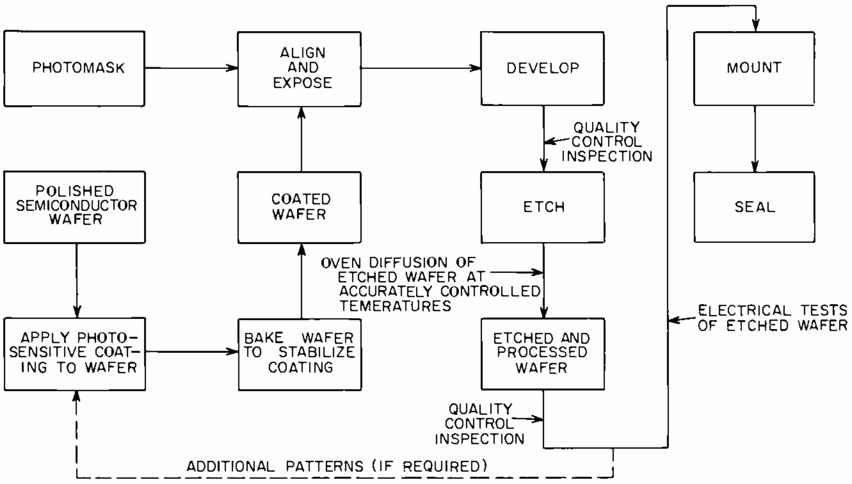


Fig. 14—Application of the photoresist process in the production of a semiconductor device.

ELECTRO-OPTICAL ENGINEERING AT BURLINGTON

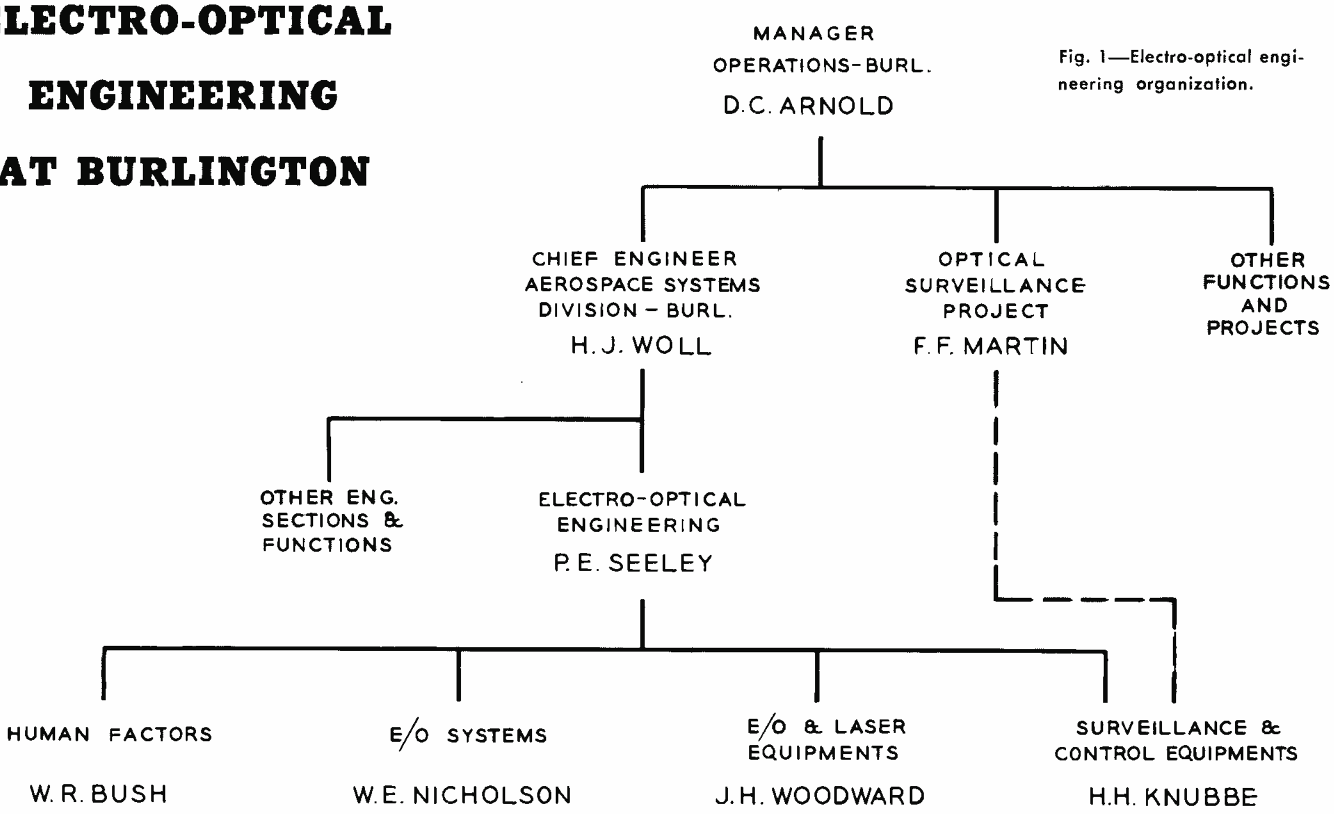


Fig. 1—Electro-optical engineering organization.

Reviewed here are the organization, facilities, and some of the technical activities of the Electro-optical Engineering group at the DEP Aerospace Systems Division in Burlington, Mass. The programs carried out there by this group include laser techniques and applications; radiometers; military television, including low-light-level TV, space surveillance, trackers, and infrared cameras; and cell scanners and trackers.

P. E. SEELEY, Mgr.
Electro-Optical Engineering
Aerospace Systems Division, DEP, Burlington, Mass.

THE MAJOR part of RCA's defense engineering activities in the electro-optical technical area is conducted at Burlington, Mass. This arrangement resulted from the decisions to transfer infrared projects in 1958 and certain types of military TV projects in 1962 to Massachusetts from other RCA locations; moreover, new business activities were generated by the Burlington Engineering Department in electro-optical surveillance, laser systems, and techniques.

Changes in the structure of the Engineering Department at Burlington in June 1963 required an enlarged activity devoted to electro-optical work; thus, the personnel engaged in the new infrared, optical, and laser programs were re-assigned from the existing Advanced Systems and Techniques and Surveillance Products Sections and joined together into one section. The organizational arrangement of this new Electro-optical Section and its relationship to the other functions of the Engineering Department are shown in Fig. 1.

Briefly, the section is organized to conduct the current developmental and techniques programs most effectively, as well as to afford the pursuit of new business proposals and opportunities. Personnel assignments are generally flexible to maximize skill utilization and to balance the work force on a variety of programs. Many such programs undergo level-of-effort changes from time to time, and noticeable, if not substantial, technical changes.

ENGINEERING PERSONNEL

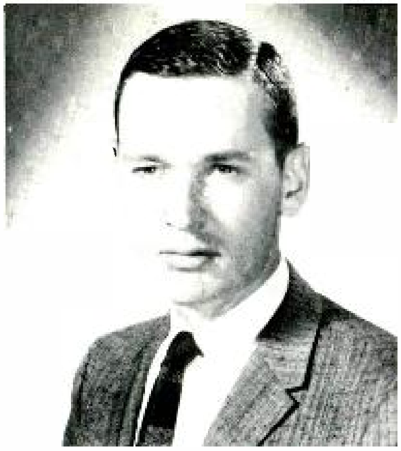
As with many RCA engineering functions, electronic circuit and mechanical design play a large part in the electro-optics activity. About half of the professional personnel can be so classified, although a majority have specialized, practical experience with optical and television or related equipments for a number of years before their present assignments.

The remainder of electro-optics personnel have had training and experience in mathematics and physics, the latter being particularly important in infrared and laser work. Personnel trained in these fields and experienced in optics design, to cite one example of essential work specialization, are strong assets to the electro-optics activities. Experimental psychologists, a subgroup within electro-optics are involved in the important support areas of man-machine interfaces, and personnel subsystem training and optimization.

EMPHASIS ON LASER WORK

The laser technical area, because of its rapid growth, has occasionally utilized personnel in industry with little experience in optics and physics. This was somewhat a repeat of the situation found in the mid-1950's in the infrared equipvelopment and growth at that time.[1]

With the recent advances in laser devices as amplifiers and radar devices,



P. E. SEELEY graduated from MIT in 1949, S.B. in Physics. He did graduate work in Electrical Engineering at Northeastern University, 1956-59; and studied management training in 1962 at Harvard Graduate School of Business Administration. Following service assignments in airborne communications, Mr. Seeley was engaged in field engineering on shipboard radars and geophysical electronic equipment from 1949 to 1950 and was employed at the Dynamic Analysis and Control Laboratory, MIT until 1953. He was with Westinghouse Electric Corp. in 1954-1955 as project engineer concerned with design and development of the radar seeker system and CCM techniques for the BOMARC missile. Mr. Seeley joined RCA in 1955 at the Waltham Airborne Systems Laboratory where he was involved in design and development of an advanced pulse-doppler radar receiver system. Subsequently, he supervised HF and radiometric measurements, advanced infrared, laser, and microwave equipment engineering development. In 1963 he was appointed Manager of the Electro-Optical Engineering Section. Mr. Seeley holds several patents for electronic circuits and control devices; he is a Senior Member of IEEE, and a member of the Optical Society of America as well as the Armed Forces Communication and Electronic Association.

electronics engineers skilled in radar or microwave design are being engaged in advanced developmental work. Thus the interaction between physics and electrical engineering personnel continues on new technical grounds. Fortunately, any rivalries that do exist have little direct bearing on working relationships, but they do produce effects in the professional journals and symposia. The Electro-Optical Group, at the present level of activity, consists of 55 engineering and scientific personnel.

CLASSIFICATION OF WORK

The method used to classify the work in the Electro-Optical Group is by equipment characteristics. These are principally *TV or image-tube devices, cell scanners* and *trackers*, and *lasers.*

This work division is a more practical method of specialization than other approaches such as the spectrum division (i.e., an infrared group, a visible-spectrum group, or ultra violet group, etc.). For a major program such as the optical surveillance subsystem, it is best to have the majority of personnel assigned to one group under a single manager; this results in greater technical continuity and efficiency and also provides a more effective engineering and administrative exchange with the project group, as indicated by the dotted line, Fig. 1.

The electro-optics engineering force has experience or is currently working on the following equipment types: 1) radiometers, 2) image tube or TV, 3) cell scanners and trackers, and 4) optically pumped lasers.

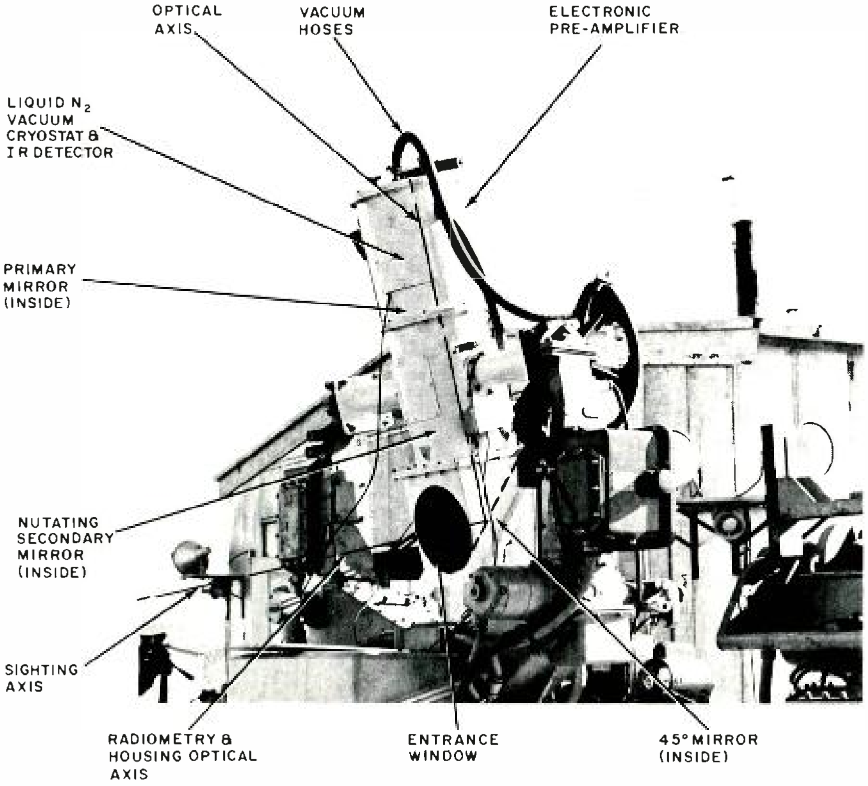
RADIOMETERS

Radiometers detect and record power emitted from distant sources. Usually, total power or temperature can be measured, once the system is calibrated and when the radiating body does not change its emissivity during the measurement. In military applications, the power modulation frequencies and percent of modulation are frequently of interest; for examples, changes in missile combustion rates may be observed by a radiometer pointed through the atmosphere at a missile exhaust; or, fluctuations in emissivity caused by tumbling can be measured when a tumbling, reentering nose cone is viewed.

The radiometers designed and built at Burlington have ranged from a large 12-inch primary mirror, infrared-cell type instrument for anti-submarine-warfare research in the measurement of sea surface temperature gradients as small as 0.005° (Fig. 2) to small ultraviolet rocket-borne radiometers for upper atmosphere probes.[2]

One radiometer provided 5 channels through the ultraviolet, visible, and infrared regions of the spectrum using a single set of reflective optics. By far the biggest radiometer program and one of the first major Electro-Optics projects for Burlington was the design and outfitting of a mobile instrumentation van for use at the Atlantic Missile Range on an ARPA-sponsored investigation. Five dual-purpose—total-power or modulation frequency-recording — radiometers in both the near and far infrared regions were designed using a Dahl Kirkham optical configuration; the radiometers were installed with other equipment, some of which is shown on a tracking pedestal atop a trailer track type van (see Fig. 3). Each radiometer is designed to receive data in a selected, narrow-band portion of the spectrum. Many months of data-taking on missile launches were obtained to add significant information to the ballistic missile defense scientific community. Most recent radiometry work has been in the ultraviolet spectral area directed toward the application of hydrogen-oxygen fire detection and alarm to afford crew protection on-board liquid hydrogen fuel spacecraft.

Fig. 2—Sea-surface radiometer.



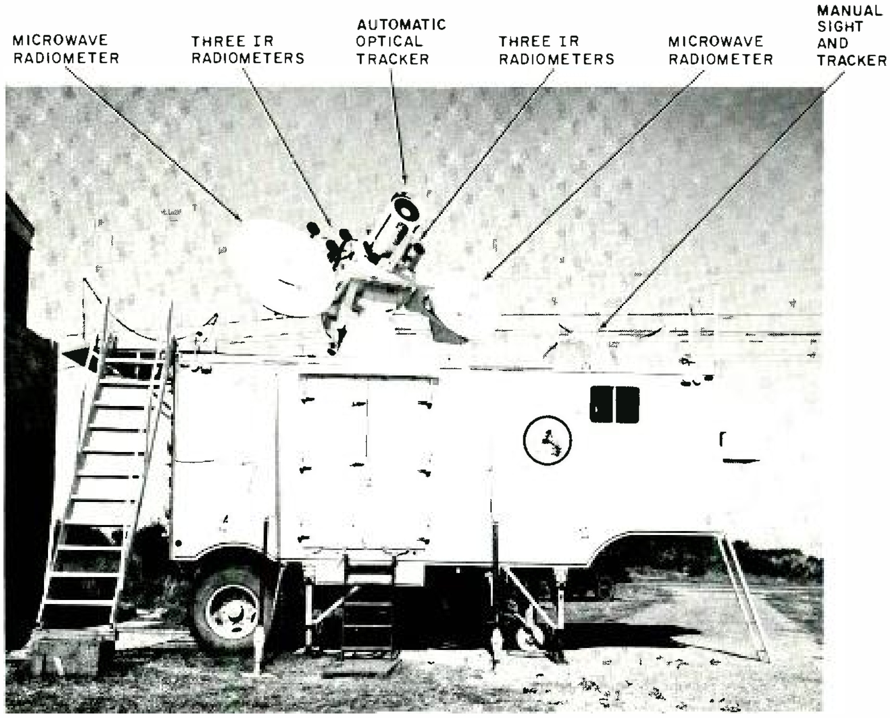


Fig. 3—Field-radiometer van.

TELEVISION

The military TV camera and equipment area consists of airborne viewing aids, low light level, space surveillance, trackers, and infrared television types.

Airborne Viewing Aids

One of the first airborne TV applications was a closed circuit system to enable the human to have fields of view not available to him in his specified, and often restricted physical location. This problem dates from the "Spirit of St. Louis" flying days, if not earlier; in fact, Charles Lindbergh in flying across the Atlantic could not see in the forward direction except via an optical periscope.

Television airborne viewing aids designed by ASD Burlington engineers and the Engineering department in Camden have been used in the B-52 and A3J aircraft. Equipment for the A3J is currently being manufactured at the Camden plant. The technical and design problems are mainly ruggedization to withstand the airborne vibrational environments and lightweight component selection and packaging.

Although not airborne in usage, but aerospace in nature and scope, are the closed-circuit TV, and visual display systems for flight simulation and human operator training. The areas of training and simulation are a growing business field, due in part to the many complexities and expenses incurred in actual flight. Burlington has participated in some of these programs for the Air Force and the Navy, and recently conducted visual and function studies for the Lunar Excursion Module (LEM).

Low Light Level TV

Low light level TV work at Burlington has centered about image orthicon and image-intensifier orthicon equipments for "seeing-in-the-dark" systems applications. For the most part, this technical area is an outgrowth of airborne viewing aids.

With presently available equipments[3] and studio-type lens, 400-line resolution pictures can be obtained at scene illuminations approaching 10^{-7} foot-candle. This is somewhat darker than countryside outdoor conditions on a moonless night with a heavy cloud-cover blocking celestial light.

Applications of these equipments are under consideration for numerous aircraft, particularly for patrol aircraft in which the pilot's ability to recognize objects on the ground is essential or important to the mission. Such new equipments can extend these missions into a wide range of nighttime conditions. As with the daytime operations, the mission must be compatible with human observer capabilities. This latter constraint involves human engineering laboratory studies and flight tests to fully assess performance and to reach effective configurations. The possibilities for missile control by a remotely located human operator who watches the TV picture relayed from the missile nose are now made considerably more attractive; the image-intensifier orthicon is used to remove technically-imposed restrictions of daylight operation only.

Current endeavors at Burlington are directed toward further refinement of the orthicon equipments for aerospace applications; new work is being performed to solve the problems associated with applying equivalent or higher performance, simpler, and more ruggedized pick-up tubes to these applications.

Space Surveillance

Space surveillance equipments meet the need for passively searching many square degrees of an optical field of view for aerospace targets such as satellites or missiles. The TV design problems are extensive because of low light level target conditions, background problems, and the high-resolution requirements. A wealth of new technical-applications knowledge has been generated at ASD Burlington concerning the use of orthicons outside of their known commercial functions to solve these problems.

Space surveillance equipments also present complex design tasks in the optics design, the fiber-optics coupling from the image plane to the orthicon faceplate, and in video signal processing and integration and storage problems. Such design requirements include, for example, the enhancement of the target signal while eliminating or minimizing effects of fixed star-field backgrounds; this is an area of complex electro-optical system design and fabrication, as opposed to the field of specialized TV cameras alone. Burlington personnel closely coordinate their application requirements with the RCA conversion tube specialists at Lancaster; further information on this subject is contained in the articles by C. Park[4] and M. Cantella[5].

TV Trackers

Television trackers have been developed to track a single target by processing of the video information. Thus, optical trackers can be mechanized for missile or aerospace use to generate up-down, left-right steering information, without the use of moving parts. In many cases, mechanization of spatial discrimination is enabled because a complete field-of-view, video-image format is available. Another performance feature is that the center of the target outline can be tracked when the target is close enough to fill a sizeable portion of the field of view; the more normal spot-tracking can be performed when the target is quite small in terms of the field of view. A TV camera is necessary in some aerospace systems for picture relay or viewing; thus, the automatic optical-tracking feature comes as a simple video processing, supplemental package.

Current work on an Army-sponsored program has involved experimental studies of missile semi-active homing. An image-tube receiver is used in conjunction with a laser target illuminator.

IR Cameras

Development of the lead sulphide infrared pick-up tube was conducted at the RCA Laboratories some years ago for the U.S. Army.[6] Since that time, work has continued on more sensitive infrared pick-up tubes and some have been optimized for various regions of the spectrum. The use of these tubes in infrared cameras began shortly after. One of the first design problems encountered in the infrared camera area was lack of a suitable and economic approach to the lens or imaging optical system. In most applications the problem has been solved by designing optical configurations which use all reflective elements. Some progress has been made on infrared refractive optics using primarily arsenic trisulfide and germanium mainly; to date, several cameras have been built and delivered to various military and government agencies. The uses are largely for experimental data-taking to obtain more information about the infrared characteristics of various aerospace targets. In addition, a program is being performed for the Air Force to determine the capabilities of infrared pick-up tubes as primary sensors in ground-mapping systems; this work has involved the application of new technology in infrared fiber optics[7] (Fig. 4).

CELL SCANNERS AND TRACKERS

Most of the Burlington scanning cell equipment experience has been with infrared detectors, although some work has been conducted in the ultraviolet and the visible bands. This technical area underwent an explosive growth during the 1950's. Because of successful infrared tracker application in the SIDEWINDER, GAR-2, and other heat-seeking missiles, and through advances in infrared detector sensitivities in the long wavelength regions to implement high-performance ground-mapping scanners, it has been a high volume and dollar sales product for the three or four suppliers in the field. RCA upon entering the field concentrated its attention on the development of scanning cell equipments for search and warning devices. This application placed new demands on infrared cell speeds of response, detection range or sensitivity, and background discrimination through signal processing. As with a search radar, a reliable system with high detection probability and low false-alarm rates was required.[2]

LASERS

The first laser built at ASD Burlington used a crude laser cavity made of aluminum foil and produced stimulated emission of a ruby crystal by energization with a helical flash tube. Since that early cavity designs, about 50 laser cavities and equipments of an advanced nature have been produced and tested. Fig. 5 shows an early type of cw-laser equipment produced at Burlington for RCA Laboratories. Contract-sponsored work has enabled many advances in the area of optically-pumped, inorganic-crystal-laser applications to scientific problems and techniques, as well as to the practical one of a lightweight rangefinder for the U.S. Army and the study work on semi-active missile guidance.

The techniques and know-how in the laser field[8-11] most pursued and perfected have been as follows:

1) high rate *Q*-control with spinning reflectors to delay laser action until the higher-energy atomic states in laser material are highly overpopulated by optical pumping from the flash tube; then, the necessary optical reflection and regeneration paths necessary for laser action are suddenly permitted which produces a single, short, high-power pulse output[11];
2) methods of elliptical and cylindrical cavity construction and coating handled in-house to best understand and optimize performance;
3) studies of optical properties of crystals as they effect the desired laser properties;
4) low-temperature performance investigations to best achieve the configurations that will operate in field equipments under a wide range of temperature variations;
5) methods of crystal and flash tube cooling for achieving reliable, high-power operation for extended periods of time;
6) generation of optical harmonics[10];
7) laser power amplifier techniques; and
8) special techniques in the area of experimental physics, as well as electrical engineering for the power supply and signal-processing electronics areas.
9) laser receiver techniques for accurate, light-weight range finders.

SPECIAL FACILITIES

To perform electro-optical engineering work effectively, many special and noteworthy facilities have been installed at Burlington. Five dark rooms plus a long dark tunnel are available for infrared,

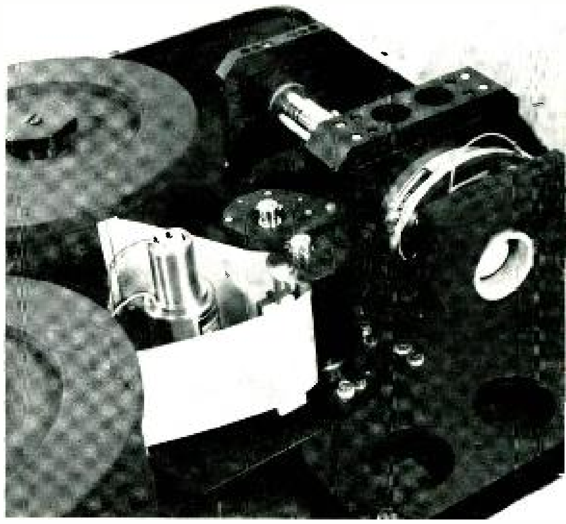
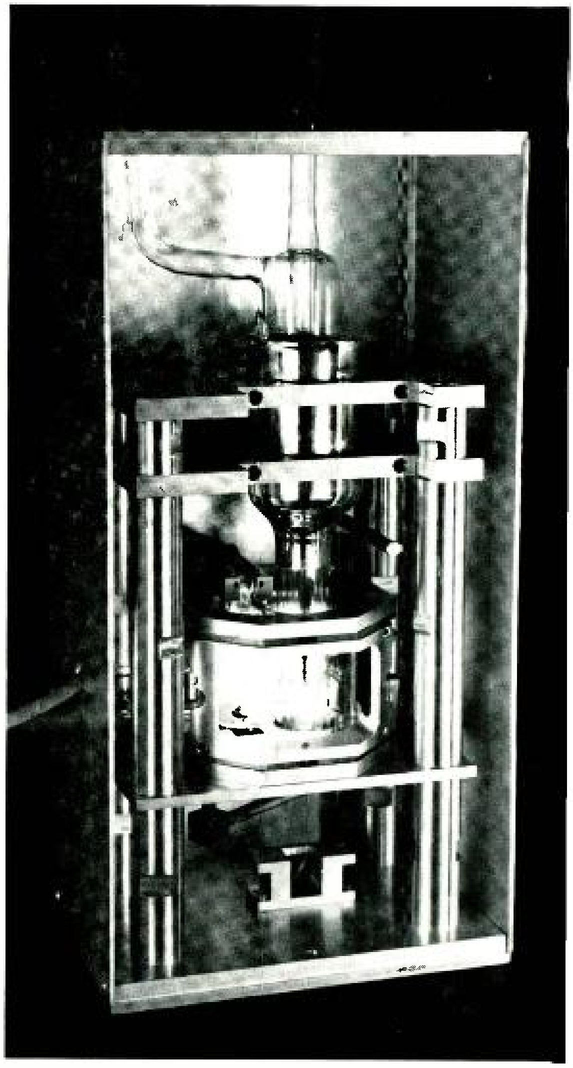


Fig. 4—Raster-to-line converter and film recorder for infrared-vidicon experimental airborne equipment.

Fig. 5—Closeup of a liquid-nitrogen-cooled, crystal laser; it is operated at about ¼-watt and pumped by an incandescent tungsten lamp.



low-light-level, and photometric measurements. Seven optical benches (two of 15-foot length), a high-quality gas laser, two Perkin-Elmer spectrometers (one a dual-beam), an infrared-optical target simulator, and numerous photometric and collimating equipments have been installed. The experimental physics laboratory contains: equipment for handling, forming, cutting and grinding glass and crystals; heat treating ovens; vacuum equipment for metal film deposition and low-temperature experiments and other similar equipments (Fig. 6). Through close liaison and working relationships with DEP Applied Research and the RCA Laboratories it has been possible to produce laboratory equipment and experimental device models at Burlington for use at those locations. Thus, the special facilities and the skills of the personnel are used frequently in supporting roles on many activities outside of Burlington rather than existing in duplication.

TECHNOLOGICAL CHANGES AND THE FUTURE TRENDS

There have been many technological changes in the past two years, particularly the impact of the laser and its fast-moving developments which affect future trends.

Table I gives summary information on how recent advances in fiber optics, video (image) data signal processing, and orthicon noncommercial engineering technology are enabling space surveillance systems to come into being;[4,5] until two years ago, such systems were impractical and unapproachable.

The laser area is an excellent example of electro-optics fast-changing technology; in terms of R&D contracts, this field in three years has moved from obscurity to a $20 million or greater annual effort. Fig. 7 shows the technical changes of one interesting parameter, that of peak power. The microwave approximate peak power achieved as the state-of-the-art progressed year-by-year is shown with the laser's capability; although the microwave device is far superior on an average power basis based on present art, the curves for this parameter show much the same interesting shapes. The microwave generating device shows the mature product curve characteristic; the laser device is barely past infancy.

Laser applications do not come automatically and certainly not in an immediate profusion. It appears, as in the case of practically all inventions, such as the steam engine, the rocket motor, or even TV, that a time lag follows the concept, the early demonstration models, and the first limited applications, before broader and more useful applications can be achieved. Thus, the device or machine must overcome economic and efficiency problems, technological or physical obstacles such as size, heat, noise, etc.) before it can compete successfully with existing and competitive approaches and find its proper place in the market.

Early applications of lasers include rangefinder equipments, satellite trackers, and wideband communication exploratory devices. Later, reconnaissance systems, radiation weapons, doppler navigators, missile guidance systems, and many other applications will utilize lasers. The Electro-Optical field is on the threshold of a new era made possible by the advent of the first precise and controllable light generators.

The Burlington Electro-Optics function will be an active part of this technological revolution, not only in the expected areas of impact by the laser devices but throughout the realm of optics and passive device design.

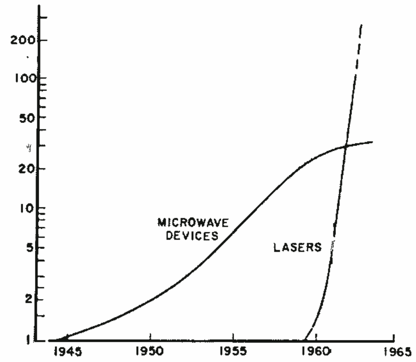


Fig. 7—Development curves of peak power for lasers and microwave devices.

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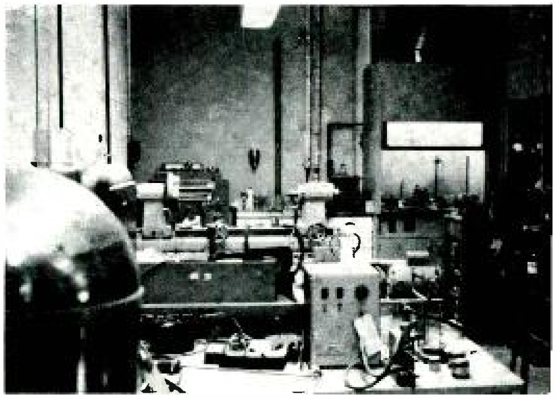
TABLE I—Electro-Optical Problems and Solutions

General Problem.	*Problem Examples*	*Solution*
1. Search a large, instantaneous field of view and achieve a high angular resolution	10° x 25° field of view and 15 seconds of angular resolution	Use 10 image tubes in parallel (each tube covers 5° x 5°) with fiber optics bundles to transfer a contiguous image from the curved optical image plane to the individual image tubes. Note: Fiber optics face plate tubes are required.
2. Low illumination	Scene illumination 10^{-1} ft-candles or less, star magnitude 10 or greater (i.e. dimmer)	a) Use special design fast optics (f-1.5 or less.) b) Use image orthicon or intensifier orthicon pick-up tube.
3. High background levels or other adverse conditions for point target detection	Uniform background equivalent to star magnitude 18 per square second of arc and star fields throughout the field of view	a) Video frame-to-frame subtraction (optical MTI to detect moving targets). b) Spatial electronic discrimination to detect point source targets.
4. Low contrast	(a result of problems 2 and 3 above but the advances in device technology enable handling separately)	a) Separate read-erase modes and automatic brightness control in the orthicons.

Fig. 6—Experimental physics laboratory.



J. H. WOODWARD received an AB degree in Engineering Sciences from Dartmouth College Thayer School of Engineering in 1941. After graduate study at Harvard, he joined the General Electric Co. in 1942. With General Communication Company from 1947 to 1959, he directed development and was program manager for a number of military contracts for ECM, magnetic recording, IFF operational and test equipment, and radar and microwave components. He was in charge of the development laboratory until 1952 when he became Chief Engineer. His association with RCA began in 1959 as Manager, Design Operations Integration in Burlington. He became Manager, Infrared Design and Development in 1961 and is currently Manager, Aerospace Surveillance Equipment Engineering in the Electro-Optical Engineering Section at Burlington and acting manager of the Laser Distance Measuring Equipment program. He is a Senior Member of the IEEE.

PASSIVE INFRARED TRACKING EQUIPMENT

Most applications of infrared equipment in the past have been limited directl or indirectly by the available detectors. Continuing progress in the development of detectors and of thermoelectric and closed-cycle liquid refrigeratio systems will extend the application and capability of infrared trackers and scanners. Additional development of electronically scanned imaging detectors fo the infrared will further enhance the art. Background radiation poses difficul discrimination problems for infrared equipment yielding poor false alarm rate for some equipment. Application of sophisticated signal processing technique developed at ASD Burlington and proven through extensive flight testing car improve the reliability and capability of future infrared trackers and seekers

J. H. WOODWARD, Mgr.
Aerospace Surveillance Equipment Engineering
Electro-Optical Engineering Section
Aerospace Systems Division, DEP, Burlington, Mass.

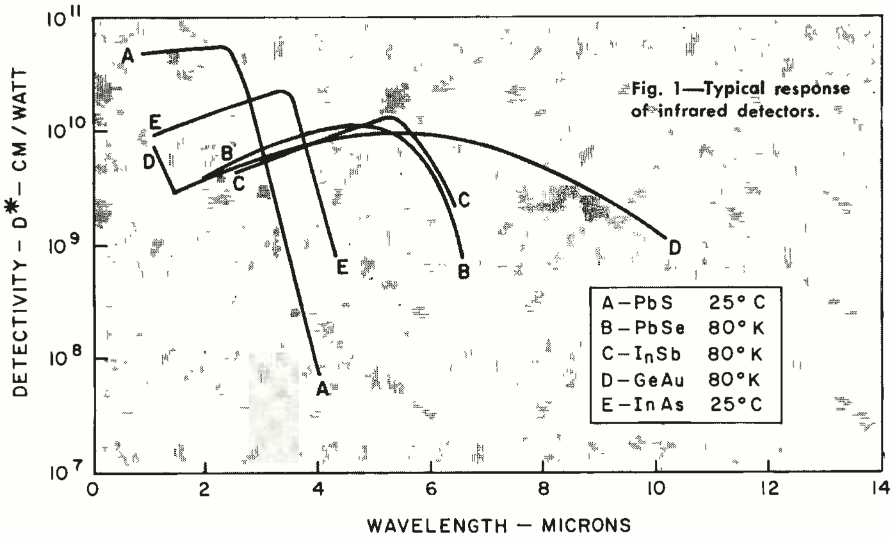


Fig. 1—Typical response of infrared detectors.

THE PROBLEMS of search, detection, acquisition, tracking, identifying or measuring objects in aerospace have been increasingly emphasized in recent years. Considerable effort has been expended on systems which are in themselves passive. For signal sources, such systems depend upon the direct radiation from the object of interest, or upon reflection of radiation from a natural source such as the sun.

The spectral region of passive detection operation ranges from a fraction of a micron to several tens of microns. In the shorter-wavelength region, the radiation source is at a high effective color temperature, typically sunlight or an engine igniting flash. Intermediate-wavelength systems may detect radiation from hot objects, such as engine manifolds, exhaust stacks, tailpipes, and plumes. Longer-wavelength equipments are used to detect radiation or differences in radiation from objects at temperatures near 300°K, and must generally sense very small differences in temperature or emissivity.

SYSTEMS APPLICATIONS

Passive systems have been developed for reconnaissance and surveillance, for acquisition and tracking, for warning and detection, for guidance and control and for monitoring and measurement. A multitude of variables is presented to the systems engineer in designing for these applications, but the choice may fortunately be narrowed by the specific application. Wide-field scanning may be required for reconnaissance and for search and detection. Image forming may be required for surveillance, but not for search. A narrow field of view may be adequate for a tracker if there is no initial acquisition problem, or both a wide acquisition and a narrow-track field may be needed. The optical aperture may be a compromise involving system sensitivity, field of view, spectral region, angular resolution, off-axis aberrations and installation constraints. Operation in the most desirable spectral region may require cryogenics which are logistically insupportable, or at best difficult.

The tradeoff study for each system application considers such factors as the nature of the target or scene of interest, its characteristic radiation, emissivity, reflectivity, range and trajectory. The nature of background radiation, large objects or point sources to be detected, single or multiple targets to be processed, real-time or recorded data required, must all be evaluated. On occasion no clearly defined choice of alternatives results from the study. In this event, previous experience with operational hardware of various types will indicate a preferred approach.

IMAGING SYSTEMS

A surveillance system usually requires imaging of the area of interest, accompanied by either real-time presentation of the image, or recording on film or tape. The use of electronically scanned detectors for surveillance has been generally restricted to the visible spectral region (0.4 to 0.7 micron) by the limitations of presently available, sensitive photoemissive and photoconductive surfaces.

Imaging systems operating in the infrared region have been constrained to rely for detection upon photoconductive or photovoltaic cells, with the field of view scanned mechanically by rotating optical elements. Limitations of data rate in these systems are established by the size and velocity of the scanned optics, the response speed (time constant) of the cells and the allowable limit of complexity imposed by use of a matrix or linear array of cells. Each cell element of an array requires its own amplification and display or recording transducer channel. Thus, a multiple element system is complex and cumbersome to implement. Electronically scanned infrared imaging detectors have been under development in recent years and may eventually be used to supplant the mechanically scanned systems. Of particular significance in this connection is the *iricon*, developed by RCA Electronic Components and Devices in their laboratories in Princeton.

DETECTION AND TRACKING

Tracking of objects by their gray-body radiation at elevated temperatures, or by the radiation bands of their combustion products can be accomplished in the near or intermediate infrared. The wavelength of maximum radiation from a black-body as given by the Wien displacement law is: $\lambda_m = 2891/T$, where T is the absolute temperature of the black-body in degrees Kelvin, and λ_m is the wavelength of maximum radiation in microns. (25% of the total radiation will occur at wavelengths shorter than the maximum, and 75% at longer wavelengths.) For black body temperatures between 2,000 and 600°K. the wavelength of peak emission will fall between 1.4 and 4.8 microns. Gray-body radiation from most types of aerospace vehicle engines will thus peak in these spectral regions.

Typical engine combustion products are carbon dioxide and steam. Radiation from these hot gases will predominate in the bands in which the cooled gases exhibit absorption spectra. Most prominent bands are the 2.8 micron region of both CO_2 and H_2O and the 4.3-micron CO_2 band. As a consequence of increased pressure occurring in the flame, the radiation bands tend to be broader than the corresponding atmospheric absorption bands. A gasoline flame, as from a blowtorch, exhibits this band radiation, with several times more energy near 4.3 microns than in the 2.8-micron region.

The range of a tracking system depends, in addition to the system characteristics per se, upon the target radiation density in the spectral region chosen (watts per steradian per micron) and the attenuation of the intervening medium. Within the atmosphere, attenuation results primarily from absorption by water vapor and carbon dioxide. *Windows*, regions of relatively lower absorption between attenuation bands, occur between 2.0 and 2.6 microns, 3.1 to 4.2 microns, 4.5 to 5.5 microns, and 8 to 13 microns. These are qualitative rather than quantitative windows, which broaden or narrow as a function of altitude, barometric pressure, and concentration of water vapor and carbon dioxide in the atmosphere. Mie scattering also contributes to a lesser degree to atmospheric attenuation but is usually negligible as compared to water vapor absorption in the lower atmosphere.

Under the assumption of a uniform, homogeneous propagating medium, the irradiance received at a tracker as a result of target radiation can be expressed by:

$$H_\lambda = J_\lambda \left[\frac{\exp(-aR)}{R^2} \right]$$

Where: H_λ = spectral irradiance at tracker, watts/micron/cm²; J_λ = spectral radiant intensity of target, watts/ster/micron; a = atmospheric attenuation coefficient; and R = range to target, cm. The signal received by the detecting cell is then:

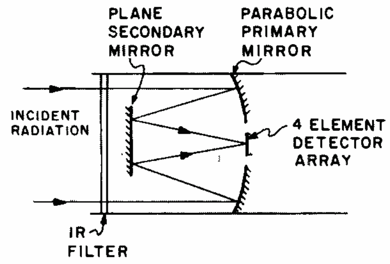
$$W = H_\lambda A_r K_r \Delta\lambda$$
$$= J \frac{A_r K_r \exp(-aR) \Delta\lambda}{R^2}$$

Where: W = power incident on call, watts; A_r = effective aperture of tracker optics, cm²; K_r = transmittance of total receiver optical system; and $\Delta\lambda$ = tracker bandwidth, microns. The tracker sensitivity is then a function of the detectivity of the cell in the passband of interest, and of the post-detection bandwidth.

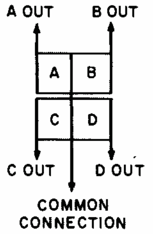
INFRARED DETECTORS

Factors which dictate the detector cell to be used in an infrared tracker are the choice of spectral region, the speed of response required, the gain, field of view and maximum allowable size of the optical system, the method of error signal generation, the nature of the propagating medium and of the background radiation, and the degree to which cooling and temperature stabilization can be utilized.

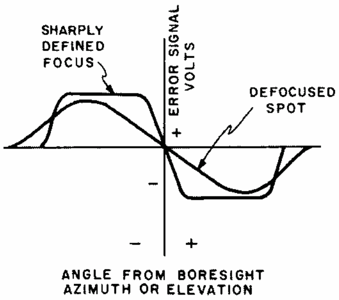
Two figures of merit are in general use for infrared detectors. These are the *detectivity* (D^*) and the *noise equivalent power* (*NEP*). The term D^* is a thoroughly circumscribed definition which attempts to encompass most of the significant factors relating to cell performance, requiring several sub-



a OPTICAL SCHEMATIC FOLDED PARABOLIC TELESCOPE



b 4 ELEMENT DETECTOR ARRAY CONFIGURATION



c EFFECT OF DEFOCUSING ON TRANSFER FUNCTION

Fig. 2—Monopulse optical tracker configurations: a) optical schematic of folded parabolic telescope, b) 4-element detector array and c) effect of defocusing on transfer function.

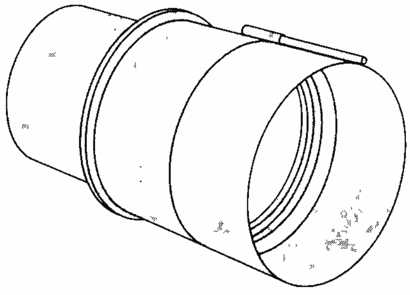
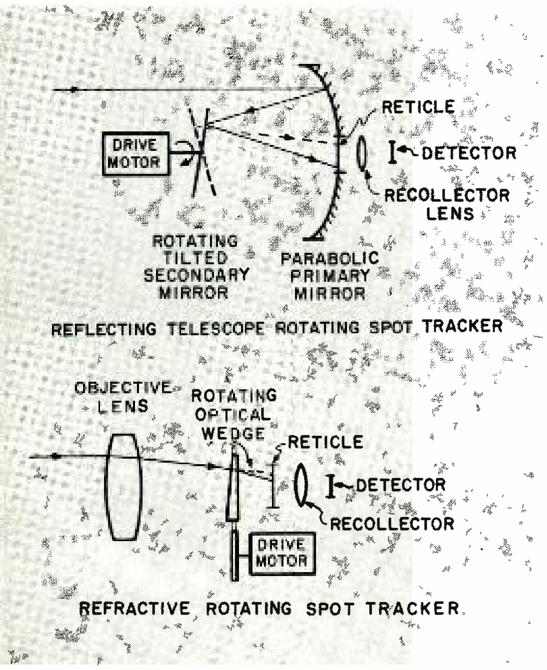


Fig. 3—Infrared plume tracker optical head.

scripts to define its frame of reference; *NEP* is the value of radiant power incident on the cell required to yield an output signal voltage equal to the cell noise voltage. Normally *NEP* is defined for a particular output signal frequency and bandwidth, and is measured by a chopped signal incident on the cell. The *NEP* may be measured at several wavelengths, or against a blackbody source, typically at 500°K. The dimensions of D^* are centimeters per watt; it is the reciprocal of the *NEP* multiplied by the square root of the cell area in centimeters, and by the square root of the output circuit bandwidth in cycles per second. Subscripts indicate either the blackbody source temperature in degrees Kelvin or the source wavelength in microns, and the center frequency of the output passband (the chopper frequency). Typical values of D^* for commonly used detectors vary from 10^8 to 10^{11} cm/watt.

The detectors most widely applied in the near infrared region utilize thin films of the photoconductive lead salts, particularly lead sulfide. Uncooled lead sulfide cells peak in response at about 2.4 microns, with significant response down to 1 micron, but fall off rapidly at 3 microns. Uncooled lead selenide peaks near 3.5 microns, with useful response at 1 and 5 microns. At liquid-nitrogen temperature (78°K) the spectral response of lead selenide and lead telluride are similar, peaking at nearly 5 microns.

Fig. 4—Two typical rotating spot tracker configurations.



Cooling of the lead salt cells increases detectivity by an order of magnitude or more, but also greatly increases both time constant and resistance. Time constants of cooled lead sulfide cells are of the order of several milliseconds, with typical impedances in tens of megohms.

The rapid development of indium antimonide (InSb) single-crystal photoconductive junction cells in recent years has produced detectors which, in most respects, exceed the lead-salt films. Cells of InSb are stable after exposure to extremes of temperature, have short response times, and detectivity approaching the background limited condition. Low cell impedance requires careful preamplifier design to minimize noise figure, but facilitates taking advantage of the fractional microsecond cell time constant. Optimum operation occurs at liquid-nitrogen temperature, with peak detectivity at 5.5 microns. Cells can be fabricated in almost any required size and aspect ratio, are readily mounted in dewars, and are stable and reproducible in characteristics. In most respects indium antimonide is the best available detector for the 3-to-6-micron region. The severe problem of liquid nitrogen cooling (for a field equipment) is a limitation of all high sensitivity detectors operating in this spectral region.

Indium arsenide cells permit operation in the 2-to-4-micron region with more modest cooling requirements. Maximum detectivity can be achieved at temperatures attainable with Peltier coolers, −80 to −100°C. Cells are stable and reproducible. Short time constants, high detectivity, and response peaking near 3.3 microns offer decided advantages over cooled or uncooled lead sulfide. The low cell impedance requires preamplifier optimization for noise figure and mitigates against operation at ambient temperatures.

Operation with high detectivity at longer wavelengths is accomplished with doped germanium or germanium-silicon alloy detectors. Minimum cooling requirement is pumped-over liquid nitrogen, with liquid neon or liquid helium temperatures desirable. The logistics and maintenance problems imposed by cryogenics have largely limited use of cooled long-wavelength detectors to installations where laboratory type conditions can be achieved.

Bolometers are applicable to temperature sensing systems for which speed of response is unimportant. Low detector impedance is best accommodated in systems in which the incident radiation can be modulated by chopping at a low audio rate. Narrow-bandwidth audio amplification following the detector yields optimum signal-to-noise ratio; detectivity characteristics of representative cells are shown in Fig. 1.

OPTICAL CONFIGURATION

Infrared equipments are generally broadband devices, necessitating the use of broadband optical elements and materials. To minimize chromatic aberration, first-surfaced, reflective optical elements are frequently selected. Irdomes or windows needed in most systems are chosen for high transmission in the spectral region of interest. Refraction introduced by these elements is minimized by design, and compensated for in the figuring of the reflective telescope. Quartz, sapphire, silicon and germanium, as well as a number of proprietary materials, are used in the near infrared for refractive elements and windows. Materials transmissive at the longer wavelengths (10 to 40 microns) tend to have less desirable mechanical and physical properties, are difficult to fabricate, may not withstand operational environmental conditions and may be toxic.

Telescopes for tracking systems are normally required to image point sources located within a few degrees of the optical axis. Either the detector or a modulating reticle is located at the image plane. Folded parabolic or Cassegranian telescopes have the virtue of placing the image plane behind the optical elements, so that cell leads, preamplifiers or dewars may be conveniently located without aperture blockage. In the near infrared, refractive optics are used for tracking systems; their performance can be optimized for a narrow field surrounding the optical axis.

Search and detection systems may require an instantaneous field of view which is fairly wide, in azimuth, elevation, or both, depending upon the scanning method used. A system which scans only in azimuth and depends upon a linear cell array for elevation coverage must maintain good imaging over the total elevation field. Spherical aberrations, coma, flare and defocusing must be minimized. Limitations imposed by materials and system bandwidth seriously compromise performance of intermediate infrared (4 to 6 microns) systems of this type. Somewhat better characteristics can be achieved in the near infrared.

BACKGROUND DISCRIMINATION

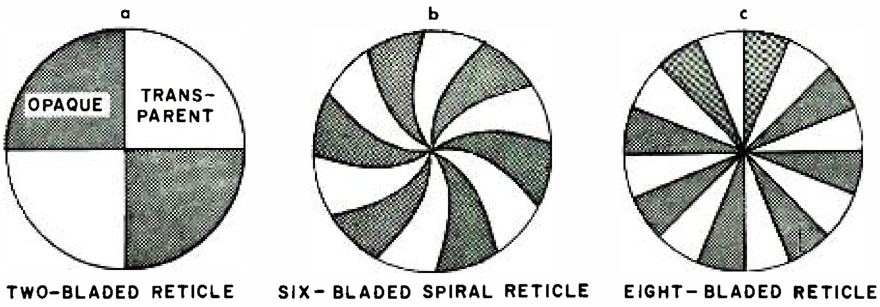
Infrared systems must function in an environment of radiation from natural or man-made sources other than the target. The sun may be excluded by shuttering or rejected logically by signal processing as a function of its extreme intensity or apparent angular width, but solar illumination of clouds and spurious solar reflections within an optical system pose severe problems. Spectral filtering can be implemented to maximize the ratio of target-to-background signal, by making the cut-on occur at as long a wavelength as possible without significantly attenuating the detectable target signal. Below about 3 microns, cloud reflection of sunlight is the predominant natural background. Above 4 microns, cloud radiation becomes significant. If the predominant radiation of the target of interest falls within a narrow spectral band, filtering and the choice of a detector to accept only the target radiation band generally provide optimum spectral discrimination.

Spatial filtering in tracking systems is generally limited to shaping of the reticle pattern so that little modulation takes place for an extended area source, or linear source, such as an illuminated cloud edge, or the horizon. In an imaging or raster scanning system, spatial discrimination can be implemented by the processing of the detected signals. Pulse-width discrimination is effective in a system with a small instantaneous field of view and a fast response detector. Line-to-line and frame-to-frame storage and comparison are effective in dealing with linear background sources. These techniques and more sophisticated extensions of them have been applied successfully to both electronically scanned and mechanically scanned equipments developed at Burlington.

If the source to be tracked has a unique modulation "signature" the signature may be demodulated and used as a means of discriminating between true target and background.

THERMAL LIMITS

Long wavelength systems are subject to limitations imposed by self radiation. Insofar as possible, the detector must be isolated from radiation of objects warmer than the detector itself, including supporting structures. Aperture and field stops, reticles or chopper blades, should, if possible, be cooled to near cell temperatures so that their radiation will not obscure the received signal or even saturate the detector.



TWO-BLADED RETICLE SIX-BLADED SPIRAL RETICLE EIGHT-BLADED RETICLE

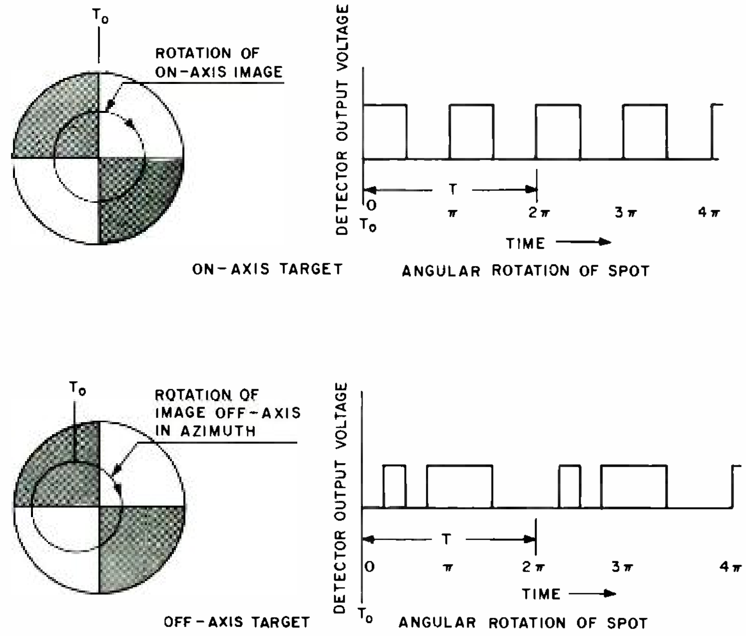
Fig. 5—Types of reticle patterns for rotating spot trackers: a) two-bladed reticle, b) six-bladed spiral reticle and c) eight-bladed reticle.

ENVIRONMENTAL STRESS

The design of mechanically scanned infrared trackers and search equipments to resist thermal and mechanical stress is an exacting task because of the nature of the materials used and the dimensional stabilities required. Glasses, sapphire, and quartz have relatively low thermal conductivity, resulting in uneven stresses when heating or cooling. Elements of these materials may be mounted by clamping, with resilient gaskets or spring members to prevent chipping and to allow for differential expansion between the element and the supporting metal. Invar, Nyspan and other ferrous alloys with expansion coefficients approximately matching those of the optical materials must be used when the optics are bonded directly to the metal. Adhesives, usually epoxy- or rubber-based, must be carefully controlled to minimize local stresses on the optics. Focal distances between optical elements and detectors may have to be maintained within a few thousands of an inch over a range of temperature of 150°C. The requirements for matching thermal coefficients, extreme stability and precision are usually coupled with severe size and weight restrictions, necessitating sophisticated and elegant design.

Vibrational stresses can result in serious microphonics, because most infrared detectors are somewhat microphonic, and amplifiers must handle microvolt signal levels. Stiff design, to raise the structural resonant frequencies as high as possible, and local or overall isolation mounting may be required. Relative motion between the detector and the optics can result in modulation of the received signal at the frequency of the

Fig. 6—Error signal developed in on-axis and off-axis targets.



DUAL FIELD SPIRAL "FM" RETICLE

CARDIOD"PULSEWIDTH" RETICLE

DUAL FIELD STRAIGHT BLADE "FM" RETICLE

Fig. 7—Three rotating reticle patterns: a) dual-field spiral FM, b) cardioid "pulse-width," and c) dual-field, straight blade FM reticle.

induced vibration. This cannot be tolerated. Optical systems which rotate relative to a fixed detector are particularly susceptible to this difficulty. Although designs of this type may be necessary with liquid cryogenic detector cooling, little short of complete vibration isolation will permit their operation in a vibration environment.

Drive mechanisms for scanning optics must be designed to accommodate wide temperature variations without significant change in gear tooth clearances. Gears must be of fine pitch, but with wide tooth faces for low unit stress. Choice of bearing type and fit must be such as to minimize radial and end play under all combinations of vibration and temperature.

Flight testing of Burlington-designed equipment has demonstrated that it is possible to design and fabricate units which will perform their intended function under conditions as severe as —60°C temperature and vibration to 10 g at 600 cps and to 6 g at 2,000 cps.

TRACKING EQUIPMENT

Tracking of targets with infrared passive systems can be simply accomplished with a degree of accuracy not achievable with radar, by virtue of much shorter wavelengths and resultant narrower beamwidths. Error signals are generated in a variety of ways, by monopulse cell configuration, nutating spot or rotating reticle, to produce amplitude, frequency, pulse width, or pulse time modulation varying as a function of target position. Fig. 2 illustrates a monopulse configuration in which a folded reflective telescope images the target on a four-cell detector array. If *A*, *B*, *C*, and *D* represent the signal outputs from cells *A*, *B*, *C*, and *D*, respectively, the error signals can be written by inspection, as follows.

Elevation channel:

$$e_e = \frac{(A+B)-(C+D)}{A+B+C+D}$$

Azimuth channel:

$$e_a = \frac{(A+C)-(B+D)}{A+B+C+D}$$

Fig. 2 illustrates the effect on the tracking-error transfer curve produced by varying the focus of the target image. A sharply defined image will yield the steep transfer curve which reaches saturation for relatively small bore-sight error. The second type of transfer curve occurs for a spot so defocused that an appreciable portion of the received energy impinges on each of the cells except when angular positional error is large.

A tracker of this type was developed by ASD Burlington for the DEP Missile and Surface Radar Division (Moorestown) as an adjunct to the AN/FPS-16 radar to allow lift-off tracking of missiles in the presence of radar ground clutter. The unit, which consists of the folded optical system, germanium window-spectral filter, quad-cell detector, solar shutter and preamplifiers is shown in Fig. 3. This tracker head is mounted on the axis of the FPS-16 antenna ahead of the feedhorns. A particular feature of this system which contributes to its successful operation is its use of the modulation inherent in the target plume to provide a signal for tracking. Selection of proper limits for the audio passband for the signal provides discrimination against background caused by artificial light sources. The use of the AC signal component eliminates the necessity for DC balance of the detectors, chopping of the signal either pre- or post-detection, or the use of DC amplifiers. The tracker error signal is demodulated and processed to operate the radar servo system thus driving the antenna to maintain boresight so that switchover from infrared to radar mode can be accomplished after ground targets have left the radar field of view.

Conical scanning is also used to develop tracking error signals. Typically it is accomplished by rotating a wedge or tilted secondary mirror so that the target image traverses a circular path in the focal plane. Positional modulation of the target signal is produced by a reticle which consists of an opaque pattern on a transparent substrate, normally located at the image plane. A re-collector lens or light pipe may be used between the reticle and detector to permit the use of a small area cell. Fig. 4 displays diagrammatically a rotating spot optical configuration. Several reticle patterns are shown in Fig. 5. The type of error signal developed by the most rudimentary of these patterns appears in Fig. 6. Error information is of the ρ-θ type, with θ given by signal phase relative to a time reference synchronized to the rotating element and ρ by the ratio of maximum to minimum pulse duration. Many-bladed reticles perform in a manner analogous to the two-bladed one, but yield higher modulation frequencies for a given rotational speed.

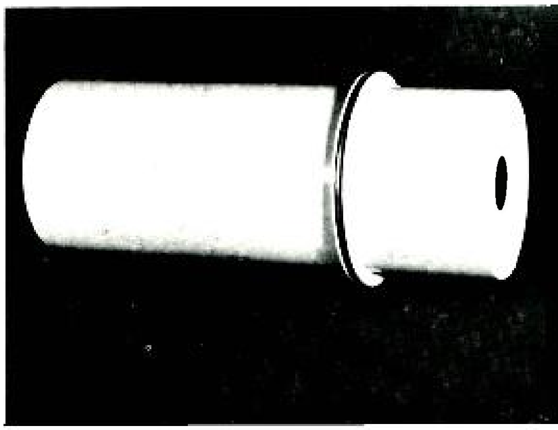
Another type of scanning is accomplished by rotating a reticle located at the focal plane of a fixed optical system. The FM reticle shown in Fig. 7a produces modulation having increasing frequency deviation, both positive and negative, from a mean modulation frequency as target deviation from boresight increases. A measure of spatial discrimination against linear targets (e.g., the horizon) can be provided by curving the blades of the reticle in a spiral pattern.

Error sampling rate for either the rotating spot or the rotating reticle configuration is identical to the rotational speed of the spot or reticle, although the modulation frequency may be much higher, depending upon the number of reticle blades.

An equipment combining both of these types of scanning, developed for tracking a missile having a flare source, is shown in Fig. 8. This unit has two separate telescopes and detectors, with a

Fig. 8—Infrared command unit tracker head.

Fig. 9—Miniature radiameter.



single motor driving the scanning mechanism for both. A rotating spot scan is used with a relatively long-focal-length reflective telescope to provide a tight inner-field tracking loop. A rotating reticle at the focal plane of a wide field, refractive triplet develops the acquisition field error signal. Detectors are uncooled lead sulfide.

RADIOMETRY

Thermal detectors of the bolometer type offer flat response out to 40 or 50 microns and may be applied to remote temperature or radiation measurement. A miniature radiometer for balloon or missile-borne operation developed at ASD-Burlington, is shown in Figs. 9, 10, and 11. Measurement is made by alternately exposing the flake bolometer detector to the radiation to be measured and to a source of constant temperature and emissivity, by a rotating chopper. The chopper blade, bolometer, and preamplifier are maintained at a temperature of 75°C by means of a precision temperature controller and copper heat sink. The AC signal from the bolometer is amplified by a stable-gain amplifier, synchronously detected at the output to provide a DC analog of the incident radiation. Synchronous detection is accomplished by a mechanical commutator on the same shaft as the radiation chopper.

The optical window of this equipment is of thallium bromide iodide, (KRS-5), which transmits throughout the region of 0.5 to 40 microns. The unit is designed to have a conical field of view without collecting optics of 55°. Optical gain and field narrowing can be achieved by the addition of an external telescope.

HORIZON AND PLANET SENSORS

Many missile and satellite missions require vehicle positioning with respect to the earth's horizon or the centroid of a planetary object. Infrared detection of the contrast at the horizon between planetary radiation and that of space provides effective horizon detection. Scanning may be accomplished by vehicle spin and angular horizon or interhorizon distance determined from synchronized time references. Wide field optics may be used with a monopulse type of cell array for detection and position sensing. The unit may be servoed to track the centroid of the planet, or positional information fed to navigation or guidance equipment. Communications from space vehicles to earth require pointing of the directional antennas toward the earth. An infrared tracker provides a simple and reliable means of maintaining proper antenna orientation in the absence of RF signals. For this application, data rates need not be high and signal contrast is excellent, making bolometers very suitable detectors.

CONCLUSIONS

Most applications of infrared equipment in the past have been limited directly or indirectly by the available detectors. Continuing progress in the development of detectors and of thermoelectric and closed-cycle liquid refrigeration systems will extend the application and capability of infrared trackers and scanners. Additional development of electronically scanned imaging detectors for the infrared will further enhance the art.

Background radiation poses difficult discrimination problems for infrared equipment yielding poor false alarm rates for some equipment. Application of sophisticated signal processing techniques developed at ASD Burlington and proven through extensive flight testing can improve the reliability and capability of future infrared trackers and seekers.

ACKNOWLEDGEMENTS

Many individuals have been responsible for the development of infrared cell equipment at Burlington. Particular contributions have been made by L. Alston, W. Barratt, E. Corey, D. French, R. Guyer, J. Lefebvre, G. Sievers, H. Slade and J. Stakun. E. Kornstein and C. Park have provided support in the review and generation of optical concepts and designs. T. Haddad has fabricated and coated a variety of optical elements for experimental efforts. The tracking augmentation for the FPS-16 was made possible by the enthusiastic cooperation of R. Paglee and R. Harralson of M&SR.

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Fig. 10—Miniature radiometer of Fig. 9—base electronics.

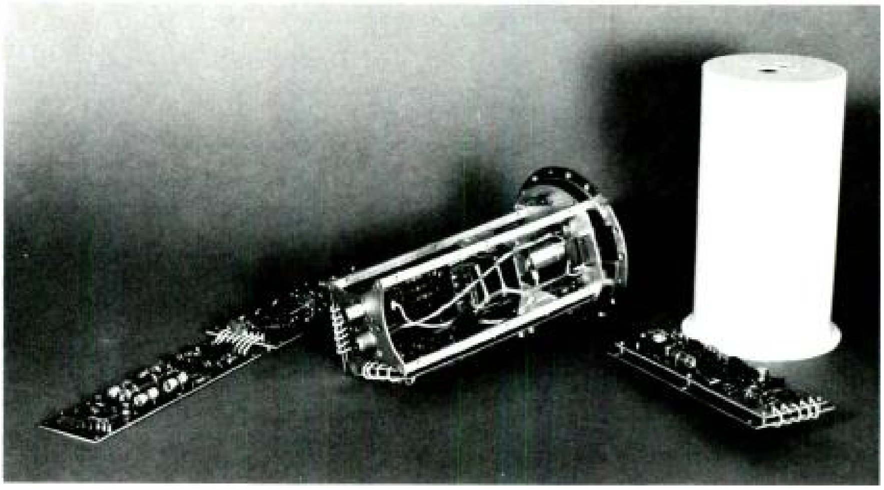
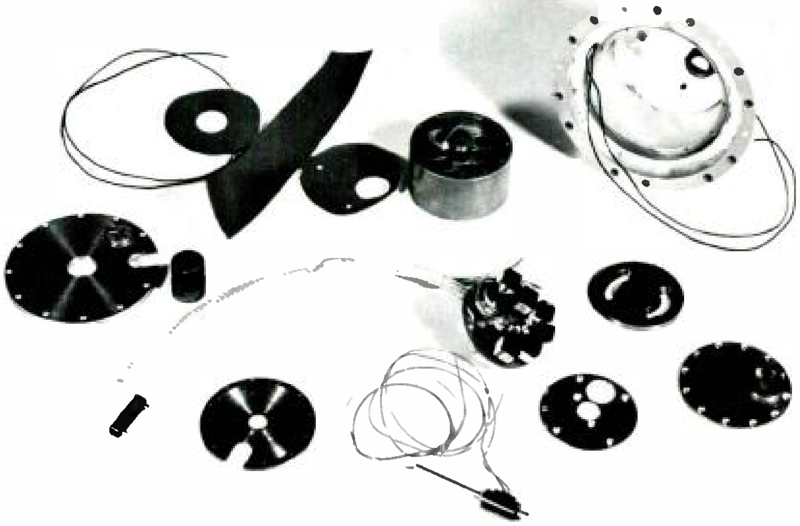
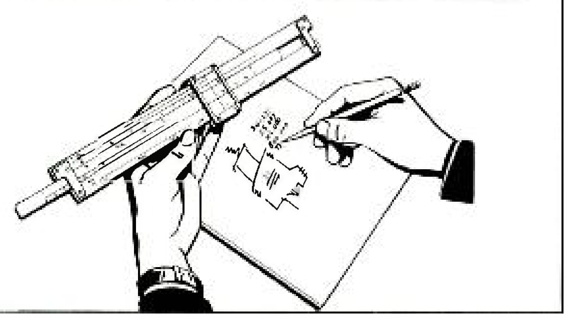


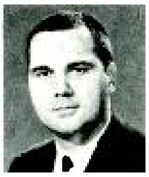
Fig. 11—Miniature radiometer of Fig. 9—thermally controlled sensor head, disassembled.



Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST





An S-Band Traveling-Wave Maser With a 30% Tunable Bandwidth

D. J. Miller, *Applied Research, DEP, Camden, and*
H. B. Yin, *Missile and Surface Radar, DEP, Moorestown, N. J.*

Chromium-doped rutile and a meander-line slow-wave structure have been combined into a traveling-wave maser having a 3-db tunable bandwidth of 30% at s-band. This method is limited only by the tunable bandwidth of the slow-wave structure and the noise temperature of the maser.

Meander lines exhibit very wide passband characteristics. The region of high slowing is in the order of several hundred megacycles at s-band. However, the meander line propagates frequencies above and below this high slowing region with very low loss. The two curves in Fig. 1 show typical measured slowing factors of an unloaded meander line with a finger length of 0.600 inch, a finger width of 0.040 inch, and an air gap of 0.020 inch and 0.040 inch, respectively. The slowing factor is increased and the bandwidth is decreased by reducing the air gap. Since rutile has a very high relative dielectric constant (100 to 250), the slowing factor is considerably increased by the dielectric loading.

The dielectric loading and the meander-line finger length determine the center frequency of the passband. The solid line in Fig. 2 is a typical measured gain-versus-frequency curve for a meander-line traveling-wave maser over the frequency range from 2 to 3 Gc. The length of the rutile crystal used was 2.5 inches, with the rutile itself being on one side of the meander line and the ferrite on the other side. Maser tunability was accomplished by varying the pump signal and the dc magnetic field for the corresponding signal frequency. The 3-db tunable bandwidth was about 270 Mc and the center frequency could be shifted by varying either the finger length or the dielectric loading, or both. However, the width of the active material had to be comparable to the finger length (approximately 80% of the finger length) in order to maintain a good filling factor (i.e., RF energy coupled to the rutile). For a fixed finger length, wider rutile resulted in a lower center frequency. Similarly, a longer finger length lowered the center frequency if the width of the rutile remained fixed.

Fig. 1—Typical slowing of an unloaded meander line.

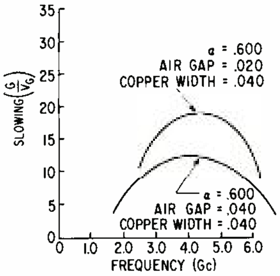
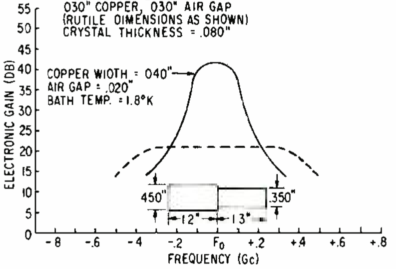


Fig. 2—Comparison of gain for no stagger tuning and stagger tuning for same length of active material.



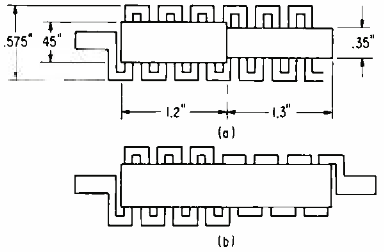


Fig. 3—Various stagger tuning techniques.

Since the insertion losses are very low above and below the region of high slowing, it is possible to stagger-tune two maser amplifiers to increase the operational tunable bandwidth. The stagger-tuning is done by varying either the dielectric loading or the finger length, or both, as mentioned above. The dashed line in Fig. 2 shows the results of stagger-tuning a meander-line maser by varying the dielectric loading; i.e., one section of the meander line is loaded with a slightly wider rutile bar. The total length of the active maser is only 2.5 inches, with the wide section of the rutile 1.2 inches long and the narrow section 1.3 inches long, as illustrated in Figure 3a. The tunable bandwidth obtained is 800 Mc, showing the feasibility of multiple crystal loading incorporated into a single structure. Notice, however, that this would not be feasible if the passband of the slow-wave circuit was inherently narrow.

Fig. 3b illustrates a different version of loading that will result in a similar effect. In this case the finger length is the varying parameter. Similar experiments are being conducted to investigate this technique.

Acknowledgement: Lewis C. Morris, John P. Lauriello and Edgar Denlinger assisted in performing the experiments.

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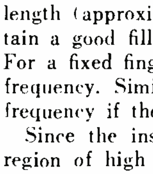

A Suggested Approach to Local-Noise Discrimination

N. I. Korman, *Director, Technical Programs, (DEP & EDP), Princeton, N. J.*

From the very earliest days of radio communications, it has been recognized that the most important sources of noise for all wavelengths greater than several meters have been external to the receiver itself. Much effort and ingenuity has been devoted over the years to minimize this noise.

It came as some surprise to this writer therefore to find that apparently little, if any, thought had been given to the utilization of the well-known property of radiated energy *that the electric and magnetic field vectors have a fixed ratio and are in time phase with each other.*

Radio signals and noise from distant sources are radiated signals and possess this property. However, local noise, such as is particularly troublesome on mobile equipment which cannot always locate itself in noise-free areas, should *not* in general possess this property. It therefore could be discriminated against with a receiver in which the electric and magnetic components of the wave are independently picked up, amplified, and then detected together in a multiplier circuit. Such a receiver would have the property of being relatively insensitive to noise components in which the electric and magnetic vectors are not in the proper ratio and are not in time phase with each other.

Fig. 1 shows how this might be accomplished: The key component is the detector which is variously known as a *phase detec-*

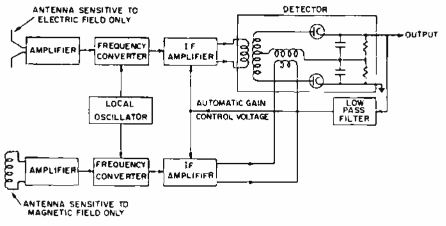

Fig. 1—Suggested receiver system.

tor, or *balanced modulator*. It has the property of providing a detected output which is the product of the two inputs. Such a receiver would be considerably more expensive than one not containing this particular feature. The increase in performance would depend to a large measure on the characteristics of local noise encountered in specific applications. Since there is probably little data available as to the actual characteristics of various local noise sources, the increase in performance of such a receiver would have to be tested in real situations to determine whether the extra cost involved were justified.

Upper Limit of Time Dispersion in Transmission Secondary-Electron Emission

D. J. Blattner, H. C. Johnson, *and* F. Sterzer,
Electronic Components and Devices, Princeton, N. J.

The time dispersion in emission of secondary electrons from conventional reflection-type secondary emitters is known[1] to be less than 7×10^{-11} second. This *Note* describes a measurement of the upper limit of time dispersion from transmission-secondary-electron-multiplier (TSEM) films;[2] i.e., in multipliers where the primary electrons are incident on one side of a film, and the secondary electrons are drawn from the opposite side. A knowledge of this dispersion time is important for the understanding of the secondary-emission process, and also in the design of multiplier tubes for studying high-speed phenomena[3] such as mixing of laser beams or laser modes, detection of light modulated at microwave frequencies, and high-resolution coincidence measurements with nuclear scintillation counters.

The TSEM dynode studied (Fig. 1) consisted of a sandwich of three films: a porous supporting substrate of AL$_2$O$_3$ which is 500 angstroms thick, a conducting film of aluminum 150 angstroms thick, and a film of the emitting material, KCl, 500 angstroms thick.

The time dispersion in such films can be measured by amplifying an amplitude-modulated (bunched) electron beam in the film, and determining the degree of debunching, if any, that occurs. The debunching becomes appreciable if the time dispersion approaches the period of the modulation frequency.

A convenient vehicle for measuring debunching is a helixtype microwave phototube.[4] Such a phototube can operate with modulation periods of fractions of a nanosecond, and its power output at a given frequency is proportional to the square of the depth of modulation of the electron beam at this frequency. Debunching of the electron beam results, therefore, in a lower power output. This drop in power output can be accurately measured, and can be correlated with the amount of debunching and, therefore, with the time dispersion in the film.

The experiments described compared the power outputs of a conventional microwave phototube and a microwave phototube equipped with a TSEM dynode. Care was taken to make the two tubes as similar as possible except for the inclusion of the TSEM dynode in the gun of one tube. To produce the bunched electron beam, the photocathodes of the tubes were illuminated by a He-Ne gas laser operating at 6,328 angstroms. This laser was adjusted to operate in purely longitudinal modes. As is well known,[5] these longitudinal modes mix in a photocathode and produce a modulated electron beam with modulation frequencies that are approximately integral multiples of the frequency spacing between adjacent modes.

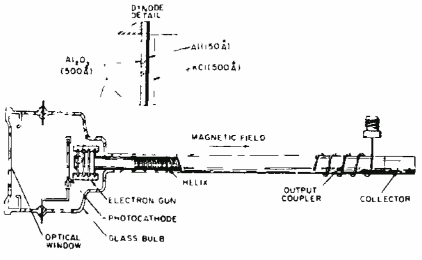

Fig. 1—Microwave phototube with transmission secondary electron multiplication (TSEM) dynode.

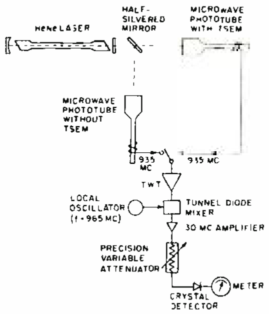

Fig. 2—Experimental arrangement for studying time dispersion of secondary electron emission in thin dielectric films.

In the TSEM tube shown in Fig. 1, the modulated primary electron beam was first amplified by the TSEM dynode, and was then focused by means of an axial magnetic field through a traveling-wave-tube helix. The bunched beam excited an RF traveling wave on the helix that was taken off at the output coupler. The mode spacing of the laser used was approximately 94 Mc, and the tube voltages were optimized for maximum power output at the tenth difference frequency (~935 Mc). The output of the tube was amplified in a traveling-wave tube, heterodyned down to 30 Mc, amplified in an IF amplifier, fed into a crystal detector, and displayed on an output meter as shown in Fig. 2.

In the experiment, great care was taken to insure that all measurements were made under the following conditions:

1) The same collector current in both tubes. (The light incident on the TSEM tube was attenuated with a neutral density filter to compensate for the TSEM gain.)
2) Current interception on the helix less than 15%.
3) Constant laser excitation.
4) The distance of the output coupler from the electron gun the same in both tubes.

The experiments revealed no differences in the power outputs of the two tubes. The accuracy of the experiment was such that any deterioration in power output of the TSEM tube exceeding 2 db would have been detected. If it is assumed that the time dispersion of secondary emission is Gaussian, it can be shown that 2-db deterioration of power output from a TSEM tube corresponds to time dispersion with a half-width of about 2×10^{-10} second. Thus 2×10^{-10} second represents an upper limit for the time dispersion in transmission secondary-electron emission from thin KCl films.

Acknowledgements: The authors are grateful to Dr. J. E. Ruedy for fabricating the photocathodes and the TSEM dynode and for supervising the construction of the microwave phototubes, and to Dr. G. A. Morton for many valuable discussions.

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Mechanical Integration of Spacecraft—Problems and Procedures

T. D. Tilton, *Astro-Electronics Division, DEP, Princeton, N. J.*

Spacecraft mechanical integration begins when the hardware concept is firmed and continues through the fabrication, shipping, and prelaunch phases. The effort, thus, is primarily divided between design optimization at the fabrication site, and ensuring operational capability at the launch site. The mechanical integration function begins by listing the specific components of each subsystem—since during the early stages of a project, these are considered (and referenced) in groups of components (the power-supply subsystem, etc.). Since many parameters limit the mechanical design and arrangement of a payload, a *matrix* is developed, listing separately each component involved and the limiting factors for each unit (Table 1).

TABLE 1—TYPICAL MATRIX OF SPACECRAFT COMPONENTS

Component	*Physical Characteristics*			*Environmental Requirements*				
	Weight pounds	*Dimensions l x w x h inches*	*Location of Center of Gravity* (inches)*	*Position*	*Electrical Condition*	*Thermal Condition*	*Sensitivity to RF*	*Sensitivity to Vibr.*
camera No. 1§	6.31	13 x 4 x 5	−0.5	Axial†	grounded	n.r.	high	high
camera electronics	3.18	7 x 3 x 5	2.3	n.r.	isolated	n.r.	n.a.	n.a.
battery pack No. 1	13.71	6 x 4 x 4	3.0	n.r.	grounded	grounded	n.a.	n.a.
battery pack No. 2	13.71	6 x 4 x 4	3.0	n.r.	grounded	grounded	n.a.	n.a.
tape recorder¶	9.85	13 (dia) x 6	1.7	Axial‡	isolated	n.r.	mod.	high
tape control assembly	3.43	6 x 3 x 6	3.0	n.r.	n.r.	n.r.	n.a.	n.a.
tape rec. pwr. supply	4.72	7 x 4 x 6	2.9	n.r.	n.r.	grounded	n.a.	n.a.

* Referenced to mounting plane
†Optic axis parallel to spacecraft spin axis
‡ Axis of rotation parallel to spacecraft spin axis
§ Optical axis alignment tolerance: ±2 minutes angular deviation
¶ Container pressurized
n.r.: no restriction n.a.: not applicable Mod: moderate

When the development of this "bible" is complete, the first layout of a component arrangement is possible. At this point, a clear definition is needed of payload requirements such as the center-of-gravity position, dynamic and static balance limits; and inertia ratio. When the arrangement layout is first completed, these parameters are calculated, and then such rearrangement as might be necessary to get each parameter within its limit is made. A wiring harness is then fabricated; and simultaneously the component arrangement is accurately laid out on a Mylar sheet, to be used as a template. The baseplate is then drilled from the template (usually to a pilot-size hole) and the initial fitting of boxes to the mounting surfaces of the structure begins.

It is at this point that the mechanical conflicts are inevitably discovered; the causes traced; and changes to the arrangement and the pertinent drawing are introduced so that a compatible arrangement of components is established.

After completion of the initial component assembly and harness installation, the electrical debugging operation is performed. Upon satisfactory electrical checkout, final mechanical assembly is completed and the spacecraft is put into flight configuration for environmental testing. Important to this preparation is the balancing done in one of two machines: the horizontal unit (fabricated at AED, Fig. 1) or the vertical unit (built to AED specifications). After determining the unbalance, it is eliminated either by adding lead or brass weights, mechanically fastened in place, or by casting weights in place, using a Cerrobase alloy (a low-melting point alloy, used to avoid overheating of temperature-sensitive components). The present capability at AED is a 1,500-pound spacecraft, rotation speeds up to 500 rpm, and a sensitivity of balance of 0.001 inch center-of-gravity offset statically and $\tan^{-1}$ 0.0001 angular deviation dynamically between the geometric and principal inertia axis.

Moment-of-inertia and center-of-gravity control and determination is performed on a bifilar system (Fig. 2) consisting of two 30-foot wires suspended from load cells for force equalization, and supporting a universal bar to which any spacecraft or object may be attached. The period of oscillation is measured by feeding a signal from a collimated light source which is reflected by a mirror, mounted on the bar at the point of revolution, into an electronic counter. Measurements taken of the equalized load on the universal bar provide the location of the center-of-gravity, and the moment of inertia is determined using the general formula $I = (wr^2t^2)/4\pi^2l$, where I is the moment of inertia, w is the total suspended weight, r is half the distance between suspension wires, t is the period of oscillation, and l is the length of the suspension wires. Accuracy within 0.2% is obtained by this method.

Setups for many special tests have been constructed by the Mechanical Integration group. One such test is the determination of the angular relationship between various sensors on a TIROS spacecraft. Other tests of this nature have been the despin rate determination of TIROS and other spacecraft, the transmission capability of RELAY at sustained high spinrates, and the camera angle and field of view determinations on RANGER.

Handling procedures are worked out and auxiliary equipment is designed and fabricated for all handling and assembly, from start of assembly, through all testing, to delivery of the spacecraft at the launch site. This phase of mechanical integration is one of the most demanding requirements imposed. This is because the surfaces of many presently-designed spacecraft are part of the thermal-control system, and many have unprotected sensors or solar-cells at the surface. Various types of protective shields are developed and applied, but additional protection in the form of constant vigilance in every move made in the vicinity of a spacecraft also is necessary.

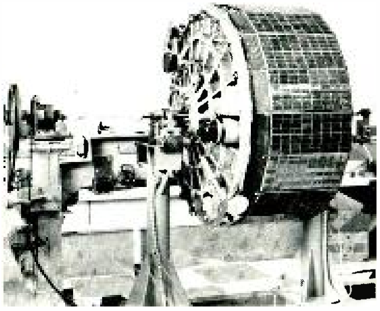


Fig. 1—Horizontal balancing machine with a TIROS in place.

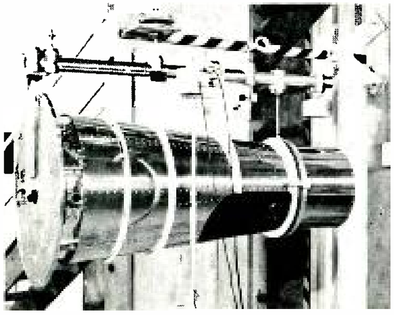


Fig. 2—Bilfilar system.

Problems relating to the interface between the final stage of the launching vehicle and the spacecraft are worked out in conjunction with the vehicle launch team and vehicle builders. After delivery at the launch site, the spacecraft is given a final mechanical check. Antennas and spin rockets are installed. The payload is then given a final electrical check, and is delivered to the vehicle team for assembly with the final stage rocket. This and subsequent operations up to installation on the previously placed booster stages of the vehicle is monitored by Mechanical Integration personnel. The final contact is made as the nose-cone fairing is installed, just prior to actual firing and liftoff.

Acknowledgement: The assistance of H. Van Elkan in the preparation of portions of this *Note* dealing with dynamics is gratefully acknowledged.

A New Concept in Packaging for the Space Environment

M. WADIAEFF, *Astro-Electronics Division, DEP, Princeton, N. J.*

Space, weight and power limitations in satellites generally dictate the use of miniaturized components and the AED Electro-Mechanical group is using, or experimenting with, minimods, micromods, welded-cordwood modules, and integrated and molecular circuits. At times, however, conventional components may be specified, or a short lead time may be scheduled, or RF radiation shielding problems may be encountered, thus requiring a different approach.

New Concept: Recently faced with the above problems, a novel concept was followed in package construction: the use of *molded fiberglass* instead of sheet metal. Molded fiberglass is light, inexpensive to manufacture, has excellent dielectric properties, and has excellent shock and vibration damping qualities; it is used extensively in tough applications such as rocket motor casings, and in everyday electronic use in printed-circuit boards. In addition, it is a good base for metal plating, and the tooling required to make containers from it can be made economically of wood. Therefore, in small runs molded-fiberglass containers can be made cheaply, accurately, and quickly.

One problem is gaining acceptance of it for space applications. Also, when large quantities are required, molded fiberglass containers cannot compete with sheet metal containers made with the proper tooling.

Two packages using molded fiberglass were designed at AED: a *command receiver* for the RELAY satellite and a *power control unit* for the RANGER satellite.

RELAY *Command Receiver:* On the command receiver, which was to be redesigned electrically and improved, the new package was to replace the old one, at the same location, without interfering with other packages. The original command-receiver case was 0.040-inch-thick sheet aluminum, in which two back-to-back receivers were separated by a copper-coated fiberglass board. Each receiver had a separate ground plane, electrically isolated from the case, but RF-connected to the case through capacitors.

In operation, it was found that: 1) the radiation leakages into the command receiver, or from the receiver to other functional boxes, were objectionable; 2) it would be advisable to add a number of RF filters; and 3) it would be more convenient to stack the receivers on top of each other (rather than back to back) to simplify the cabling.

While a molded-fiberglass case would reduce fabrication time required by the more complex new configuration, the prime advantage was that selective copper plating would insure that the two different grounds required were available with complete separation of the inside ground from the outside ground. An additional bonus would be the ability to select the power-supply polarity to be grounded.

The new command-receiver case was made of two shells, identical except for mounting flanges. The receiver mounted on the RELAY structure has flanges that extend on two sides and in the back (side opposite connectors) to pick up the mounting hardware, as in the earlier command receiver. The cover of the first receiver is made slightly heavier with two partial flanges (because of the interference with other packages) on the sides and one flange in the back. The other receiver with matching flanges is mounted on the cover of the first receiver. A lighter cover closes the second receiver shell.

Grounding planes were established by selectively plating shells and covers with copper (0.002 ± 0.001 inch) and flash gold; with an unplated glass epoxy area separating the two plated sections. The RF radiation was eliminated by making wrap-around covers and by using Metex shielding in grooves around the edge of the container (Fig. 1) which is squeezed tight by the covers. The stand-offs, made of copper-gold plated glass epoxy, ground the printed circuit board with its components to the inside ground, but not to the outside or vehicle ground.

RANGER *Power Control Unit:* Another application of molded fiberglass packages was the RANGER *power control unit* (Fig. 2). In this unit, lead time was also short, space extremely small, and components big and different (two GE tantalytic capacitors with dimensions of 1.312 by 0.75 by 1.275 inches, a minimum of five Potter and Brumfield relays, two Silicon Controlled Rectifiers, two 15-pin Cannon connectors, a number of diodes, several quarter-watt resistors, and a cable harness).

To save space, the new package eliminates all mechanical clamping devices and relies entirely on an egg-crate fiberglass shell to position the components. The shell is 3.25 by 3.45 by 2 inches, and weighs 18 ounces. For this construction, the molds are simple with wide tolerances, utilizing wood blocks or other inexpensive material. The "egg-crating" was simply done with standard fiberglass boards (G10/G11) by cutting them to size, cementing them in the molded shell with epoxy, and curing the whole unit.

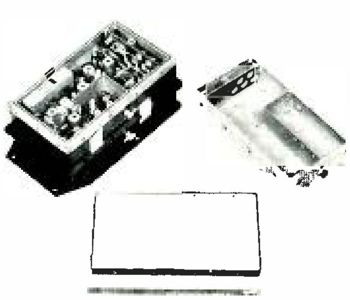


Fig. 1—RELAY command receiver container with receiver in place.

Fig. 2—RANGER power control unit, interior view.

Environmental Tests: Both these shells were subjected to all the environmental tests specified for RELAY and RANGER and qualified without noticeable damage of any sort. These tests included severe random vibrations and thermal-vacuum environments.

Trade-off Analysis: The following table compares some of the properties of glass fiber and aluminum.

	Glass Fiber (G10/G11)	*Aluminum (6061-T6)*
specific gravity	1.82	2.7
tensile strength (lengthwise), psi	35,000	45,000
shear strength, psi	19,000	30,000
compressive strength, psi	60,000	—
coeff. of therm. expansion, cm/cm PL	0.7 x 10^{-5}	—
insulation resistance	excellent	conductor
ease of fabrication	good	good
molding and casting (with inexpensive tooling)	excellent	difficult
damping	excellent	—

In summary, glass fiber packaging for space applications has a number of excellent properties, and is light and strong with good damping properties. It can be readily and inexpensively molded in complicated sections that would be difficult to emulate in aluminum. Finally, it presents a simple, fast, and inexpensive way of providing flight-quality packages for equipment with a short lead time.

Molding Technique for Elliptical Glass Substrates for Laser Pump Cavities

T. A. HADDAD, *Aerospace Systems Division, DEP, Burlington, Mass.*

In order to take advantage of the high reflectivity obtainable with vacuum evaporated metal deposits on glass, glass substrates were molded to right elliptical cylinder contours required for high efficiency laser pump cavities. A concave mold having an elliptical contour to form half the required elliptical cylinder was machined from stainless steel. Pyrex glass tubing with a nominal size equal to or slightly larger than the minor diameter was cut to length and then cut longitudinally leaving a section larger than the required final size. The glass section was positioned in the mold so that the longitudinal edges were above the mold on both sides (Fig. 1).

Fig. 1—Elliptical forming process for mirror inserts.

Fig. 2—Trig method for calculating foci spacing angle.

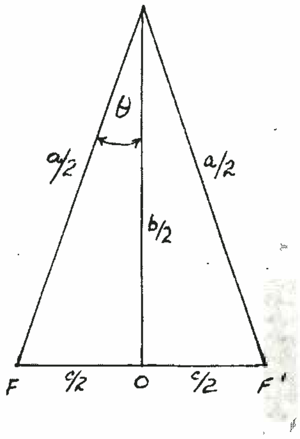
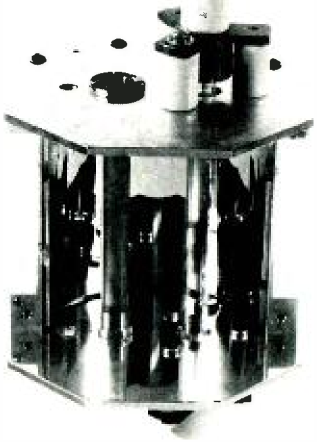


Fig. 3—Laser pump assembly showing imaging of crystal in flash lamp.



The assembly was then heated to 1,240°F in an electric oven and held at this temperature for at least 4 hours permitting the glass to sag into the mold. The power was turned off and the assembly allowed to cool slowly to approximately 200 to 300°F. The glass was then scribed with a tungsten scriber along the edge of the mold thus referencing the glass elliptical portion of the molded piece. Since the stainless steel mold has a higher coefficient of expansion than pyrex glass, upon cooling it tends to hold the glass under compression. The glass is easily released from the mold by using the excess glass "ears" for finger grips; and by slight compression using one hand, the glass is easily removed. The glass is then cut along the scribed lines and coated to form one half the required ellipse.

The generation of the elliptical cavity and mold is based on the analytical geometric premise that "*An ellipse is the focus of a point such that the sum of its distance from two fixed points is constant.*" The two fixed points are the foci of the ellipse and the constant sum is the major diameter.

The mold is machined in a milling machine using a boring bar set at an angle to the axis of the proposed cavity such that the required foci spacing will be obtained. In order to arrive at this required angle, the foci separation and either the major or minor axis must be decided upon. Having chosen two of the parameters, the third can be calculated by trigonometry (Fig. 2).

In Fig. 2, $a/2$ and $b/2$ are the major and minor semiaxes and c is the separation of the foci. The angle Θ is the angle to which the cutter bar should be set to generate the elliptical form having the prescribed parameters. For example, to generate an elliptical cavity having a foci separation of 0.5 inch and a minor semiaxis of 1 inch, $\tan \Theta = (c/2)\ (6/2) = 0.25/1$ or $\Theta = 14° 29'$ and $a/2 = 1.035$ inches. The cutter of the boring bar is then set to extend 1.035 inches and milling head is set at an angle of 14° 29′. The mold block is then fed through horizontally.

The dimensions of the mold are the outside dimensions of the glass substrate; the inside major and minor axes of the glass shell will be smaller by twice the thickness of the glass tubing and must be kept in mind when the design is made. A representative cavity showing the surprising good imaging properties is shown in Fig. 3.

Fabrication and Test of a CW Laser of CaF_2:Dy^{2+}

B. R. Clay and T. A. Haddad, *Aerospace Systems Division, DEP, Burlington, Mass.*

RCA Laboratories has developed a new laser material which is unique in that: 1) its line width is extremely narrow (too narrow to be measured by standard spectographic instruments, known to be less than 0.01 angstrom); 2) it will go CW with moderate pumping; 3) its pump bands are quite broad and extend more or less throughout the visible spectrum; and 4) the output radiation amplitude and frequency may be changed by the application of relatively weak axial magnetic fields (Zeeman splitting). This material is divalent dysprosium in calcium flouride. Its output wavelength is in the infrared at 2.3588 microns. The broad pumping spectrum makes sources such as sunlight[1] or tungsten filament lamps[2] quite suitable.

This *Note* describes design, fabrication, and experimental results of a laser using this new material. An apparatus was designed and constructed for obtaining continuous laser action from CaF_2:Dy^{2+} excited with a tungsten lamp. The pump optics consisted of an elliptical cylinder substrate with an evaporated coating in which liquid nitrogen was circulated and the exhaust was reflexed into the pump interior for additional cooling. A continuous output was achieved with an input of approximately 500 watts.

The problems peculiar to CaF_2:Dy^{2+} lasers are as follows:

1) The crystal must operate at or below the boiling point of liquid N_2 (77°K at 1 atmosphere). The thermal conductivity of CaF_2 does not permit cooling by way of the holder so the crystal must be immersed. The cryogenic immersion unit must not obstruct either the pump light or the output radiation.

2) The coolant should not be allowed to boil in either the pump or the output paths since the bubbles would cause attenuation and scattering.

The problems were solved by mounting the crystal as shown in Fig. 1. Supercooled liquid nitrogen is circulated at a flow rate just high enough to prevent boiling in the optical paths. Boiling starts after heat has been absorbed from the crystal. The flowing liquid, which has now become superheated, encounters a suddenly expanded cross-section. The resulting pressure drop induces boiling and the bubbles owing to the position of this section are out of the optical paths.

The crystal containment vessel is an especially constructed Dewar with vacuum insulated output windows in the bottom. Those areas of the Dewar that are not in the optical paths are silvered.

This structure is located at one focal axis of an elliptical cylinder; the other focal axis contains an incandescent lamp Fig. 2). The cylindrical walls are of pyrex and coated with a multilayer dielectric stack which reflects the pump bands but transmits infrared so that the unwanted heat from the lamp escapes from the system. There have been difficulties in obtaining a durable dielectric stack. The severe thermal gradients tend to encourage flaking of the coating. This problem, however, appears to be one of refinement and is not thought to be a fundamental limitation. Evaporated aluminum coatings have been used with success but the rate of coolant expenditure is higher than with the dielectric layer. Fig. 3 shows the schematic and Fig. 4 the final structural configuration of a unit built for the government in which the boiling exhaust (mostly gas phase) from the Dewar is used to cool the interior volume of the pump. A program is underway at ASD Burlington to study magnetic modulation of a CaF_2:Dy^{2+} in a similar structure.

The lamp used was the 115 2-volt Sylvania sun-gun lamp. It uses a tungsten filament in an iodine atmosphere and is contained in a Quartz envelope. It is rated at 1,000 watts, and has a color temperature of 3,400°K at its rated voltage.

Continuous laser action was observed with an input of 72 volts to the lamp when the coolant was liquid N_2. Lower thresholds were observed with lower temperature coolants. The crystal was confocal, had silvered ends, was 3/16 inch diameter and 1 inch long.

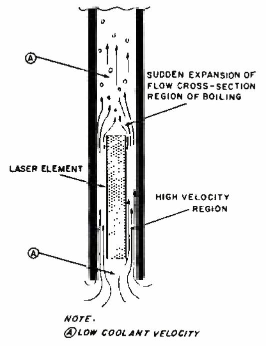


Fig. 1—Method for coating laser.

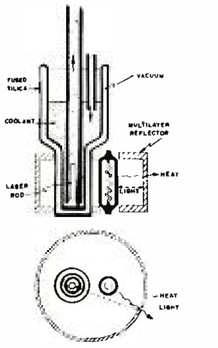


Fig. 2—CW laser schematic.

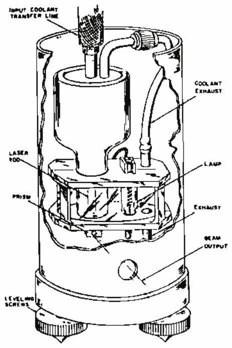


Fig. 3—Apparatus for CW laser.

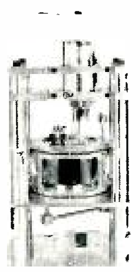


Fig. 4—Final unit configuration.

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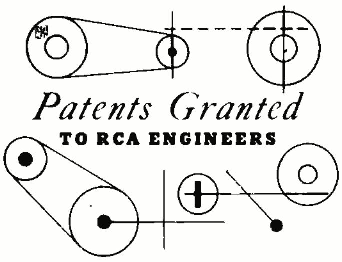
1. Z. J. Kiss, H. R. Lewis, R. C. Duncan, "A Sun Pumped Optical Maser," *Journal Applied Physics*, Vol. 2, No. 5, March 1963; *also in* RCA Engineer, (*E&R Notes*) Vol. 8, No. 5, Feb.-Mar. 1963.
2. Z. J. Kiss, "Survey of Spectra of Divalent Rare Earth Ions in Cubic Crystals," *Journal Chemical Physics*, Jan. 1964.



Patents Granted
TO RCA ENGINEERS

As Reported By RCA Domestic Patents, Princeton

DEFENSE ELECTRONIC PRODUCTS

3,117,231—Optical Tracking System, Jan. 7, 1964; H. E. Haynes, Assigned to U.S. Government)

3,121,010—Electrostatic Printing, Feb. 11, 1964; S. W. Johnson and J. P. Lauriello

3,123,677 — Magnetic Recording System, March 3, 1964; C. Lauxen, M. L. Levene, and D. L. Nettleton

3,125,674—Full Binary Adder Including Negative Resistance Diode, Mar. 17, 1964; B. Rabinovici and C. A. Renton

3,126,447—Television Black Level Setting, Mar. 24, 1964; S. L. Bendell

3,126,498—Thermoelectric Cooling of Vidicons, Mar. 24, 1964; S. L. Bendell

3,127,525—Cascaded Tunnel Diodes with Means to Apply Advance and Reset Pulses to Different Terminals, Mar. 31, 1964; B. Rabinovici

ELECTRON COMPONENTS AND DEVICES

3,120,054—Method of Making Tungsten Coils Class, Feb. 4, 1964; J. B. Fitzpatrick

3,121,182—Cathode Ray Tube, Getter, and Method of Gettering, Feb. 11, 1964; W. L. C. Hui and J. A. Files

3,122,464—Method of Fabricating Semiconductor Devices, Feb. 25, 1964; J. Krynock

3,123,957—Apparatus for Processing a Plurality of Articles or Materials, Mar. 10, 1964; W. J. Helwig and G. M. Rose, Jr.

3,124,169—Apparatus for Winding Helical Wire Grids for Electron Tubes, Mar. 10, 1964; O. H. Schade, Sr.

3,124,232—Electron Tube Apparatus, Mar. 10, 1964; N. Humen

3,124,269—Apparatus for Freeing Elements in a Chute, Mar. 10, 1964; A. Tobler

RCA LABORATORIES

3,120,653—Memory Systems, Feb. 4, 1964; J. C. Miller and A. W. Lo

3,121,009—Preparation of Etched Plates, Feb. 11, 1964; E. C. Giaimo, Jr.

3,121,176—Shift Register Including Bistable Circuit for Static Storage and Tunnel Diode Monostable Circuit for Delay, Feb. 11, 1964; J. R. Burns, J. J. Amodei

3,123,667—Color Kinescope Display System, Mar. 3, 1964; L. B. Johnston

3,124,456—Electrostatic Printing, Mar. 10, 1964; T. H. Moore

3,124,482—Apparatus for Developing Electrostatic Image, Mar. 10, 1964; R. G. Olden

3,124,484—Electrostatic Printing Apparatus, Mar. 10, 1964; K. J. Magnusson

ELECTRONIC DATA PROCESSING

3,122,649—Tunnel Diode Flip-Flop with Tunnel Rectifier Cross-Coupling, Feb. 25, 1964; D. E. Roop

3,123,181 — Braking Mechanism for Tape Feeding Apparatus, Mar. 3, 1964; S. Bavbick and S. M. Shelley

RCA VICTOR CO., LTD.

3,122,647—Pulse Length Discriminator Utilizing Two Gating Circuits, Feb. 25, 1964; S. T. Huey

HOME INSTRUMENTS DIVISION

3,124,266 — Casing for Portable Electrical Apparatus, Mar. 10, 1964; G. W. Morgan

BROADCAST AND COMMUNICATIONS DIV.

3,125,691—Pulse Stretcher Employing Alternately Actuated Timing System Monostable Circuits Feeding Combining Circuit to Effect Stretching, Mar. 17, 1964; W. Astheimer

3,126,446—Means for Optical Focusing, Mar. 24, 1964; F. C. Blancha

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DATES *and* DEADLINES

Professional Meetings and Calls for Papers

Meetings

May 19-21, 1964: Intl. Symp. on Microwave Theory and Techniques, PTG-MTT; Intl. Inn, Kennedy Airport, N.Y. *Prog. Info.:* Dr. L. Swern, Sperry Gyroscope Co., 3 T 105, Great Neck, N.Y.

May 25-29, 1964: Automatic Control and Programming in Mechanical Production, IEEE, ISA, ASME, AIAA, AICE; Brussels, Belgium. *Prog. Info.:* W. E. Miller, General Electric Co., One River Rd., Schenectady 5, N.Y.

June 2-4, 1964: Natl. Telemetering Conf., IEEE-AIAA-ASA; Biltmore Hotel, Los Angeles, Calif. *Prog. Info.:* W. S. Pope, North American Aviation, Downey, Calif.

June 2-4, 1964: Intl. Symp. on Global Comms. (Globecom VI), PTG-CS, EC, et al; Univ. of Penn. and Sheraton Hotel, Philadelphia, Pa. *Prog. Info.:* R. Guenther, RCA Comm. Systems Div., Bldg. 1-3-1, Camden, N. J.

June 8-10, 1964: Symp. on Quasioptics, PIB-IEEE; Statler-Hilton, N. Y., N. Y. *Prog. Info.:* Prof. L. Felsen, PLB, 55 Johnson St., Brooklyn 1, N. Y.

June 9-11, 1964: 6th Ann. Symp. on Electromagnetic Compatibility, PTG-EMC; Los Angeles, Calif. *Prog. Info.:* J. A. Eckert, Dept. 3441/32, Northrop and Norair, 3901 W. Broadway, Hawthorne, Calif.

June 11-12, 1964: 8th Ann. Product Eng. and Production Conf., PTG-PEP; Pratt Institute, Brooklyn, N. Y. *Prog. Info.:* R. R. Batcher, 24-02 42nd St., Douglaston, N. Y.

June 15-16, 1964: Chicago Spring Conf. on Broadcast and TV Receivers, PTG-BTR; O'Hare Inn, Des Plaines, Ill. *Prog. Info.:* J. H. Landeck, Admiral Corp., 3800 W. Cortland, Chicago 47, Ill.

June 16, 1964: Air and Surface Navig. by Artificial Satellites, ION, PTG-ANE; Barbizon-Plaza, N. Y. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, New York 21, N. Y.

June 23-25, 1964: Conf. on Precision Electromagnetic Measurements, IEEE; Boulder, Colo. *Prog. Info.:* C. F. Hempstead, Bell Tel. Labs., Murray Hills, N. J.

June 23-25, 1964: 6th Natl. Symp. on Electromagnetic Compatibility (Formerly RFI), PTGEC-IEEE, (Los Angeles District); Los Angeles, Calif. *Prog. Info.:* J. A. Eckert, Tech. Prog. Chairman, Dept. 3441/32, Northrop-Norair, 3901 W. Broadway, Hawthorne, Calif.

June 23-25, 1964: San Diego Symp. for Biomedical Eng., IEEE; Ocean House, San Diego, Calif. *Prog. Info.:* D. L. Franklin, Scripps Clinic and Res. Found., La Jolla, Calif.

June 24-26, 1964: Joint Automatic Control Conf., IEEE, ASME, AIChE, ISA; Stanford Univ., Stanford, Calif. *Prog. Info.:* L. Zadeh, Univ. of Calif., Berkeley, Calif.

June 29-July 2, 1964: First Ann. Mtg. and Tech. Display of the American Institute of Aeronautics and Astronautics; Sheraton Park Hotel, Washington, D.C. *Prog. Info.:* F. A. Cleveland, II, Prog. Chairman, AIAA, 2 E. 64th St., N.Y., N.Y.

July 6-10, 1964: Intl. Conf. on Magnetic Recording, Region 8, IEE, BIRE; London, England. *Prog. Info.:* IEE, Savoy Place. London, W.C. 2, England.

August 25-28, 1964: 1964 Wescon Show and IEEE Summer Genl. Mtg., Region 6, WEMA, All PTG's; Los Angeles, Calif. *Prog. Info.:* WESCON, 3600 Wilshire Blvd., Los Angeles, Calif.

Sept. 7-11, 1964: Intl. Conf. on Microwaves, Circuit Theory and Inf. Theory, IECE of Japan, et al; Akasaka Prince Hotel, Tokyo, Japan. *Prog. Info.:* Dr. K. Morita, % IECE of Japan, 2-8 Fujinticho Chiyoda-Ku, Tokyo, Japan.

Sept. 14-16, 1964: 8th Ann. Convention on Military Electronics (Mil-E-Con), PTG-MIL; Washington-Hilton Hotel, Washington, D.C. *Prog. Info.:* G. C. Ruehl. Shoreham Hotel, Conn. Ave. and Calvert St., N.W., Wash. 8, D.C.

Sept. 17-18, 1964: 12th Ann. Eng. Management Conf., IEEE-ASME-et al; Pick-Carter Hotel, Cleveland, Ohio. *Prog. Info.:* Dr. J. Savy, General Electric Co., Nela Park, Cleveland, Ohio.

Sept. 22-24, 1964: Ptg. on Antennas and Propagation Symp., PTG-AP; Kennedy Airport, L.I., N.Y. *Prog. Info.:* Dr. H. Jasik, Jasik Labs., 100 Shames Dr., Westbury, N.Y.

Sept. 23-24, 1964: 13th Ann. Industrial Electronics Symp., IEEE, PTG-IECI; Phila., Pa. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y. 21, N.Y.

Sept. 23-25, 1964: First Intl. Congress on Instrumentation in Aerospace Simul. Facilities, PTG-AS, AGARD; Paris, France. *Prog. Info.:* P. L. Clemens, ARO Inc., Arnold Air Force Sta., Tenn., 37389.

Sept. 25-26, 1964: 3rd Canadian Symp. on Communications, IEEE; Montreal, Canada. *Prog. Info.:* A. B. Oxley, Canadair Ltd., Box 6087, Montreal, P.Q., Canada.

Calls for Papers

August 30-Sept. 5, 1964: Sensitivity Analysis of Nonlinear Systems, IEEE, AIAA, ISA, ASME, AICE; Dubrovnik, Yugoslavia. **For Deadline Info.:** J. E. Gibson, EE Dept., Purdue Univ., Lafayette, Ind.

Sept. 1964: Component Parameters and Characteristics, IEEE, AIAA, ISA, ASME, AICE, IMEKO; Stockholm, Sweden. **For Deadline Info.:** Prof. H. R. Weed, EE Dept. Ohio State Univ., Columbus 10, Ohio, or Prof. J. Lowen Shearer, Rm. 213, ME Bldg., Penn State Univ., University Park. Pa.

Sept. 1964: Digital Process Control, IEEE, AIAA, ISA, ASME, AICE, IFIP; Stockholm, Sweden. **For Deadline Info.:** W. E. Miller and Dr. T. J. Williams, Monsanto Chemical Co., 800 N. Lindbergh Blvd.. St. Louis 66, Missouri.

Sept. 22-23, 1964: First Natl. Conf. on Automotive Electrical and Electronics Engineering; McGregor Memorial Center of Wayne State Univ., Detroit, Mich. **Deadline:** 500-1,000 wd. abstract, **7/15/64**, *TO:* E. A. Hanysz, Chairman of Papers Committee, Genl. Motors Res. Labs., G.M. Tech. Center, Warren, Mich.

Oct. 1964: Symp. on Optical Information Processing, PTG-EC, Boston Section, ONR; Boston, Mass. **For Deadline Info.:** A. Vanderburgh, MIT Lincoln Lab., B-115, Lexington, Mass.

Oct. 5-7, 1964: 10th Ann. Comms. Symp., PTG-CS; Utica, N. Y. **Deadline:** Abstracts, approx. **6/17/64**, manuscripts, approx. **9/1/64**. To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y. 21, N. Y.

Oct. 6-9, 1964: Ann. IEEE Symp. on Space Electronics, PTG-SET; Dunes Hotel, Las Vegas, Nev. **For Deadline Info.:** Dr. O. L. Tiffany, The Bendix Corp., Ann Arbor, Mich.

Oct. 19-21: Natl. Electronics Conf., IEEE, et al; McCormick Place, Chicago, Ill. **Deadline:** Abstracts, approx. **5/15/64;** manuscripts, **8/1/64**. *TO:* Natl. Elec. Conf., 228 N. LaSalle St., Chicago, Ill.

Oct. 21-23, 1964: East Coast Conf. on Aerospace and Navig. Electronics (ECCANE), PTG-ANE, Baltimore Section; Baltimore, Md. **Deadline:** Abstracts, approx. **6/4/64**. *TO:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

Oct. 27-29, 1964: Fall Joint Computer Conf., AFIPS (IEEE-ACM); Civic Center, Brooks Hall, San Francisco, Calif. **Deadline:** Abstracts, approx. **5/1/64**. To: Mrs. P. Huggins, PO Box 55, Malibu, Calif.

Oct. 28-30, 1964: Symp. on Space and Lab. and 11th Anniversary PTGns Mtg., PTG-NS; Phila., Pa. **For Deadline Info.:** L. Costrell, NBS, U. S. Dept. of Commerce, Wash. 25, D. C.

Oct. 28-30, 1964: Soc. for Experimental Stress Analysis Ann. Mtg. and Exposition; Hotel Manager, Cleveland, Ohio. **For Deadline Info.:** SESA, 21 Bridge Square, Westport, Connecticut.

Oct. 29-30, 1964: Electron Devices Mtg., PTG-ED; Sheraton-Park, Washington, D. C. **Deadline:** Abstracts, approx. **8/1/64**. To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Nov. 4-6, 1964: Nerem (Northeast Res. and Eng. Mtg.) IEEE; Boston, Mass. **Deadline:** Abstract and Summary, **6/30/64**. *TO:* IEEE Boston Office, 313 Washington St., Newton 58, Mass.

Nov, 9-11, 1964: Radio Fall Mtg.. IEEE-EIA; Hotel Syracuse, Syracuse, N.Y. **For Deadline Info.:** V. M. Graham, EIA, Eng. Dept., 11 W. 42nd St., N.Y., N.Y.

Nov. 16-18, 1964: 17th Ann. Conf. on Eng. in Medicine and Biology, IEEE-ISA, PTG-BME; Cleveland-Sheraton Hotel, Cleveland, Ohio. **Deadline:** Abstracts, approx. **8/1/64**. *TO:* Dr. Peter Frommer, Cincinnati Genl. Hosp., Cincinnati 29, Ohio.

Nov. 16-19, 1964: 10th Conf. on Magnetism and Magnetic Matls., IEEE-PTG-MTT, AIP; Paddison Hotel, Minneapolis, Minn. **Deadline:** Abstracts, approx. **8/19/64**. *TO:* IEEE Headquarters, Box A, Lenox Hill Station, N.Y., N.Y.

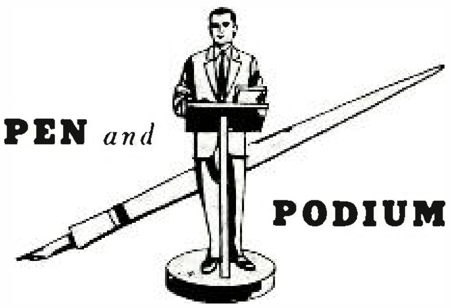
Dec. 3-4, 1964: 15th Ann. Vehicular Comm. Symp., PTG-VC; Cleveland-Sheraton, Cleveland, Ohio. **Deadline:** Abstracts, approx. **8/15/64**, *TO:* R. E. Bloor, Ohio Bell Tel. Co., 700 Prospect Ave., Cleveland, Ohio.

(late 1964): Systems Eng. for Control System Design, Tokyo, Japan, IEEE, AIAA, ISA, ASME, AICE; **For Deadline Info.:** Prof. Henry M. Paynter, ME Dept., Mass. Inst. of Tech., Cambridge 39, Mass. and H. Chestnut, Genl. Electric Co., One River Rd., Schenectady 5, N.Y.

(late 1964): Automatic Control in the Peaceful Uses of Space, IEEE, AIAA, ISA, ASME, AICE; Oslo, Norway. **For Deadline Info.:** Dr. J. A. Aseltine, Aerospace Corp., PO Box 95085, Los Angeles 45, Calif.

Jan. 12-14, 1965: 11th Natl. Symp. on Reliability and Quality Control; Hotel Fountainbleau, Miami Beach, Fla. **Deadline:** Abstracts, **5/1/64**, manuscripts, **7/14/64**, *TO:* H. E. Reese, Burroughs Corp., Military Systems Div., Box 305, Paoli, Pa.

Be sure deadlines are met—consult your Technical Publications Administrator or your Editorial Representative for the lead time necessary to obtain RCA approvals (and government approvals, if applicable). Remember, abstracts and manuscripts must be so approved BEFORE sending them to the meeting committee.



PEN *and* PODIUM

A Subject-Author Index to Recent RCA Papers

Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal from your library—or write or call the author for a reprint. For information on verbal presentations write or call the author This index is prepared from listings provided bimonthly by divisional Technical Publications Administrators and Editorial Representatives—who should be contacted concerning errors or omissions (see inside back cover). Comments or suggestions on this index should be directed to E. R. Jennings Ass't. Editor RCA ENGINEER, 2-8, Camden, PC-3396.

Editor's Note: *This new Pen and Podium index supersedes the Pen and Podium format used prior to the Feb.-Mar. 1964 issue that listed papers only by divisional source. At the end of 1964, a "Cumulative Index to 1964 RCA Papers", prepared by integrating the indexes that will appear in each 1964 issue, will be available as an* RCA Engineer *reprint.*

SUBJECT INDEX

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

AMPLIFICATION

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New Frontiers in Medical Electronics: Electronic Aids for Medical Diagnosis—V. K. Zworykin (Labs, Pr.) PAMA, Inc. 39th Anniv. Congress, Feb. 19, 1964

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Microwave System Path Planning—D. G. Hymas (BCD, Cam.) IEEE PTG on Comm. Systems, Phila, Sect., Feb. 18, 1964

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AUTHOR INDEX

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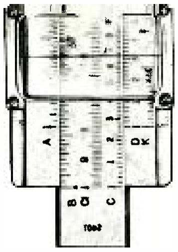
Engineering NEWS *and* HIGHLIGHTS



20 ENGINEERS HONORED WITH 1963 EC&D ACHIEVEMENT AWARDS

RCA Electronic Components and Devices has awarded its *1963 Engineering Achievement Awards* to 20 engineers. Thirteen of the recipients are from ECD's Harrison and Somerville Plants:

A. Dingwall, Special Electronic Components Division—*for technical excellence in the development and practical application of greatly improved silicon-germanium thermoelectric couples.*

M. Fromer, Industrial Tube and Semiconductor Division—*for ingenuity in the development of a practical tuning system for magnetrons.*

N. C. Turner, Industrial Tube and Semiconductor Division—*for major contributions to the design of silicon transistors.*

Team awards were presented to: **E. S. Belohoubek, M. R. Freeling, T. J. Kelly, R. G. McAvoy,** and **G. Novak,** of the Industrial Tube and Semiconductor Division—*for their pioneering development of a highly reliable traveling wave tube amplifier for the Relay communications satellite.*

M. S. Fisher, H. M. Kleinman, J. Ollendorf, M. A. Polinski, and **C. F. Wheatley,** of the Commercial Receiving Tube and Semiconductor Division in Somerville—*for their pioneering contributions to the design and application of transistors to audio amplifiers for phonographs and home receivers.*

At the EC&D Cincinnati, Ohio Plant, an individual award went to:

F. W. Bove, *for his numerous cost-saving innovations in the manufacture of receiving tubes at the Cincinnati Plant.*

Three engineers at the EC&D Lancaster Plant received awards:

F. Van Hekken, Television Picture Tube Division—*for valuable contributions to the use of computer techniques in the design and fabrication of wide angle color tubes.*

J. F. Heagy, Industrial Tube and Semiconductor Division—*for important cost-saving innovations in the production of camera tubes.*

J. C. Moor, Industrial Tube and Semiconductor Division—*for significant contributions to image tube manufacturing techniques.*

At the Television Picture Tube Division in Marion, Ohio, two engineers were honored:

A. C. Porath and **B. B. LeMay**—*for outstanding engineering achievement in establishing screening capability for color TV pictures tubes at the Marion Plant.*

RCA PLANS RECORD $70 MILLION CAPITAL SPENDING IN 1964 FOR ALL DIVISIONS AND SERVICES

RCA capital expenditures for 1964 are expected to reach an all-time high of $70 million, 16 percent greater than the previous year's investments.

Dr. Elmer W. Engstrom, RCA President, has revealed that the 1963 capital investment figure for the company was $60 million, compared with $56 million for 1962. The planned investments in 1964 relate to plant and equipment in every division and service of RCA. Dr. Engstrom underscored the importance of research and engineering: RCA spent more than $130 million to develop, introduce and promote color television, which now contributes more than half of the profits from our entire home instruments business. RCA has spent an equal amount to become established in electronic data processing, which before the end of 1964, should cross into a profit position and maintain profit growth thereafter. While an early need for another such heavy investment in a single type of product or service is not now foreseen, if the need should arise and if the profit potential should be as attractive as in these two cases, the required effort will be made.

RECEIVED YOUR ANNUAL REPORT . . . ?

RCA engineers and scientists who have not received a copy of the *1963 RCA Annual Report* can obtain one by sending their office and home addresses to TREND, Bldg. 2-8, Camden, N.J.

SENDROW EARNS DPMA DATA PROCESSING CERTIFICATION

Marvin Sendrow, an engineer in the DEP Communications Systems Division, Camden, recently was awarded a *Certificate in Data Processing* by the Data Processing Manufacturers Association (DPMA). This certificate is granted as a mark of professional competence only after a careful review of the applicant's background, training, and experience in data processing and the successful completion of a wide-ranging exam.

The objects of the DPMA Certification Program are to: 1) Establish high standards for data processing personnel by emphasizing a broad educational framework and practical knowledge in the field; 2) Develop a method for recognizing professional competence in data processing; 3) Lay a foundation for further growth of the data processing field.

REGISTERED ENGINEERS

J. W. Hensley, ECD, PE-10912, Ind.
R. K. Konrad, ECD, PE-11023, Ind.
A. C. Porath, ECD, PE-11031, Ind.
G. M. Ridgeway, ECD, PE-10962, Ind.
K. D. Scearce, ECD, PE-10967, Ind.
R. K. Schneider, ECD, PE-28908, Ohio
F. L. Ulrich, ECD, PE-9026, N.J.
H. Blust, ECD, PE-13226, N.J.
L. A. Shotliff, License Operations, PE-40390, N.Y.
J. A. Dodd, Jr., DEP-Central Eng., PE-12988, N.J.
G. L. Tate, DEP-MSR, PE-13267, N.J.

14 RCA MEN AWARDED DAVID SARNOFF FELLOWSHIPS

David Sarnoff Fellowships for graduate study in the 1964-65 academic year have been awarded to fourteen employees. The Fellowships, established in honor of the Chairman of the Board of RCA, range in value to as high as $6500 each. Although appointments are for one academic year, each Fellow is eligible for reappointment. The David Sarnoff Fellows are selected on the basis of academic aptitude and promise of professional achievement.

The new David Sarnoff Fellows are:

John R. Manning, DEP Aerospace Systems Division, Burlington, Mass.—toward a Doctorate in Mechanical Engineering, MIT.

Joseph P. McEvoy, DEP Applied Research, Camden—toward a Doctorate in Metallurgy, Imperial College, London, England.

John T. O'Neil, RCA Labortories, Princeton, N. J.—toward a Doctorate in Electrical Engineering, University of Pennsylvania.

Peyton Z. Peebles, DEP Missile and Surface Radar Division, Moorestown, N. J.—toward a Doctorate in Electrical Enginering, University of Pennsylvania.

Alfred H. Teger, RCA Laboratories, Princeton, N. J.—toward a Doctorate in Electrical Engineering, University of Pennsylvania.

James K. Drysdale, RCA Victor Co., Ltd., Montreal—toward a Master's degree in Business Administration, McGill University.

Robert G. Cram, NBC, Chicago—toward a Master of Arts in Journalism.

Two David Sarnoff Fellows were reappointed to only a first term of a third year during which time they expect to complete their Doctorate study programs. They are:

Jacob Klapper, DEP Communications Systems Division, New York, N. Y.—toward a Doctorate in Electrical Engineering, Polytechnic Institute of Brooklyn.

John J. Moscony, Electronic Components and Devices, Lancaster, Pa—toward a Doctorate in Chemistry, University of Pennsylvania.

Five Fellows were reappointed for a second year:

Alexander A. Avanessians, RCA Communications, Inc., New York, N. Y.—toward a Doctorate in Electrical Engineering, Columbia University.

Henry Kressel, Electronic Components and Devices, Somerville, N. J.—toward a Doctorate in Metallurgy, University of Pennsylvania.

Martin L. Levene, DEP Communications Systems Division, Camden—toward a Doctorate in Mechanical Engineering, University of Pennsylvania.

Robert A. Howell, DEP Communications Systems Division, Camden—toward a Doctorate in Business Administration, Harvard.

John J. Serratore, Electronic Data Processing, Cherry Hill—toward a Master's Degree in Business Administration, University of Pennsylvania.

L. H. GOOD RECEIVES HONORARY DEGREE

Lowell H. Good, of the Special Projects Group, RCA Laboratories, Princeton, N. J., was one of four scientists to receive an honorary Doctor of Laws degree from Indiana Central College, Indianapolis, at the dedication of the College's new Lilly Science Hall. Mr. Good received a BA in 1931 and a BS in 1932 from Indiana Central, and a MA in Physics from Indiana University in 1932.

RCA LABS PRESENT 1963 ACHIEVEMENT AWARDS

The RCA Laboratories have named the following as recipients of the 17th annual *RCA Laboratories Achievement Awards.* These 1963 awards are in recognition of outstanding contributions by members of the RCA Laboratories.

K. L. Cheng, *for ingenuity in devising numerous superior procedures for chemical analyses of electronically active materials.*

Glenn W. Cullen, *for research leading to techniques for the deposition of thin films of a hard superconductor on special ceramic substrates.*

Albrecht G. Fischer, *for resourcefulness in experimental and interpretive studies of electroluminescent materials and phenomena.*

Alvin M. Goodman, *for experimental measurements on the properties of metal-semiconductor contacts.*

Bernard Hershenov, *for research leading to the development of an electron gun for a linear crossed field amplifier.*

Walter H. Jamison, *for ingenuity in devising a system for the detection of speech.*

George Kasyk, *for the exploration of several ingenious and novel concepts in mechanical record changers.*

Donald E. Nelson, *for the development of high-power tunnel diode oscillators and high-power varactor harmonic generators.*

John J. Quinn, *for significant advances in the theoretical treatment of electrons in metals and in a degenerate electron gas.*

Minoru Toda, *for the origination and application of a novel microwave technique for the observation of plasmas in semiconductors.*

James P. Wittke, *for theoretical and experimental studies of the response of an emissive medium to short pulses of electromagnetic radiation.*

Howord R. Beelitz, Joseph Guorrocini, and **Morton H. Lewin,** *for team performance in the development of concepts and techniques leading to electronically addressable punched card memories.*

Rubin Braunstein and **Jacques I. Pankove,** *for studies of recombination radiation in semiconductors leading to the use of injection diodes as light sources and lasers.*

Leslie L. Burns, David A. Christiansen, Robert A. Gange, Eugene M. Nagle, and **Frank S. Wendt,** *for team performance in advancing the technology and theoretical understanding of superconductive memories.*

Alvin S. Clorfeine, George W. Leck, and **Judea Pearl,** for research leading to the development of a superconducting frequency multiplier and mixer.

Jonathan I. Gittleman and **Bruce Rosenblum,** *for team performance in experimental determinations of certain basic effects in superconductors.*

Stuart E. Hotchkiss, Rabah Shahbender, C. Wentworth, and **Kam Li,** *for team performance in research on integrated ferrite laminate structures for high-speed and low-cost computer memories.*

William D. Houghton, Seymour Naroff, and **Robert F. Sanford,** *for team performance in conceiving and developing a television facsimile message system.*

Simon Larach, Ross E. Shrader, and **P. Niel Yocom,** *for team performance in research leading to new luminescent materials containing ions of transition elements.*

William H. McCarrol and **Alfred H. Sommer,** *for the development and analysis of a new cesium-potasium photocathode.*

THREE RCA RESEARCH PROJECTS WIN AWARDS

Three RCA technical developments—a thin-film superconductive memory, a beam-plasma tube, and a gallium arsenide optical diode—were among the 100 most significant new products of 1963, according to *Industrial Research* magazine.

The 100 developments chosen, out of 10,000 reviewed, were awarded plaques in recognition of their merit. The products were selected on the basis of importance, uniqueness, and usefulness to the researcher and included new or newly improved materials, processes, and techniques, as well as instruments and equipment.

The thin-film superconductive memory singled out for merit was developed at RCA Laboratories by a research team working under the direction of **Leslie L. Burns,** of the Computer Research Laboratory.

The experimental (beam-plasma) electron tube selected as an important new development in *Industrial Research* will make accessible infrared radar channels well above the ceiling for today's microwave systems. The new tube was developed at RCA Laboratories by **Dr. George A. Swartz** and **Louis S. Napoli,** of the Microwave Research Laboratory, working under the direction of **Dr. Maurice Glicksman.**

The third RCA development honored by *Industrial Research*, the gallium arsenide optical diode, was developed by Electronic Components and Devices in Somerville, N. J., based upon earlier work done at RCA Laboratories by **Dr. Rubin Braunstein** and **Dr. Jacques Pankove.**

DEP SPONSORS MICROELECTRONICS SYMPOSIUM

Over 20 RCA engineers recently met in a one-day Symposium to interchange ideas and discuss our present status and future plans concerning microelectronics packaging. The engineer speakers at this symposium represented various divisions within RCA both in defense and commercial areas. The meeting was attended by engineering management and selected engineering manufacturing personnel.

Additional information concerning papers given at the Symposium may be obtained from **R. H. Aires,** DEP Microelectronics Engineering in Somerville.

The objective of the symposium: "to establish a clear understanding of our present status in the development of an inhouse competence in packaging techniques for integrated circuits and advanced solid state circuits." Discussions included the following:

1) Information on all active engineering efforts in any phase of microelectronics packaging design.
2) An opportunity for each group so engaged to openly discuss their problems and needs.
3) Participation in a technical "self-analysis" to solicit the critical comments of other competent personnel who may have been previously confronted with either the same or similar technical problems.
4) A clear understanding of either unique or generally applicable techniques or methods requiring further development, especially those common to several packaging concepts.
5) The establishment, at least on a conceptual basis, of the potential requirements for either current or future investment in capital facilities, including manufacturing and support activities.

NEW MICROELECTRONIC ACTIVITIES

Last October, RCA took positive steps to improve its capability in diffused silicon integrated circuits. As a result, two organizations—one in DEP and one in ECD—are now working closely together at Somerville, N. J., on a program designed to make optimum use of both the technical talents and the capital facilities of RCA in achieving this goal.

The new DEP activity, Defense Microelectronics, consists of outstanding circuit design engineers individually selected from DEP operating activities. Managed by **Ramon H. Aires,** this group reports directly to the DEP Chief Defense Engineer, **Dr. Harry J. Woters,** and is responsible for formulating the specific circuit designs to be fabricated by RCA in the initial phase of this long term program. The circuit designs are worked out cooperatively with equipment and circuit design engineers from the DEP divisions. The main objective is to insure that the circuits are tailored to meet existing or forthcoming requirements of DEP customers. The DEP group is also doing applied research on active and passive thin film devices, as well as hybrid thin film-silicon circuits.

In addition, Defense Microelectronics provides technical support to DEP activities in the evaluation of requests for proposals and in the preparation of proposals involving these advanced technologies. Moreover, Defense Microelectronics provides, both through formal technical courses and ad hoc seminars and discussions, training to interested RCA personnel.

The manager of ECD Special Electronics Components Division's Integrated Circuit Engineering activity, **Robert D. Lohman,** and the manager of the Division's Integrated Circuit Manufacturing organization, **Ray A. Wissolik,** report to **Lloyd R. Day,** Division General Manager. The primary responsibility of these activities is the development of diffusion processes and the fabrication technology required to produce the monolithic silicon integrated circuits.

Now under way at Somerville is an extensive program to install new facilities and increase the capacity of existing facilities for engineering and development work in integrated circuits. Also under way is a program to provide a production capability for the manufacture in quantity of the integrated circuits required to meet the goals of DEP business plans. *(Requests for additional information concerning Defense Microelectronics services, integrated circuits applications data, specific assistance and/or training should be directed to DEP Defense Microelectronics, Somerville, N. J. The August-September* RCA ENGINEER *will feature papers on RCA microelectronics efforts.)*

A list of the symposium subjects and participating speakers, is given below:

Computers—**S. P. Patrakis** (ASD-B), **J. A. Brustman** (AR), **B. Walker** (AR), **J. J. O'Donnell** (EDP)

Tactical Systems—**E. Eigner, E. Lichtenberg** (AADS-7), **H. Lumb** ((CSD))

Space Control Systems—**P. J. Truscello** (AED)

Digital Communications—**R. J. Araskewitz, R. C. Leunis** ((CSD))

Tactical Radar **S. Malasky** (M&SR)

Fabrication Techniques—**S. F. Burtis** (Corp. Staff); **D. P. Schnorr** (CE)

Design Automation—**R. H. Bergman** (AR), **W. W. O'Neill** (EDP)

Other Packaging Programs—**J. L. Vossen** (DME/(CSD)), **M. Kidd** (ASD-B), **Dr. N. Crooks, D. Mackey, G. Rezek** (CSD)

Panel Members: **R. J. Araskewitz, M. Kidd, B. Metonick, E. A. Szukulaski, H. Eigner, S. Malasky, C. Dunalef**

PROFESSIONAL ACTIVITIES

RCA Service Co., Patrick AFB, Fla., RCA-MTP: A seminar outlining many aspects of value engineering, with emphasis on how they can be applied to operations on the Atlantic Missile Range, was held January 31 by the Missile Test Project for its management personnel. Authorities on value engineering and improvement who conducted the program were: **John Bryant,** Value Improvement Administrator, RCA Aerospace Systems Division; **Robert Trick,** Value Engineer, Air Force Systems Command Contract Management Office; **Carlos Fallon,** Director, Value Analysis, RCA Corporate Staff; **Morgan Roderick,** Chief Value Engineer, U. S. Bureau of Ships; and **Ervin Leshner,** Administrator, Defense Value Improvement, RCA Defense Electronics Products. In addition there were several guests from Pan American World Airways, Inc., and the Air Force.—*W. Strayer*

DEP Central Engineering: **J. R. Hendrickson** has been appointed Radiological Health Officer for DEP. Mr. Hendrickson succeeds **H. R. Dyson.**

DEP Missile and Surface Radar, Mrstn.: **W. J. Welsh** has been elected to serve a three-year term on the National Administration Committee of the Professional Technical Group on Product Engineering and Production of the Institute of Electronic & Electrical Engineers. He is also Membership Chairman of the Philadelphia Chapter of this Professional Group and the IEEE representative at Moorestown. **Ralph Taynton** was appointed co-chairman of a recently formed Steering Committee on Military Specifications by the Institute of Printed Circuits (IPC). The IPC is a national association consisting of the major design, fabrication, and user companies in the printed wiring industry, and will serve to coordinate and direct the coordination of Military Specifications and their revisions relating to printed wiring—*T. G. Greene*

RCA Victor Co., Ltd., Montreal: **Dr. J. R. Whitehead,** Director of Research, has been appointed a Member of the Physical and Chemical Sciences Exhibit Committee and Chairman of the Communications Exhibit Committee for the official 1967 Worlds' Fair in Montreal, "EXPO 67." He has also been elected to the Board of Directors of the Canadian Research Management Association, with the membership portfolio.
—*H. J. Russell*

Home Instruments Division, Indianapolis: **G. E. Kelly** has been appointed Member of the IEEE Receiver Committee. **C. W. Hoyt** was appointed to the Indianapolis Executive Committee of the IEEE responsible for educational activities of the local section.
—*K. A. Chittick*

ECD, Lancaster, Pa.: **Hubert H. Wittenberg** was appointed Chairman of the IEEE Electron Tube Committee. He was also appointed to Membership on the IEEE Electronics Committee.—*G. G. Thomas*

G. E. Jannery and **R. G. Neuhauser** attended the Society of Motion Picture and Television Engineers Seminar held January 8 and 9 in New York City. **Dr. Ralph W. Engstrom,** Mgr., Advanced Development Conversion Tube Operations, lectured on "Highlights of Conversion Tube Development Programs" at the RCA-Princeton Colloquium on Feb. 10, 1964.—*R. L. Kauffman*

STAFF ANNOUNCEMENTS

Research and Engineering, Princeton: **F. S. Misterly,** Staff Vice President, Patent Operations announces his organization as follows: **P. G. Cooper,** Director, Foreign Patents; **O. V. Mitchell,** Director, Domestic Patents, and **J. A. Wortmann,** Manager, Trade-Marks.

Research and Engineering, Camden: **J. W. Wentworth** is appointed Manager, Current Concepts in Science and Engineering Program. Mr. Wentworth will report to **C. M. Sinnett,** Director, Product Engineering Professional Development. **Mr. A. Bezgin** has been appointed Administrator, Course Development and will report to J. W. Wentworth.

ECD-Commercial Receiving Tube and Semiconductor Division: **W. H. Painter,** Division Vice President and General Manager announces his organization as follows: **F. R. Buchanan,** Manager, Financial Planning and Controls; **J. T. Cimorelli,** Manager, Cryoelectric Devices Laboratory; **N. H. Green,** Manager, Commercial Receiving Tube and Semiconductor Operations Dept.; **G. J. Janoff,** Manager, Marketing Dept., and **K. M. McLaughlin,** Manager, Memory Products Operations Department.

ECD-Commercial Receiving Tube and Semiconductor Division: **R. M. Cohen,** Manager, Engineering, announces his organization as follows: **J. W. Englund,** Manager, Semiconductor Consumer Applications; **H. V. Kettering,** Manager, Semiconductor Design; **R. R. Painter,** Manager, Semiconductor Computer Applications; **L. R. Shardlow,** Manager, Semiconductor Development Services; and **W. H. Warren,** Manager, Receiving Tube Engineering.

W. H. Warren, Manager, Receiving Tube Engineering announces his organization as: **M. Bondy,** Manager, Receiving Tube Design; **W. E. Babcock,** Manager, Receiving Tube Applications; **J. J. Carrona,** Manager, Chemical and Physical Laboratory; **P. L. Farina,** Manager, Engineering Administration; **E. C. Hughes, Jr.,** Administrator, Technical Committee Liaison; **W. E. Lynar,** Manager, Quality Control; **R. N. Peterson,** Manager, Advanced Product Development; and **G. Wolfe,** Manager, Engineering Methods and Standards.

ECD-Industrial Tube and Semiconductor Division: **C. C. Simeral, Jr.,** Manager, Microwave Tube Operations Department, announces his organization as follows: **J. W. Caffry,** Manager, Microwave Accounting; **W. G. Hartzell,** Manager, Microwave Product Operations; **H. K. Jenny,** Manager, Microwave Engineering; **J. F. Kucera,** Manager, Microwave Quality Assurance; and **A. F. Pheasant,** Manager, Microwave Materials.

DEP Communications Systems Div.: **S. M. Zollers** gave a talk on "C Stellarator for Plasma Fusion" before the Joe Berg Society at Haddonfield High School on Mar. 4, 1964. Twenty-one students attended the lecture and asked many perceptive questions. The Haddonfield High School Science Seminar is a group of gifted students who meet after school hours to hear lectures on science and technology. The Joe Berg Society takes its name from the sponsor and founder of the society.—*C. W. Fields*

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.

Communications Systems Div.—DEP

J. F. Biewener: from Mgr., Eng. to *Mgr., Mfg. Programs* (Plant Mgr., Cambridge)

Astro-Electronics Division—DEP

K. Robinson: from Mbr. Tech. Adv. Staff to *Mgr. Space Observation Systems* (A. J. Vaughan, Chief Engr.) Hightstown

L. J. Rosenberg: from Engr. to *Ldr., Publication Engineers* (I. M. Seideman, Mgr. Reports & Proposals) Hightstown

Aerospace Systems Div.—DEP

L. Andrade: from Ldr., Tech. Staff to *Mgr., Radar Eng.* (N. Laschever) Burlington

H. L. Fischer: from Sr. Proj. Mbr. Tech. Staff to *Ldr., Technical Staff* (P. M. Toscano) Burlington

E. P. Wendkos: from Ldr., Dev. & Des. Eng. Staff to *Mgr., Specifications & Stds.* (F. Thiel) Van Nuys

Electronic Components and Devices

W. B. Hall: from Sr. Engr. Prod. Dev. to *Eng. Ldr. Prod. Dev.* (Mgr., Thermionic Converter Eng.) Lancaster

R. E. Reed: from Sr. Engr., Prod. Dev. to *Eng. Ldr., Prod. Dev.* (Mgr., Super Power Tube Design & Dev., Lancaster

F. Hunter: from Eng. to *Eng. Ldr.* (H. Kettering) Commercial Prod. Design, Somerville

J. F. Vance: from Engr. to *Eng. Ldr. Aerospace Prod. Assurance & Rel.* (M. Geller) Somerville

Broadcast and Communications Products Div.

R. N. Hurst: from Engr., Des. & Dev. to *Ldr., Design & Dev. Engrs.*, Studio & Scientific Instr. Eng. (A. H. Lind) Camden

A. E. Jackson: from Engr. Des. & Dev. to *Ldr., Des. & Dev. Engrs.*, Studio & Scientific Instr. Eng. (A. H. Lind) Camden

Electronic Data Processing

S. Cooper: from Engr. to *Ldr., Des. & Dev. Engrs., Stds.*, Power Supply & Packaging Eng. (J. O'Donnell) Camden

RCA Service Company

M. H. Stearns: from Engr., Facilities to *Ldr., Engineers*—BMEWS Facility and Support (K. R. Lewis) Cherry Hill

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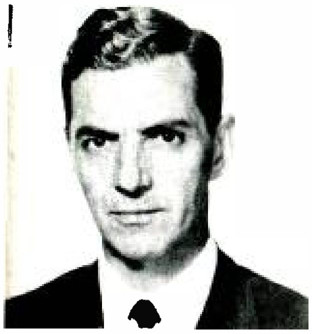
DEP-Communications Systems Division: **S. W. Cochran,** Division Vice President and General Manager, announced the appointment of **James E. Sloan** as Manager, Data Communications Programs, Communications Systems Division. In his new position, Mr. Sloan will have responsibility for RCA's random access "fieldata" computer, AUTODIN program, and other defense data communications systems.

Data Systems Center, Bethesda, Md.: **A. L. Malcarney,** Group Executive Vice President has assigned the responsibility for the Data Systems Center, as follows: **G. A. Peters,** Manager, Data Systems Center, who will report administratively to **W. G. Bain,** Vice President, Defense Electronic Products, **C. A. Gunther,** Division Vice President, Technical Programs, DEP and EDP, will be responsible for functional control of the operations of the center.


F. Harris


C. F. Frost


D. J. Buch

NEW ED REPS: HARRIS, RCA INTERNATIONAL; FROST, RCA COMMUNICATIONS; BUCH, ASD-BURLINGTON

New RCA ENGINEER Editorial Representatives recently appointed are: **Frederico Harris,** who will represent RCA International, Inc., engineering activities. His offices are in Clark, N.J., and he replaces **L. S. Beeny.** In addition, Mr. Harris will serve as Technical Publications Administrator for RCA International.

Cecil F. Frost has been named as Editorial Representative for RCA Communications, Inc. in New York City. Mr. Frost, who will serve as Technical Publications Administrator for RCA Communications, replaces **Wayne Jackson,** who has retired (see story). Within Defense Electronic Products, **Donald J. Buch** has been named to succeed **Bob Glendon** as an Editorial Representative at Aerospace Systems Division, Burlington, Mass. Mr. Buch will serve on **F. D. Whitmore's** DEP Editorial Board.

Frederico Harris received his MSEE in in 1939 from the University of LaPlata, Argentina. From 1939-49, he worked in Buenos Aires for CSEA, an I.T. & T. subsidiary company. He started as a design engineer and in 1948 became Chief Engineer, Broadcast Transmission, Sound and Video. From 1949-56, he did consulting work for various broadcast networks in Argentina, Uruguay and Chile. He joined RCA International in 1956. During 1956-60, he was in Cuba assigned to the RCA project for a nationwide microwave telecommunications system in that country. In June 1963, he was promoted to Manager, Engineering, Broadcast and TV Department of International Marketing Operation. In December 1963, he assumed his present position of Manager, Engineering, Broadcast and Communications, I.M.O. He is a Senior member of IEEE. During 1952-53, he was vice chairman of the Buenos Aires section of the IRE. From 1945-48, he was part-time assistant professor to the Radio Communications courses for graduated engineers held at the University of Buenos Aires.

Cecil F. Frost graduated from the University of California at Berkeley with a BSEE and joined RCA as a transmitting station technician at Bolinas, California in 1929. He was in charge of construction of a combined transmitting and receiving station near Seattle, Washington in 1934 and remained as Engineer-in-Charge when the domestic radio telegraph circuit with San Francisco was opened in 1935. He has held a variety of engineering, administrative, and managerial positions since that date and after several years as Engineer-in-Charge of the International Receiving Station at Riverhead, Long Island, was transferred in 1947 to the RCA Communications headquarters offices in New York City where he is presently Manager, Technical Training and Engineering Services, and Staff Assistant, reporting to the Vice President and Chief Engineer.

Donald J. Buch studied Electrical Engineering at Iowa State College in 1941-43. He then entered the Navy, serving until 1946 as an instructor in various technical training courses. From then until 1954, he was associated in design and sales capacities with his family's manufacturing business, which included electronic organs, intercoms, hearing aids, and PA systems, thereby accruing considerable experience in audio engineering. In 1954, he joined the Collins Radio Co. as a technical writer, advancing first to Head of the Editorial Department, and then to Assistant Manager of the Publications Dept. He joined RCA in 1961 as Manager of Engineering Publications and Motion Picture Production for the DEP Aerospace Communications and Controls Division in Camden. In 1962, he moved to ACCD-Burlington as Manager of the Documentation and Logistics Dept. He presently holds that position for the Aerospace Systems Division, Burlington. He is active in STWP, IEEE, and EIA, and has prepared articles for both the EIA and the DOD. He is now representative to AIA Service Publications Committee.

WAYNE JACKSON, RCA ENGINEER AND ED REP, RETIRES AFTER 36 YEARS

Wayne C. Jackson, retired on March 1, 1964, after almost 36 years of service with RCA Communications, Inc., in New York City. Mr. Jackson was most recently Manager of Engineering Services, Technical Publications Administrator, and RCA ENGINEER Editorial Representative for RCA Communications, Inc. Mr. Jackson received his BScEE from Oregon State College in 1924. Between 1924 and 1928 he was associated with the Southern Pacific Railroad Company in block signal installation, Pacific Gas and Electric Company, in valuation engineering, and Frank Rieber Company in geophysical exploration of areas for oil production possibilities. In 1928 he joined RCA Communications, Inc., being associated with station operations and engineering activities both in the United States and abroad.

CORRECTION:

In the last issue, (Feb.-Mar. 1964, Vol. 9, No. 5) please note the following correction in the paper by B. A. Cola, and J. M. Uritis, "A High-Speed Precision Instrumentation Tape Recorder." In the text, references to Figs. 3 through 15 are incorrect. Change as follows:

Printed text reference:	**Should be respectively:**
Figs. 3, 4, 5	Tables I, II, III
Figs. 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 (i.e., text reference to Fig. 6 actually refers to the illustration captioned as *Fig. 3,* and Fig. 7 to *Fig. 4,* etc.)

NEW TPA's ANNOUNCED

New Technical Publications Administrators (TPA) recently announced include **Cecil Frost,** RCA Communications, Inc., New York City; and **Frederico Harris,** RCA International, Clark, N.J. Mr. Frost replaces **Wayne Jackson,** now retired and Mr. Harris replaces **L. S. Beeny.**

In Defense Electronic Products, **F. D. Whitmore's** responsibilities as TPA have been expanded to include *both* technical papers and RCA Technical Reports (TR's) and Engineering Memoranda (EM's). Assisting Mr. Whitmore in DEP's papers and reports activities are:

J. Carter—Data System Center, Bethesda, Md.

E. Williams—ASD, Burlington, Mass.

S. Hersh—ASD, Van Nuys, Calif.

C. W. Fields—CSD, Camden, N.J.

T. Greene (*papers*) and **H. J. Schrader** (*TR's, EM's*)—MSR, Moorestown, N.J.

M. Pietz—App.Res., Camden, N.J. and DEP Microelectronics Eng., Somerville, N.J.

J. Lamb (*papers*) and **O. A. Cerami** (*TR's, EM's*)—Central Eng., Camden, N.J.

I. Seideman (*papers*) and **J. Phillips** (*TR's, EM's*)—AED, Princeton, N.J.

TPA's *(marked with an asterisk on the inside back cover)* administer approvals of technical papers; these same men also administer the approvals and distribution of TR's and EM's. (Staff coordination of papers and TR-EM activities continues to be provided for RCA by **W. O. Hadlock,** TPA, and **E. R. Jennings,** Ass't TPA, Product Engineering 2-8, Camden, N.J.)

RCA ENGINEERS ARE ACTIVE IN IEEE-PTGEWS SEMINAR

RCA representatives from several engineering and research groups were active participants in a recent seminar conducted by the IEEE Professional Technical Group on Engineering Writing and Speech. At the seminar on Feb. 24-25, devoted to the subject "Writing Improvement Programs for Engineers" **C. A. Meyer** Technical Publications Administrator and Mgr., Commercial Engineering Technical Service, ECD, Harrison, of Electron Components & Devices in Harrison, served as Chairman. **W. J. Underwood,** Engineering Personnel, MSR, Moorestown was moderator of Session No. 1 devoted to the "Specific Needs of Engineers for Writing Improvement." On this same panel, **George Kiessling,** Administrator of Product Engineering Professional Development, RCA Staff, was one of the panelists. **C. W. Sall,** Technical Publications Administrator, RCA Labs., Princeton was the moderator for a panel devoted to "Content of Writing Improvement Courses for Engineers." On another panel devoted to administration of writing improvement courses, **Eleanor McElwee,** Publications Engineer at ECD Harrison, served as moderator. **W. C. Praeger** of the Technical Staff, Communications Systems Div. Cambridge, Ohio, was one of the panelists on a panel devoted to "Evaluation and Prognosis." Subject of Mr. Praeger's speech was "A New Approach to an Old Problem."

Dr. J. H. Hillier, Vice President, RCA Laboratories, was the banquet speaker for the seminar.

Mr. Meyer, the Seminar Chairman, gave a paper at the International IEEE Convention held recently in N. Y. on the results of the entire seminar.

A *Proceedings* of the Seminar is to be published, and articles summarizing it will also appear in the *IEEE Trans. on EWS.*

INDEX TO RCA ENGINEER VOLUME 9

This subject and author index covers Vol. 9, No. 1 (June-July 1963) through and including the present issue, Vol. 9, No. 6 (April-May 1964). In the Subject Index, "E & R Note" indicates that the item was published as an "Engineering and Research Note." All technical and nontechnical articles published in Volume 9 are indexed herein (news items are not indexed). The format and indexing terms used are the same as in the RCA ENGINEER Pen and Podium Indexes, which cover RCA papers presented and published elsewhere.

SUBJECT INDEX

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

Local-Noise Discrimination, A Suggested Approach to—N. I. Korman (Tech. Prog., Cam.); *E&R Note*, RCA ENGR, 9-6, Apr.-May 1964, p74

Telephone Channel Noise Measurements—F. M. Brock (BCD, Cam.); RCA ENGR, 9-5, Feb.-Mar. 1964, p64

LASERS

CW Laser of CaF_2:Dy^{2+}, Fabrication and Test of a—B. R. Clay, T. A. Haddad (DEP-ASD, Burl.); *E&R Note*, RCA ENGR, 9-6, Apr.-May 1964, p78

Elliptical Glass Substrates for Laser Pump Cavities, Molding Techniques for—T. A. Haddad (DEP-ASD, Burl.); *E&R Note*, RCA ENGR, 9-6, Apr.-May 1964, p77

GaAs Laser, Preliminary Experience with the—Dr. J. I. Pankove, J. E. Berkeyheiser, F. Z. Hawrylo, H. Nelson (Labs, Pr.); RCA ENGR, 9-4, Dec.-Jan. 1964, p68

MANAGEMENT; BUSINESS

Computer R&D at RCA—A. K. Weber (EDP, Cherry Hill); RCA ENGR, 9-2, Aug.-Sept. 1963 *(Inside Cover Message)*

Creative Mechanical Engineering and RCA Patents—F. S. Misterly (Labs., Pr.); RCA ENGR, 9-6, Apr.-May 1964 *(Inside Cover Message)*

David Sarnoff Outstanding Achievement Awards, The 1964—(Editorial Staff); RCA ENGR, 9-6, Apr.-May 1964, p44

Decision—E. A. Laport (Com. Eng., Pr.); RCA ENGR, 9-3, Oct.-Nov. 1963, p8

Direct Energy Conversion—W. W. Watts (Corp. Staff, N. Y.); RCA ENGR, 9-3, Oct.-Nov. 1963 *(Inside Cover Message)*

Direct Energy Conversion — A Management Viewpoint – L. R. Day (ECD, Hr.); RCA ENGR, 9-3, Oct.-Nov. 1963, p9

Eighth Anniversary—Dr. G. H. Brown (R&E, Pr.); RCA ENGR, 9-1, June-July 1963 *(Inside Cover Message)*

IEEE Fellows, Four RCA Men Named (Editorial Staff); RCA ENGR, 9-4, Dec.-Jan. 1964, p15

History of RCA: Part III—The Years 1958-1962 (The Engineer and the Corporation)– Dr. E. W. Engstrom (Corp. Staff, N. Y.); RCA ENGR, 9-1, June-July 1963, p2

Laboratories RCA, Inc.—RCA Research in Japan—Dr. M. C. Steele (Labs, Pr.); RCA ENGR, 9-1, June-July 1963, p8

Legal Restraints on the Exportation of Technical Data (Engineer and the Corporation)—C. E. Yates (Labs, Pr.); RCA ENGR, 9-5, Feb.-Mar. 1964, p2

Magnetic Recording—H. E. Roys (Record, Indpls.); RCA ENGR, 9-5, Feb.-Mar. 1964 *(Inside Cover Message)*

Managing Creative Engineers—G. L. Dimmick (DEP-CSD, Cam.); RCA ENGR, 9-1, June-July 1963, p7

Modern Management for R&D Programs: A Case Study—TRADEX (Engineer and the Corporation) – R. A. Newell (DEP-MSR, Mrstn.); RCA ENGR, 9-3, Oct.-Nov. 1963, p2

Patents, RCA and You (Engineer and the Corporation)—O. V. Mitchell (Labs, Pr.); RCA ENGR, 9-2, Aug.-Sept. 1963, p2

Patents, Some Representative Examples of RCA's Electromechanical—(R&E, Pr.); RCA ENGR, 9-6, Apr.-May 1964, p8

RCA Institutes—I. Engelson, J. Brody (RCA Institutes, N. Y.); RCA ENGR, 9-1, June-July 1963, p36

RCA Missile Test Project—G. D. Clark (Svcs. Co., PAFB, Fla.); RCA ENGR, 9-4, Dec.-Jan. 1964, p58

RCA's Role in Direct Energy Conversion—D. W. Chace (ECD, Hr.); RCA ENGR, 9-3, Oct.-Nov. 1963, p10

SEER—Systems Engineering, Evaluation, and Research—D. Shore (DEP-SEER, Mrstn.); RCA ENGR, 9-4, Dec.-Jan. 1964, p40

Space—and Systems Engineering—B. Kreuzer (DEP-AED, Pr.); RCA ENGR, 9-4, Dec.-Jan. 1964 *(Inside Cover Message)*

Systems Engineering at RCA, The Role of (Engineer and the Corporation: Systems Engineering—Three Viewpoints: I)—N. I. Korman (DEP-AMS, Pr.); RCA ENGR, 9-4, Dec.-Jan. 1964, p2

Trademarks; Basic Principles and Concepts (Engineer and the Corporation)—J. A. Wortmann (R&E, N. Y.); RCA ENGR, 9-6, Apr.-May 1964, p2

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