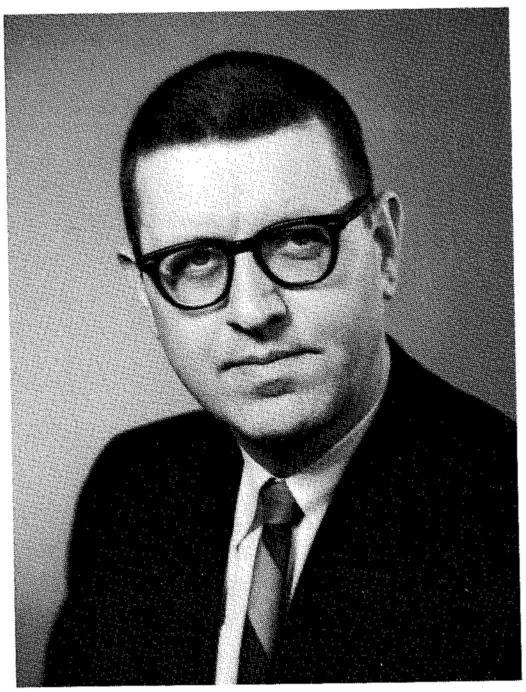
Interdisciplinary engineering

There was a time, perhaps 100 years ago, when an engineer was able to speak with authority on many of the then-known aspects of the physical sciences. Jules Verne, for instance, in his book *The Mysterious Island,* portrayed one engineer of the Civil War period as skilled in chemistry, geology, communications, and aerodynamics. Today, the working professional knows that the complexities of our current system and device concepts require intensive specialization to understand the state of the art and to extend it. At the same time, we have become acutely aware of the need for very broad skills to complement, overlay, and unite the specialist's output for an end result that is both balanced and complete.

The new skills that have arisen to cut across classical disciplinary boundaries have been collectively called interdisciplinary engineering. The papers in this issue serve to illuminate the current status and problems of interdisciplinary engineering as practiced in RCA, and indicate the many directions for future growth of this essential activity.



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Our Cover

. . . symbolizes the often-elusive and complex interfaces between different engineering disciplines. The engineers in the photo represent several engineering disciplines—different and specialized yet unified by their desire to apply their knowledge to the solution of a common problem. Clockwise from the top are Ken Weir, Rocco Ficchi, Frank Brown, John Allen, and Tso Wang—all of the Defense Communications Systems Division in Camden, N.J. **Photo credits:** Andy Whiting (concept), William Eisenberg (photography).

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RCA Engineer

• 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.

Contents

editorial input

project interface

Years ago, an engineer could count on one hand the different engineering disciplines, and it was relatively simple for him to communicate and to interface with others of his own profession. However, since World War II, the breadth of technology has expanded exponentially, while the number of engineers has increased only linearly. Concurrently, the complexity of the products blossomed to unbelievable proportions during this period. So in the interest of achieving greater efficiency, engineers became specialists, and this narrowing of interest has come to the point today where the specialties are often difficult to relate to one another. How much, for example, should the thermal design expert be involved with the human factors that contribute to a particular design, and what does the laser expert have in common with the integrated-circuit designer?

Three general problems exist: 1) it is more difficult for disciplines to interface with one another, 2) engineers find it more difficult to learn new specialties when their particular fields become obsolete, and 3) it is a monumental task to tie all the specialties together to achieve the best cost/performance tradeoff in the design of a system.

As editors, we learn something from each issue, and the lesson of this issue is particularly significant — not only to us as editors but to engineers of all specialties, to engineering management, and to corporate management. The significance is that the engineers themselves have recognized the problem and have offered, in these pages, some recommendations for a solution.

Mr. Ficchi, for example, directs our attention to the underlying unity of all engineering — common methodology and application of physical laws — and concludes that technical obsolescence will not be a real threat to the engineer who continually sharpens his skills in applying the basics of his profession. Mr. Daggett reinforces this thesis in his discussion of specific programs that RCA Institutes has developed to train (and to re-train) engineers in the application of fundamentals.

In their discussions of concept engineering, Mr. Day and Dr. Wetzstein identify the ingredients that blend to produce a successful product: teamwork, technical competence, knowledge of the marketplace, and a realistic view of the costs involved. Mr. Day's discussion centers on the individual who can successfully combine these ingredients, while Dr. Wetzstein discusses the environment in which this individual can function best.

Mr. Kolodkin provides us with some specific examples of engineers who can, and do, expand their skills into other areas. These are the multi-disciplined engineers who have applied their knowledge in new and, possibly, revolutionary ways.

Dr. Wolff's article then highlights some of the more subtle problems that engineers face in communicating with other disciplines. The problem is neither an unwillingness to communicate nor a language barrier; ironically, in spite of their common backgrounds, engineers of different disciplines often seem to visualize the same concept in entirely different ways.

Following these rather general papers are several articles treating specific engineering disciplines—from manufacturing engineering to environmental testing — from ceramic engineering to field engineering—and from quality assurance to metallurgy.

Taken as an entity, the issue demonstrates that RCA engineers know they must be capable of crossing the bounds of their disciplines to communicate effectively group-to-group and to benefit from the interaction. They recognize that the potentials of "project interface" are great and the challenges unusual.

Future issues

The next issue of the *RCA Engineer* features laser developments and applications. Some of the topics to be discussed are:

Future of lasers

Injection lasers

Gas lasers

Semiconductor lasers

Lasers in education

Lasers in communications

Lasers for aerial reconnaisance

Lasers for seeing through fog

Insulating materials for solid lasers

Laser rangefinders

Laser intrusion alarms

Discussion of the following themes are planned for future issues:

RCA engineering on the West Coast

Linear integrated circuits

Consumer electronics

RCA engineering in New York

Computers: next generation

Mathematics in engineering

Advanced Technology Laboratories

Balancing "knowing and doing" for engineers

B. I. Daggett

Engineering accomplishments require "doing" which is based on the application of knowledge. However, "knowing and doing" are continuously thrown out of balance by our educational system, our society, and the rapid advance of technology. Consequently, it is a continuing effort for the engineer to balance knowledge and its application from his first day of employment until his retirement. This article provides a brief overview of the problem and what the Institute for Professional Development of RCA Institutes is doing to help.

The Engineer and the Corporation

KNOWLEDGE AND UNDERSTANDING are stressed throughout our educational system, but what happened to the "how to do it" approach for engineers which used to be emphasized? It is fading away with the rapid advance of technical knowledge and changes of humanitarian values within our society.

Why the imbalance

A crowded curriculum is limiting the applied approach. Educational institutions must maintain breadth in the subject matter being presented to provide the information base required by the engineering class at large. The technological explosion has expanded this basic quantity of subject matter to the point that little time is available for applied engineering.

Another limiting factor is the lack of experience in "doing" on the part of the teacher. The vast majority of our engineering teachers do not have practical experience in applying the subject matter being taught. This is a subject of great concern which has prompted many schools to set up cooperative exchange arrangements for teachers and students with industry.

The sheer fascination by both faculty and students in pure principles and their derivations also inhibits the "how to do it" approach. They become deeply involved in basic principles to the point that applications are neglected.

These factors, combined with the search for individualism and the idealistic society, condition many graduates to view the engineer's function as the extension of pure principles through research with little other responsibilities. The scientist has been trained for this job, not the engineer. As a result, many engineering graduates are finding they are not fully prepared or satisfied to do the daily engineering tasks that must be done. The engineer must know "how" to apply his knowledge to be of value to our society.

This problem is not isolated to recent graduates but also manifests itself among older employees. It is not unusual for research scientists and engineers to get so "hung-up" in theory that they tend to overlook realities of the experiment.

The rapid advance of technology is creating technical obsolescence. The amount of basic technical knowledge is doubling approximately every ten years. Using this as a basis and assuming an engineer is employed for 40 years, the amount of technical knowledge will be increased by a factor of 16 during his employment. It has been estimated that the rapid growth in technology has reduced "the half life" of an engineer's usefulness to less than five years.[1] Many engineers working in specialized fields have become obsolete overnight. The engineer must maintain his specialization as well as a broad base of knowledge to avoid obsolescence.

Placing and keeping engineers in the mainstream of knowledge and its application is a tremendous task. It requires not only the conveyance of scientific principles but also how the principles can be put to use.

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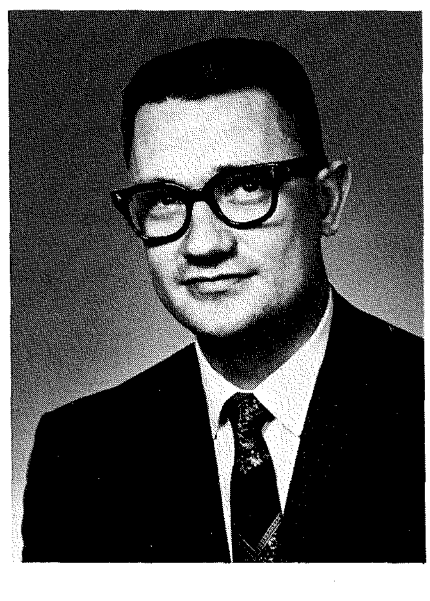
graduated with honors from RCA Institutes in 1958 and received the BS from Long Island University in 1965. He began his career wtih RCA in 1957 as an evening school instructor. Mr. Daggett transferred to the day faculty on graduation as an instructor in Computer Technology and Industrial Electronics. In 1960, he was appointed senior instructor. He was promoted to Associate Dean of the evening school in 1962. In the Fall of 1964, he directed the development of the first seminar offered by RCA Institutes. Mr. Daggett was promoted to Director of the School of Custom Educational Programs which was organized in 1964. The title of the school was later changed to the Institute for Professional Development. He has been noted for his pioneering efforts in teaching techniques and course development. In addition to his formal education, he holds certificates in a variety of technical specialties from 27 technical institutes. Mr. Daggett received the Who's Who Among Students in Universities and Colleges Award in 1965 and is listed in *Who's Who in American Colleges and University Administration.* He is a member of the American Society of Engineering Education, IEEE, American Society of Training and Development and the American Management Association. He has served as program chairman of the New York Metropolitan Chapter of ASTD. Mr. Daggett has also served on the National ASTD Committee on Professional Development.



Task of the educator

The task of the educator is to identify, assemble, and make information accessible in a lucid form under conditions which stimulate individual involvement. Learning, at its best, is a painful experience which involves both time and concentrated effort on the part of the individual. To actively involve the engineer in the learning process, the information must be in an acceptable form and readily accessible. Neither of these is easily accomplished because of the high cost of identifying and assembling information and the lack of a low-cost medium of instruction.

Identifying and assembling information

There are two primary sources of information which must be considered—education and industry. Educational institutions are the primary source for information related to principles and their understanding. Industry possesses the "know how" to apply these principles. To balance "knowing and doing" for the engineer requires the utilization of both sources.

Since preparing materials for our educational system is a well-documented subject, the topic of identifying and assembling "how to do it" information from industry will be explained. The procedures described are those used in the Institute for Professional Development of RCA Institutes.

The Institute has been stressing the "how to do it" approach for engineers over the past five years and has gained nationwide recognition for its accomplishments in this area.

The first step is to employ an experienced and highly competent engineer with writing and teaching ability to identify and assemble the information. A survey of industry and its practices must be conducted to determine if a consistency of design practice exists. If a pattern can be identified, the following questions are answered and evaluated.

Is the basic concept necessary for successful design?

Does the concept have wide application?

Just how important is the concept?

Is it the known "best way"?

Is it practical to consider in time, effort, money, and other resources for instructional purposes?

If the concept is still considered valid, it is then studied to determine the intuitive type of approach that underlines the design. A thorough study of the mathematical equations used in the design is undertaken. Painstakingly, the mathematical equations are eliminated to describe the process from a conceptual standpoint. The process of eliminating mathematics requires a high degree of mathematical ability and understanding. The mathematics must be minimized to highlight the intuitive and conceptual design approach, not as a means of lowering the level of instruction.

After all concepts have been fully identified and grouped for a given topic, the information is assembled in a written format with illustrations to provide a logical flow. This is a highly creative endeavor requiring much effort. Our experience dictates that development cost for an hour of course material of the type described runs 25 to 50 times higher than that of the conventional classroom type program. The end product is an educational program for engineers emphasizing the "how to do it" approach. It includes a text and visuals prepared by the same people who will present the program. This helps maintain continuity between the applied approach in industry and the classroom.

The presentation

Conveying the "how to do it" approach to engineers is very demanding of the teachers. A dual instructional technique is employed in the Institute for Professional Development to provide a lucid presentation. While one teacher is presenting the material, the second teacher observes the class reaction to determine if the students are grasping the material. If difficulty is noted, the second teacher politely cuts in on the main teacher to provide a slightly modified approach. To maintain the proper perspective and tempo, the teachers exchange positions with the introduction of each new topic. This technique permits adaptive instruction which is a very important requirement in teaching "applied" engineering. Highly competent teachers can tailor their presentation to the needs of the class group. A thorough mastery of the subject matter is required as well as skill in the communicative arts. To be effective, the teachers must be experienced engineers and the class group must be small in size. This combination results in a relatively high cost per student per hour of instruction.

For lack of a better title, the Institute for Professional Development refers to the programs as seminars. They are made accessible on a nationwide basis being presented at major industrial and military centers throughout continental United States. The seminars currently being offered are:

Logic Design (5-days),
Digital Systems Engineering (5-days),
Digital Communications (5-days),
Integrated Circuits (3-days), and
Optical Systems Engineering (5-days).

The programs have been widely acclaimed for increasing the productivity of engineers immediately on returning to the job. A few testimonials are given below to indicate the reaction of engineers to this type of educational program:

"This course was the most beneficial short-term course I have taken. Its success was due to the fact that it was designed to teach only *useful* techniques that could be used to advantage in an engineer's daily assignments."

"This is one of the most effective methods of teaching that I have ever run across."

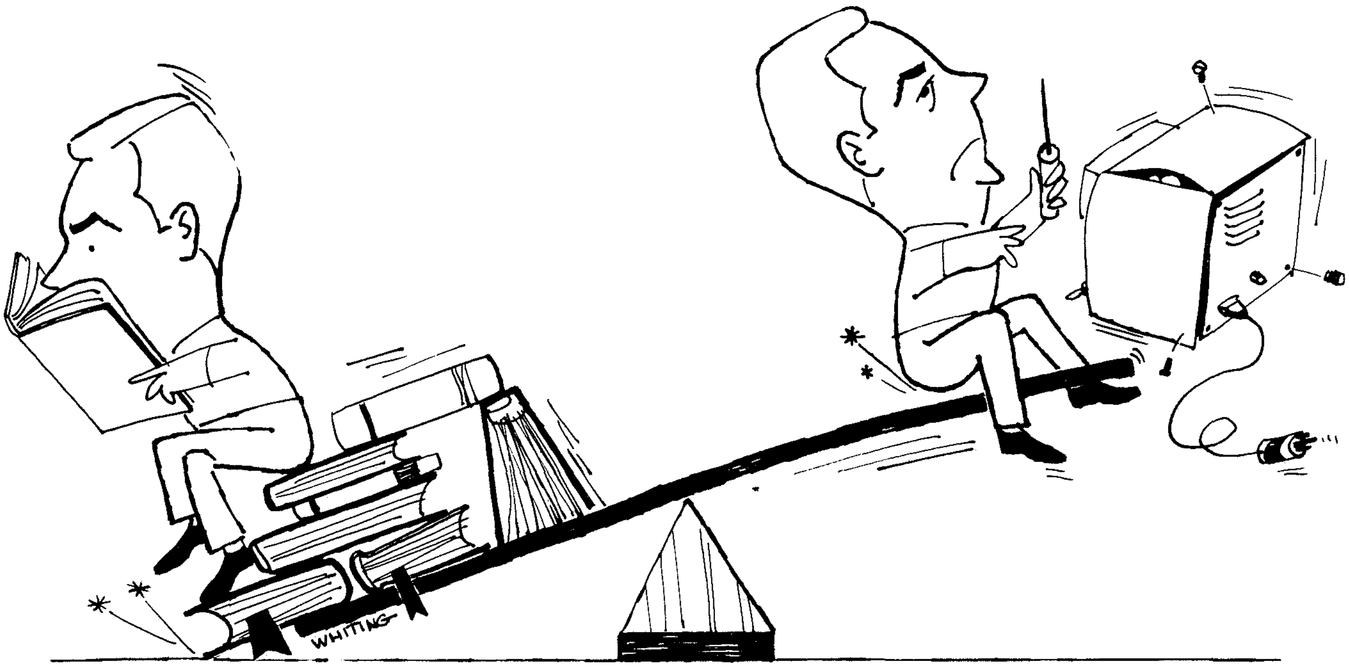
"Your training programs have proven to be a great asset and have allowed us to provide simpler, more economical fluidic control systems."

"The training was used as a springboard to solve digital logic design problems associated with a memory core my section has just recently purchased. Our section appreciates that your schedule permitted this, as one week spent in this seminar is well worth the time and money to engineers who need training in logic design techniques."

"Having attended many seminars ranging from uselessly simple to incomprehensible, my first attendance at RCA Institutes' course has been a very pleasant surprise. This has been about the best organized course that I have ever attended, including several years of graduate study."

"Excellent approach and delivery of material. If this is typical of RCA Institutes, then American colleges and universities have a great deal to learn from you."

"I have taken my share of graduate college courses, both full-time and after-hours, and of course they are good; but they do not concentrate on the most



useful, latest, direct design tools like the RCA Institute for Professional Development courses do."

"The seminar was the most rewarding learning experience in my career in terms of investment of time and money."

Educational level and experience

A presentation emphasizing the "how to do it" approach provides interest and is valuable to students with wide educational backgrounds. The results from a survey of over 5,000 students attending seminars offered by the Institute for Professional Development are given in Table I.

Table I—Comparison of educational level of participants of the Institute for Professional Development's programs to IEEE and subscribers of several magazines.

Educational Level	*RCA Institutes*	*IEEE*	*Electronics*	*Electronic Design*	*EEE*
No Degree	4%	16%	52%	46%	18%
Bachelor's	68%	60%	27%	30%	47%
Master's	21%	21%	21%	20%	35%
Doctorate	8%	3%	*	4%	*

*Not included in survey.

Engineering experience of the student body varies from no experience to many years. The engineering graduate needs to learn how to apply the knowledge he has acquired. The engineer transferred into a new or closely related field needs to learn the conceptual design techniques of that field. All, regardless of educational background or experience, are motivated to seek solutions to their engineering problems. The need for balancing "knowing and doing" has few boundaries in engineering.

The source of participants can be broken down into three groups: industrial organizations, educational institutions, and government agencies.

The industrial organizations that have intensive in-plant training programs are among the companies that have sent the highest number of participants. The ten industrial organizations sending the most participants are: RCA; Sandia Corporation; IBM; Bendix Corporation; Bell Telephone Labs; General Dynamics; Honeywell Inc.; Edgerton, Germeshausen & Grier Inc.; Grumman Aircraft Engineering; and General Motors Corporation.

Over fifty educational institutions have sent participants to the seminars offered by the Institute for Professional Development. Those sending the highest number of participants are: Johns Hopkins University, Massachusetts Institute of Technology, University of Michigan, Stanford University and Columbia University.

More than eighty government agencies including all branches of the Armed Forces and the National Aeronautics and Space Administration have sent people or have contracted for in-plant presentations.

Conclusion

The type of programs discussed is not the entire or only solution to help balance "knowing and doing" for engineers. They can, and have, helped many, but they cannot fulfill the entire need. The engineer must periodically update and extend his basic knowledge. He must be encouraged to participate on a regular basis in continuing educational programs, local university programs, or specialized in-plant programs designed for this purpose.

The RCA CEE video taped programs offered by Corporate Engineering Services provide an excellent means for RCA engineers to broaden their base and increase their usefulness to the company.

It is essential that engineers individually recognize their educational requirements and strive to fulfill them. In the end, only the engineer can balance "knowing and doing."

Reference

1. Zelihoff, S. B., "The Obsolescing Engineer," *Science & Technology*, (Apr 1969).

Interdisciplinary aspects of contemporary engineering

Rocco F. Ficchi

In this age of specialization and diversity, there is yet a unifying force that permeates all engineering, regardless of discipline. This force is the basis of engineering—the common methodology and the application of the laws of nature. Although specialization is a generally conceded necessity, the engineer who well understands the physical laws and has a firm grasp on the methodology common to all engineering will not only gain a better insight into other disciplines, but will be more versatile within his own specialty.

Technological progress depends on the specialized expertise that has created many relatively narrow, often exotic engineering disciplines such as value engineering, digital engineering, and display systems engineering. This fragmentation is to be expected because it is the most cost effective way of handling the problems of a complex, rapidly expanding technology. But specialization can be either detrimental to technological progress, or it can offer new opportunities that challenge the limits of an entire technology.

The ties that bind

Recognizing this apparent contradiction, one must weigh the benefits gained from specialization against the disadvantages of narrowing the vision of the various specialties. Fortunately, on careful analysis, there does exist a unifying force which binds all these seemingly unrelated specialties together. This interdisciplinary cement is the common engineering approach (methodology) used in all disciplines to solve their specific problems. The common methodology includes the use of mathematical models, inductive reasoning, and deductive logic. An additional adhesive is the discovery and application of physical laws common to all engineering. These combined forces—the methodology and the natural laws—are the foundation of all engineering disciplines.

To fully appreciate this commonality, still present but often hidden in contemporary engineering, delve into engineering history, and you will discover that (despite the growing complexity of engineering) common methodology and application of physical laws have always been the foundations upon which engineers worked. Whether the engineer was concerned with a relatively simple device or a complex device made little difference.

Someone, at one time, took advantage of the existing body of knowledge and applied this knowledge to some practical use. This application to practical use is the key to the identification of the engineer; he learned the laws of nature, and used the same laws to outwit nature. Paracelsus [15th century Swiss Physician] interpreted the achievement of the engineer with his technology as "co-operation with God in completing the work of the Universe." Today, however, with the myriad of individual applications of the laws of physics and chemistry, all the engineering disciplines seem to be going their own way. But despite this diversity of applications, there yet exists that unifying thread: the methodology and the physical laws.

Emergence of separate disciplines

The first telegraph was a device, simple in conception and depending on a few fundamental physical laws; the aerospace vehicle is an extremely complex device based on a wide variety of physical laws. The complete understanding of the aerospace vehicle is almost beyond the comprehension and understanding of a single individual. The system engineer understands the total operational function of the vehicle in performing its intended mission; the designer of a subsystem #1, for example, understands the design details of his particular subsystem; the maintainability engineer has determined the mean down time of the various subsystems. These disciplines have fragmented into small areas of special interest and seem to go their separate ways. In many instances, the most difficult part of making a complex device work is to ensure that all of these disciplines work toward a common goal. Thus, all of these disciplines have gone their separate ways so that no single discipline has the complete information about a product within its scope; yet each has "exclusive" detailed information of some special part of the product.

The underlying unity

This fragmentation is a natural outcome of the accumulation of detailed information. It does not mean that the underlying principles—the physical laws—have changed. In fact, the expanded information content developed by the ever-widening application of the natural laws to new situations strengthens the cohesive, underlying unity of this information. More information is developed simply because these laws are seen to be working in new situations.

Complex objects are made up of many simple parts which conceptually have much in common. The construction of a multi-layer printed circuit board depends on Euclidean geometry; the aerospace vehicle is designed with the same geometry. Therefore, conceptually from the aspect of geometry, one can understand either the geometry of the space vehicle or the circuit board, so long as one understands geometry. The complexity of the device will make no difference if one has a complete grasp of the concepts underlying these devices. And these concepts depend on one's basic understanding or knowledge. The enormous oceans of data may appear to be ready to inundate us on occasion, but this is only because one is looking at the little pieces of data as individual pieces and not as a unified application of the laws of nature.

It is interesting to note that some extremely esoteric new devices are quite simple insofar as the laws of physics

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and chemistry are concerned. Technological progress starts from a simple device, proceeds to a complex device, and eventually returns to a simple device. This cycle is due to the fact that the laws of nature upon reexamination reveal the simplicity inherent in a complex device.

A good illustration of this process is revealed by considering the basic circuit parameters of *R*, *L* and *C*. A generation ago, circuit courses were taught as though these parameters had discrete separate existences. They were represented as though resistance *R* was one item and capacitance *C* was another. This was a very idealized representation of the physical reality. Resistance *R* was actually an attempt to show (in a little wiggly symbol) the physical situation existing in the circuit. This physical situation is dependent upon the level of voltage and the magnitude of current; resistance exists everywhere in the circuit. To attempt to handle the physical situation, a model is contrived which includes this "lumped" parameter. There are actually an extremely large number of elements which go to make up this parameter, and the stylized representative of this is sort of an average of all these elements. When the engineer took a harder look at these circuit parameters, he realized the underlying relationships could be implemented in a different geometry and with different materials.

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received the BS (cum laude) from St. Joseph's College in 1941 and has completed graduate courses at the University of Pennsylvania. Prior to joining RCA in 1958 he spent 15 years wth various consulting firms, specializing in electrical distribution systems for the chemical, refinery, and atomic energy industries. He has been involved in three major programs at RCA—Atlas, BMEWS, and Minuteman—and has been particularly concerned with problems associated with the performance of electronic equipment in the electro-magnetic environment. He has authored over 20 technical papers, is the author of Electrical Interference published in 1964, and is general editor and a contributing author for the forthcoming EMC Handbook. He has been active in the History of Science Society, the New Jersey Academy of Science, and the American Association for the Advancement of Science.

Old handbook engineering days

This cyclical development from simple to complex and then back to the simple again is illustrated very pointedly in recent engineering development. Engineering was once very straightforward in its application, because only thoroughly digested scientific laws were used for these applications. Dr. Simon Ramo has described these as the "Old Handbook Engineering Days." Handbooks contained all the data and formulas necessary for a design to be developed, and design was the heart of engineering. Basic science was merely background material—essential but absorbed early in one's education and then remembered as important and comforting to know that it was there. It was the tried and true science of the great men who had long since passed on—Newton, Faraday and Maxwell. One can almost say that this exposure to basic science was superficial; none of the deeper implications were studied nor were any of the nagging unanswered questions considered.

The age of fundamentals

However, this rather benign situation did not prevail. As the laws of physics and chemistry were more thoroughly explored and exposed by the scientists, there was spilling over of interest in these laws by engineers. The real payoff came about when some engineers, who were heavily oriented toward the economics of new devices, realized that there was real gold to be had by the more rapid utilization of these laws of nature. In fact, these people got so worked up that they slipped quietly out of the engineering field and became *bonafide* scientists. The Age of Fundamentals was upon us. The engineer realized that the deeper his understanding of the laws of nature, the more likely it would be that he would see some new application of these laws for a newly developed device. The lines of demarcation between engineer and scientist began to blur. The mass news media used the term "scientist" for people working on the space program when it was obvious that they were really talking about the engineers.

The major beneficial results of such blending of the scientist and the engineer was the fact that they were using the same methods in solving their problems. This interdisciplinary method prevailed even as the engineer/scientist became more and more specialized. They both started from the same reference point and their paths were parallel. As the engineer or scientist became more specialized, he merely added a new and different fund of data to the method which was a common interdisciplinary methodology. The old "Handbook Engineering Days" are gone forever!

Conclusion—the rewards are great

The interdisciplinary commonality of all branches of engineering, through the common use of methodology and the laws of nature, provides the unifying force for all disciplines. The recognition of this commonality has a great reward attached to it. The scientific method enables the engineer to achieve greater understanding and a higher probability of solving specific problems; additionally, he can achieve more perspicacity in problem solving; and, furthermore, he generally gets better insight into future problems because of the thorough understanding of scientific principles.

Through an understanding of these positive results, certain pitfalls of contemporary engineering can be avoided. One becomes less concerned with remembering specific data but more concerned with the utilization of relevant data as it becomes available. The concentration on underlying principles based on the laws of nature permits one to keep sharpening his engineering skills with minimal difficulty. If these basic skills are kept sharpened by use, technical obsolescence will not be a real threat to the engineer.

Concept engineering—the qualifications

R. F. Day

This paper identifies a certain type of engineer—the concept engineer—and sheds some light on the function that he performs. Certainly the concept engineer is not some recent development; however, his role is often obscure and his methods informal. In the large corporations, both the role and methods are becoming more formally structured as products become more complex and expensive.

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received the BSEE from Fournier Institute of Technology in 1952. From 1952 to 1954, he was a development engineer at Bendix Radio Corporation, engaged in the development of precision CRT displays and controls for a ground-controlled approach radar system. From 1954 to 1956, he served at Picatinny Arsenal. Mr. Day joined RCA in 1956 and until mid-1965 he held various engineering and supervisory positions with responsibilities in the development of military digital computers and control systems. In early 1965, he joined the group which formed the Graphic Systems Division.

WHO IS THE CONCEPT ENGINEER? There is a tendency to apply the term "designer," but the designer performs his task at a different level. He devises components or processes to fulfill a specific, often well-defined need. The concept engineer is more likely the one who *recognizes that the need exists* and *defines the boundaries surrounding that need.*

RCA's complex products usually encompass several diverse technologies, such as electronics, optics, chemistry, and even some of the less quantitative fields, such as human factors and maintainability. Thus, products often do not have a single originator, but are the result of many contributions.

A good example of such a complex product is the VideoComp Electronic Composition System produced by the RCA Graphic Systems Division. Several technologies were brought to bear this device:

Technology	*Utilization in VideoComp*
Electronics	Cathode ray tube deflection and control circuitry. High speed digital logic.
Dynamics	Precision high-speed film-advance mechanism.
Optics	Imaging a high-intensity CRT spot onto the photosensitive medium.
Chemistry	On-line development of photosensitive materials.
Thermodynamics	Rapid drying of developed materials. Design of equipment cooling ducts.
Human factors	Ease of operation and maintenance.
Logic design	Computer/CRT interface design.
Computer Programming	System operation and control.

The difficulty in naming the designer or even a group of designers for such a product or system is quite apparent. Often, it is easier to find designers for various components or subsystems, and, indeed, this was the case with VideoComp. Yet before the designers can do their job, someone must recognize and identify a need and then visualize a product to satisfy that need.

Thus, *recognition, identification,* and *visualization* are the marks by which we can usually tell the concept engineer. At this point, it should be emphasized that the concept engineer is not necessarily a single person, but is often a team of people with diverse talents and interests. Nor is his work done in a brief flash of inspiration. Rather, he identifies the trends of change both in needs and in technology. The job would be much simpler if market needs and technology would stand still!

This, then, is the concept engineer. He is the one who *recognizes* that the need exists for a product; he *identifies* the specific need by defining its boundaries; and he *conceives* the nature of the product that will satisfy the need.

Characteristics

Challenge of the unknown

The nature of his work, dealing with undefined needs and products, suggests that, the concept engineer must not be uncomfortable when faced with the unknown. He looks at the unknown as a challenge to be examined . . . measured . . . defined . . . and ultimately no longer unknown. A corollary to this is that the concept engineer may lose interest in rehashing or extending the solutions to old problems. The researcher who spends a lifetime in the laboratory improving upon his first invention is the antithesis to the concept engineer in this regard.

Experience

Is our man a generalist who knows a little bit about a lot of things, but not too much about any one thing? No single person can have knowledge-in-depth across the many fields that we are considering. However, a firm base in the fundamental principles of mathematics and science is generally present. More often than not, the concept engineer has done well in his chosen field, but would rather broaden his knowledge than deepen it. Possibly more important than specific detailed knowledge is the ability and the desire to cross-pollinate ideas back and forth into other fields. Examples might be a chemist who does not shy away from electronics or the mechanisms man who does not shy away from computer technology. The concept engineer should consider what can be gained by applying the new and possibly alien technology.

Teamwork and tradeoff

Teamwork is one of the key characteristics. He is not affected with NIH (not invented here) factors, but can freely work on a base of ideas from others. Further, when his ideas are torn apart, he doesn't flinch, but be-

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gins to rebuild with what he has learned. The important thing here is that the team has an interchange of ideas in which all learn something new. The mere division of a task among a group of specialists does not necessarily provide teamwork; it provides a group of specialists each working on his own part of a job. If the group is a concept engineering group, each member is constantly aware, not only of his detailed task requirements but also the task requirements on each of the other group members. Such an awareness provides the atmosphere for constant development, tradeoff, and optimization. The key factor behind this kind of teamwork is the realization that additional engineering effort or end-product costs in one development area may produce overwhelming savings in another area.

Several notable examples of this kind of teamwork arose during the development of VideoComp. Since the system is built around a stored-program control unit (RCA 1600-Series Processor), one area of tradeoff was between the hard-wired logic of the interface control electronics and the soft logic of the control program. Here is a case of hardware and software being traded against each other to provide optimum cost and performance.

In another instance, significant amounts of redundant hardware were added to the system to optimize field and factory test and maintenance procedures. In this situation, programming effort and additional hardware manufacturing cost were traded for reduced maintenance costs over the life of the system.

One of the most important characteristics of the concept engineer is an ability to weigh the cost impact of a particular function or capability. So too, the reliability and maintainability aspects of the product must be considered since the cost of maintenance may often outweigh the original equipment cost.

The concept engineer appears to work from intuition as much as from experience. When a quantitative tradeoff becomes necessary, he will often have a remarkably accurate intuitive feel for the results prior to the completion of the tradeoff study.

Where is he found?

The concept engineer can be located in many nooks and crannys of industry. In RCA Defense Electronic Products, he can usually be found leading proposal efforts and new business activities. Even though his nominal base of operations may be design, systems, or project engineering, the concept engineer usually spends a large proportion of his time in the development of new business.

On large system contracts with turnkey delivery, he frequently accompanies the equipment into the field for installation and evaluation. This can be an invaluable experience because some of the cleverest engineering often is stimulated under the pressure of imminent system acceptance tests.

In the commercial divisions, the concept engineer is more difficult to locate since he is not normally banded together in the form of a project team for a specific new-business program. Also, the customer and product are generally not so well defined as in the military case.

Now our man may be the alert salesman who recognizes the unfilled needs of prospects and reports these back to Home Office, or the system-support man who constantly questions the suitability of the systems that he synthesizes and analyzes. More likely he is in the Planning and Engineering activities where he is engaged in the various aspects of Product Definition, Analysis, Evaluation, and Justification. He is often found trading off different approaches in the development of the end product or system.

How does he work?

Now we come to the most important question of all: What are his methods—his habits of work? Most often the concept engineer will get his assignment as the result of a problem. Some product or service must be conceived which will satisfy a previously unrecognized market need.

In this situation, the concept engineer devises one or more potential solutions to the problem, and proceeds to test and evaluate. The method of test and evaluation generally will consist of asking a series of questions, such as:

1) *Is this product realizable?*

2) *Can it be manufactured economically, so as to provide a profit?*

3) *Does it do its job economically for the customer? Can it be sold easily without requiring major or abrupt changes in the customers methods or procedures?*

4) *Is there a potential for additional ancillary or related products that can be sold into this same general market area, so as to spread the marketing costs as widely as possible?*

5) *Are the Engineering and Manufacturing expertise that will be required for the development and production of the product readily available?*

If these criteria are met successfully, the product can generally proceed into the first stage of paper design. In this stage, the product is divided into its major subsystems or component parts which are individually analyzed as to performance and cost.

The concept review

At this point in a program, a concept review can be performed. Sufficient data should now be available to provide engineering cost and schedule, projected manufacturing cost for various production lots, and sufficient performance and operating characteristics to enable a comprehensive market analysis. The concept review provides a brief pause for reflection in the early development stages. It is here that consideration should be given to the cost/performance tradeoff. Must performance be improved even at increased cost? Should we reduce cost and aim for a broader market? How much performance can be sacrificed to cost reduction? The purpose of the concept review is to provide management with sufficient data to deal rationally with these kinds of questions. One of the most important functions of the concept engineer is to provide the alternate options and to clarify the implications of selecting an alternate.

Concluding remarks

The concept engineer has been with us for some time, but only recently has his task been examined in any formal sense. He is relied upon to recognize and identify a need and to conceive a product that will satisfy that need. He must be capable of crossing disciplinary boundaries to formulate his ideas, and must carefully examine the tradeoffs and alternatives at every step of the conceptual process.

Concept engineering—the environment

Dr. H. J. Wetzstein

This paper treats concept engineering, rather than systems engineering. The main distinguishing feature probably is that concept engineering is intended to imply a broad approach to utility, involving many possible alternative system approaches. Thus, concept engineering can be considered as the process of pre-system probing and definition, or system evolution.

The many forms and measures of utility as well as technology available make concept engineering a most difficult, if not impossible, discipline to formalize. Many alternative possible systems must be invented or considered. A great deal of attention to the physical, as well as behavioral, environment is implicit in assumptions and can seldom be formalized explicitly. Often such environmental factors dominate the decision to develop or acquire a potential capability.

It is the recognition of this complex environment added to the usual engineering skills and approaches, that makes concept engineering the difficult field it is. Add the increasingly complex system and interactive needs that must be addressed, and you have the environment for concept engineering, within which individuals (as well as corporations) must seek successful roles. It is hoped that the broad description of this environment attempted here will increase the awareness of engineers of the complexity of the total problem, and the strong need for interaction to achieve that success.

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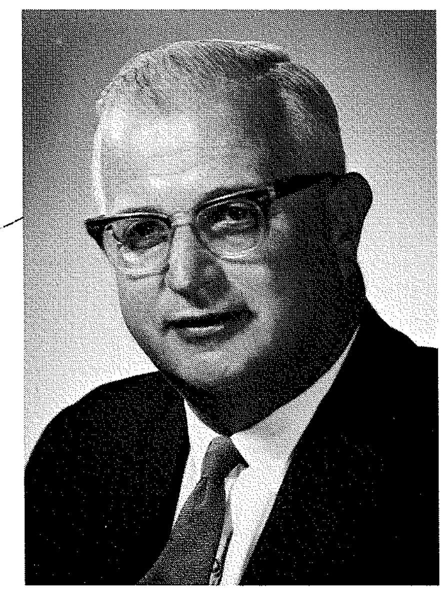

Definitions

A glossary of definitions from Webster's[1] really gives a very good introduction to the subject.

Engineering: 1. The art of managing engines. 2. A science by which the properties of matter and the sources of energy in nature are made useful to man.

Concept: 1. Something conceived in the mind. 2. An abstract idea generalized from particular instances.

Discipline: 1. A subject that is taught; a field of study. 2. Training that corrects, molds or perfects the mental faculties or moral character.

System: 1. A regularly interacting or interdependent group of items forming a unified whole as: a group of artificial objects or an organization forming a network especially for distributing something or serving a common purpose.

Evolution: 1. A process of change in a certain direction. 2. A process of continuous change from a lower simpler or worse to a higher more complex or better state.

Revolution: 1. A sudden, radical or complete change.

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received the BSEE with distinction from the University of Cape Town in 1947 and the MS and SD electrical engineering from Harvard University in 1948 and 1952, respectively. With RCA from 1955 to 1961, Dr. Wetzstein was Leader of a digital computer input/output equipment group and worked as Senior Engineering Scientist on ballistic missile re-entry detection measurement programs and systems. With the Institute of Naval Studies from 1961 to 1965, Dr. Wetzstein had responsibility for a study of power for propulsion of naval vehicles and was principal investigator on a study of science and technology needed for undersea warfare. From 1965 to 1967, Dr. Wetzstein was a Senior Staff Associate at Arthur D. Little. His case work included ASW surveillance, sonar data processing and fire control systems, extra vehicular activity, space mission studies, automatic inspection and test techniques, and hybrid computer evaluation. Dr. Wetzstein rejoined RCA in 1967 as Senior Engineering Scientist and is conducting investigations on advanced electro-optical systems. Dr. Wetzstein is a member of the Institution of Electrical Engineers (London) Sigma Xi, and the Marine Technology Society. He has published several papers in the classified and open literature.

Interaction—a key to solution

Matters concerned with concept engineering are generally discussed these days in symposia and studies under titles such as:

Management of research or innovation
Technological forecasting
Research on productivity or creativity
Technology transfer or utilization

A review of reports on such symposia and studies shows that the general concern and effort is focused on the environment in which engineers in corporate or government structures can formulate concepts. The main program appears to be in striking a good balance between the following:

Specialization (knowledge of frontier developments)
Technical breadth (systems, devices, materials)
Need and marketplace awareness (including implications)

The problem is recognized as one of embedding the individual engineer in an environment in which he can interact with others. Insofar as a concept must be synthesized from one or a few substantially novel ideas, as well as adaptations or improvisation of old ideas, it must emerge from interaction between a few key people in different disciplines, organized to allow pursuit in depth and breadth.

The way in which different technical disciplines must overlap, and the shrinking of evolutionary time scales to the revolutionary level are demonstrated in Fig. 1 (reproduced from Ref. 2).

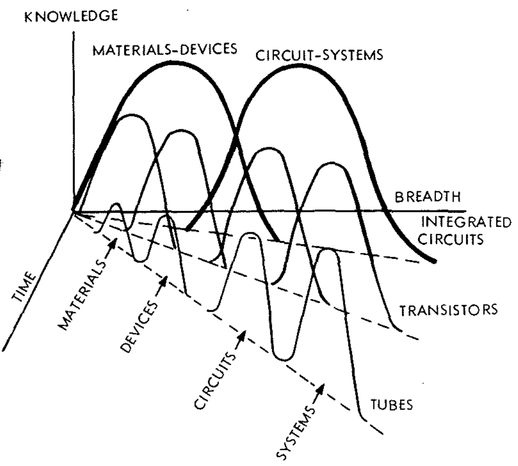

Fig. 1—Overlapping of technical disciplines as a result of evolutionary and revolutionary change.

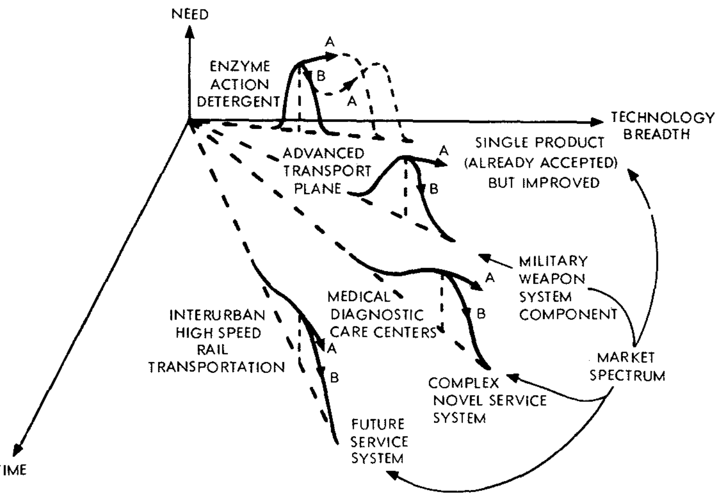

Fig. 2—Simplified spectrum of market activity.

The danger of gradualism

The introduction of new technology can often be achieved only gradually and without interrupting the functioning of an existing system. The importance of this was certainly in evidence when compatible color TV was introduced. Engineering is greatly challenged, however; the danger of gradualism in the face of a really new concept is clearly demonstrated by the following letter reproduced from Ref. 3.

November 15, 1876

Chauncey M. DePew, Esq.
President, Telegraph Co.

Dear Mr. DePew:

This committee was formed at your request to consider the purchase of U.S. Patent 174,465 by our company. Mr. Gardiner G. Hubbard and Mr. A. G. Bell, the inventor, have demonstrated their device, which they call the "Telephone", for us, and discussed their plans for its use.

The "Telephone" purports to transmit the speaking voice over telegraph wires. We found that the voice is very weak and indistinct, and grows even weaker when long wires are used between the sender and receiver. Technically, we do not see that this device will ever be capable of sending recognizable speech over a distance of several miles.

Messrs. Hubbard and Bell want to install one of their "Telephone" devices in virtually every home and business establishment in the city. This idea is idiotic on the face of it. Furthermore, why would any person want to use this ungainly and impractical device when he can send a messenger to the local telegraph office and have a clear written message sent to any large city in the United States?

The electricians of our own company have developed all the significant improvements in the telegraph art to date, and we see no reason why a group of outsiders, with extravagant and impractical ideas, should be entertained, when they have not the slightest idea of the true practical problems involved. Mr. G. G. Hubbard's fanciful predictions, while they sound very rosy, are based upon wild-eyed imagination and a lack of understanding of the technical and economic facts of the situation, and a posture of ignoring the obvious technical limitations of his device, which is hardly more than a toy, or a laboratory curiosity. Mr. A. G. Bell, the inventor, is a teacher of the hard-of-hearing, and this "Telephone" may be of some value for his work, but it has too many short-comings to be seriously considered as a means of communication.

In view of these facts, we feel that Mr. G. G. Hubbard's request for $100,000 for the sale of this patent is utterly unreasonable, since the device is inherently of no value to us. We do not recommend the purchase.

Yours truly,

(NAME DELETED)
for the committee

Note that the inventors had visualized the correct overall concept to match their invention. However, costwise, the resources allocated must be justified by *added* or *novel* utility.

The marketplace

While on the subject of costs and utility, we must recognize the fact that the marketplace in which the products of engineering have to find acceptance has quite varied and distinct classes of customers such as:

Individual (singly or in small groups)
Commercial or industrial organizations (serving each other as well as selected other classes)

Local or municipal government State or national government International organizations	each with many separate departments

By gross oversimplification of the dimensionality of both need and technology breadth, it is possible to show (see Fig. 2) the broad spectrum of market activity from a single well-defined and accepted consumer product to a novel complex service system. The concept shown omits entirely the general preparatory development effort and early abortive attempts frequently encountered.

After reaching an initial need level there are two alternatives (see Fig. 2):

A. Growth by accretion of new technology (further evolution)
B. Loss to competing approaches (technical revolution)

A typical military weapon system is also shown in perspective. Because needs are supported and well-defined, and a technological base is usually prepared, time scales are short considering the complex tasks involved. Fig. 2 further shows a future service system such as interurban, high-speed rail transportation which will probably be slow in coming, particularly because ancillary intra-urban and competing air transportation capabilities must be recognized.

Social need

Although electronics engineers are quite accustomed to revolutionary changes such as shown in Fig. 1, it is clear that in major system investments, be they of military or social utility, changes will be far slower and more evolutionary. However, this does not negate replacement markets in functional subsystems which can benefit from new technology. Just as corporations have structured and organized themselves to serve the existing commercial product and military system markets, they will meet the rising need for general and social service systems to which products can be engineered. The marketplace and structure for these systems is, at present, the subject of much industry-government soul searching and interaction. Government at all levels is involved. If and when lines are drawn, objectives defined and established, and resources allocated, it can be expected that industry as well as government will effectively address itself to those needs of society which today requires a planned systems approach. Some typical approaches are:

- Urban development
- Environment pollution
- Pockets of poverty
- Automation and re-education
- Health care and preventive medicine

Personal entrepreneurship

To clearly relate technological developments to service or product concepts in these broad areas typified above will require considerable intermediary or peripheral social and economic study and definition. The main purport of this paper is to make engineers aware that they must participate in such efforts, and that company management will continually reorganize to achieve such participation. However, there is a clear role for the engineer in proposing possible approaches, and personal entrepreneurship is very much required to make the process work. The drive for innovation is a strong American characteristic and is perhaps best identified by the following excerpt from de Tocqueville, *Democracy in America* (about 1836) in a chapter entitled "Reflections on the causes of commercial prosperity of the United States."

". . . The American starts from Boston to go to purchase tea in China; he arrives at Canton, stays there a few days, and then returns. In less than two years he has sailed as far as the entire circumference of the globe, and he has seen land but once. It is true that during a voyage of eight or ten months he has drunk brackish water, and lived upon salt meat; that he has been in a continual contest with the sea, with disease, and with a tedious existence; but upon his return, he can sell a pound of his tea for a halfpenny less than the English merchant, and his purpose is accomplished. "I cannot better explain my meaning than by saying that the Americans' effect a sort of heroism in their manner of trading. But the European merchant will always find it very difficult to imitate his American competitor, who, in adopting the system which I have just described, follows not only a calculation of his gain, but an impulse of his nature.

"The inhabitants of the United States are subject to all the wants and all the desires which result from an advanced state of civilization, but as they are not surrounded by a community admirably adapted, like that of Europe, to satisfy their wants, they are often obliged to procure for themselves the various articles which education and habit have rendered necessaries. In America it sometimes happens that the same individual tills his field, builds his dwelling, contrives his tools, makes his shoes, and weaves the coarse stuff of which his dress is composed. This circumstance is prejudicial to the excellence of the work; but it powerfully contributes to awaken the intelligence of the workman. Nothing tends to materialize man, and to deprive his work of the faintest trace of mind, more than extreme division of labour. In a country like America, where men devoted to special occupations are rare, a long apprenticeship cannot be required from any one who embraces a profession. The Americans therefore change their means of gaining a livelihood very readily; and they suit their occupations to the exigencies of the moment, in the manner most profitable to themselves. Men are to be met with who have successively been barristers, farmers, merchants, ministers of the Gospel, and physicians. If the American be less than perfect in each craft than the European, at least there is scarcely any trade with which he is utterly unacquainted. His capacity is more general, and the circle of his intelligence is enlarged.

"The inhabitants of the United States are never fettered by the axioms of their profession; they escape from all the prejudices of their present station; they are not more attached to one line of operation than to another; they are not more prone to employ an old method than a new one; they have no rooted habits, and they easily shake off the influence which the habits of other nations might exercise upon their minds, from a conviction that their country is unlike any other, and that its situation is without a precedent in the world. America is a land of wonders, in which everything is in constant motion, and every movement seems an improvement. The idea of novelty is there indissolubly connected with the idea of amelioration. No natural boundary seems to be set to the efforts of man; and what is not yet done is only what he has not yet attempted to do.

"This perpetual change which goes on in the United States, these frequent vicissitudes of fortune, accompanied by such unforeseen fluctuations in private and in public wealth, serve to keep the minds of the citizens in a perpetual state of feverish agitation, which admirably invigorates their exertions, and keeps them in a state of excitement above the ordinary level of mankind. The whole life of an American is passed like a game of chance, a revolutionary crisis, or a battle. As the same causes are continually in operation throughout the country, they ultimately impart an irresistible impulse to the national character. The American, taken as a chance specimen of his countrymen, must then be a man of singular warmth in his desires, enterprising, fond of adventure, and above all, of innovation. The same bent is manifest in all that he does; he introduces it into his political laws, his religious doctrines, his theories of social economy, and his domestic occupations; he bears it with him in the depth of the back woods, as well as in the business of the city. It is this same passion, applied to maritime commerce, which makes him the cheapest and the quickest trader in the world."

The spirit described, which pervaded marine commerce enterprises, did not suffice to keep America in the forefront of that industry. However, it was a powerful influence in the industrial and commercial development of America and is today, perhaps, best exemplified in our electronics and computer industry, and space exploration. Clearly, then, the individual drive to invent, develop, and create must be harnessed effectively to attack very broad objectives.

The corporate organization

The success of this kind of effort is accomplished most effectively by an appropriate organizational structure implemented by large companies or corporations. Although structurally complex because of size, the organizations must continually be adaptable in this environment to reap a profit by producing goods and services in the broad market area. Further, they must consider the pool of skills and facilities very carefully in selecting appropriate sectors of these markets. Emphasis on services as contrasted with consumer products is likely to increase, and this emphasis will, in turn, influence the design of products.

Engineers and scientists function as organized into major divisions or subdivisions within larger corporations. Reviewing commercial productivity, the consensus reinforces the previous statement that an awareness of needs and the market is essential. One such review gave a rather interesting comparison of productivity and profitability in the electronics industry of several countries. It is reproduced in Table I from Ref. 6. Table II has been drawn up from Ref. 4 to show the growth of a single U.S. company on the basis of a single novel product line. The profitability of a new product is strongly evident and is motivating the emphasis on growth via innovation.

The differences between countries in terms of productivity and profitability is, of course, related to the living costs and standards. The ability within the US to achieve high levels of productivity and profitability is fundamentally the basis of high living standards reflected in costs. US industry is generally able to achieve the desired high levels more easily in areas with new and high technology content. Thus, there is considerable incentive for the engineer and scientist to help evolve solutions. The increasing emphasis on service will lead to solutions which are related to convenience and habit such that the large internal US market will not be as subject to international competition as it is in basic materials such as steels, textiles, etc.

It is then by changes in internal structure that corporations adapt themselves to grow within the environment and in turn, of course, the environment is influenced.

We have here, in fact, problems as complicated as those of living organisms within and part of an ecology. "The Strategy of Evolution," for example, states that the survival of a species is insured by properly time-scaled adaptability via flexibility of organization.[7] In studying and modeling the growth and success patterns of small technical companies in the Route 128 Boston area ecology, Professor Forrester of MIT has found that the main identifiable ingredient required was consistency and patience with a line of attack once adopted. Companies which changed objectives and approach too frequently did not do well. Thus, the time scale for flexibility and adaptability is quite important.

Research and development

To put the matter of R&D effort as related to overall effort into perspective, we quote from Ref. 6:

> "The purpose of R&D in a company is clear. The production employees will, in general, go on making the same products in the same way next year unless someone introduces new products or new and more efficient manufacture of existing products. It is the job of the R&D departments to do this and they in turn must look to the market place to colour their thoughts and to sort out their priorities. In a so-called 'science based' company, the research spending might amount to about 2% of sales, and the development to about 8%. However, for a new product the R&D costs might only be about 15% of the total costs of introducing the new product—the remaining 85% would be spent on market research, application research, the design and manufacture of production machinery, and on the training and 'warming up' period."

Clearly the purely technical inventive

Table I—Sales, profits, and employees of various companies of the electrical/electronics industry.

Company	*Country*	*Year*	*Sales ($M)*	*Pre-tax Profits ($M)*	*No. of empl'ys*	*Sales per employee ($)*	*Profit per employee ($)*
Plessey	U.K.	1966	307.0	29.0	65,000	4,740	446
GEC/AEI*	U.K.	1966	1015.0	64.5	162,000	6,260	400
English Electric/Elliott*	U.K.	1966	736.0	43.1	103,000	7,150	417
Philips	Holland	1966	2220.0	235.0	244,000	9,120	960
AEG/Telefunken	W. Ger.	1966	1210.0	76.7	138,000	8,800	561
Ericsson	Sweden	1966	388.0	43.1	43,000	9,050	1,005
RCA	U.S.A.	1966	2590.0	250.0	124,000	20,320	1,940
General Electric	U.S.A.	1966	7070.0	665.0	350,000	20,280	1,900
Westinghouse	U.S.A.	1966	2550.0	224.0	125,000	20,350	1,760
Perkin-Elmer	U.S.A.	1966	76.7	7.2	5,300	14,350	1,360
Matsushita	Japan	1966	960.0	93.6	60,000	16,000	1,560

*The GEC/AEI and English Electric/Elliott amounts are the separate figures for 1966 added together.

Table II—Same data as in Table I showing growth of company based on a new product.

Company	*Country*	*Year*	*Sales ($M)*	*Pre-tax Profits ($M)*	*No. of empl'ys*	*Sales per employee ($)*	*Profit per employee ($)*
Xerox	U.S.A.	1966	650.0	170.0	30,000	21,660	5,660
		1948	8.6	0.76	672	13,000	1,150

Table III—Interactions between specific divisions of North American Rockwell in technology exploitation effort.

		Aerospace & Systems Group							
		Executive Office	*Automatic International*	*Autenetics*	*Columbus Division*	*Los Angeles Division*	*Rocketdyne*	*Space Division*	*Total*
Commercial Products Group	Executive Office	49	6	15	4	3	8	6	91
	Aero-Cdr.	10			2	5		1	18
	Air-Maze	4		1		5	3	1	14
	Boston Draper	5		4		2	2	2	15
	Gear	2		1	1	1	1	1	7
	Heim	22		1					3
	Turbo-Systems				1		1		2
	Rockwell-Standard	13		4	1	11	4	4	37
	Total	85	6	26	9	27	19	15	187

effort is only a small part, and its relation to the larger one of market acceptability is vitally important.

Under the topic of Technology Utilization and Transfer, there are major efforts going on within large organizations. NASA has a special office which does its best by means of publications, seminars, and consulting to find applications for its new technology in non-space applications. Within large multidivision corporations special efforts are undertaken to provide cross-feed. One such venture by North American Rockwell is covered, along with others, in Ref. 8. The strong catalytic influence of the Executive Office is quite evident and apparently necessary to achieve effective followup as shown by Table III.

In Ref. 5, Dr. Hillier characterizes the main approaches to product innovation within RCA as:

"Selling" incremental improvements.
"Applied research" funding.
Corporate funding of existing divisions.
Establishment of new divisions.
Establishing a corporate entrepreneurial task force to operate across divisions.

He states the problem very succinctly:

"It does not take much study to recognize that in our business climate good research is a necessary but not sufficient condition for business success. The innovations coming out of research must be threaded through a bewildering maze of financial, organizational, and psychological barriers before they reach the marketplace where they must undergo the final and most rigorous test of all."

His paper (and the panel discussion following it) dwells on the topic of centralized research vis-a-vis divisional organization. It also contains specifics of approaches utilized within RCA.

Concluding remarks

The listed references are intended to serve the reader who would like to follow up in some detail, approaches viewed by different individuals for different situations, and as such, they contain some specific case histories. These are all responses to the environment which was considered the prime purpose of this paper, because it really takes the engineer into considerations outside and beyond his discipline and into areas where disciplines are far less well defined.

The Aerospace Systems Division in which the writer is located is heavily engaged in automatic test equipment for complex military weapons and spacecraft. Essentially, this provides a service function, but influences basic product design. Such testing is at present growing into the commercial transportation field as airliners become faster, larger, and more complex, and the need for automotive diagnostic centers rises. Longer range growth may take this technology into home appliance servicing and eventually to the most complex system of all, the human body, in diagnostic centers supporting preventive medicine. The applications are, however, in marketplaces quite different from those presently served by the division.

The main point in presenting the environment has been to stress the importance of attention to the "whole" of it. Matters of taste, quality of individual life, and society objectives require increasing attention as important features of the marketplace. To create the necessary synthesis many approaches are followed, and system analysis and other analytic tools are used. An early effort to emphasize the importance of wholeness or systems approach via the philosophy of "Holism" is contained in Ref. 8 from which the following quotation is taken:

"Wholes are not mere artificial constructions of thought; they point to something real in the universe, and Holism is a real operative factor, a *vera causa.* There is behind Evolution no mere vague creative impulse or *Élan vital,* but something quite definite and specific in its operation, and thus productive of the real concrete character of cosmic Evolution.

"The ideal of wholes and wholeness should therefore not be confined to the biological domain; it covers both inorganic substances and the highest manifestations of the human spirit. Taking a plant or an animal as a type of a whole, we notice the fundamental holistic characters as a unit of parts which is so close and intense as to be more than the sum of its parts; which not only gives a particular conformation or structure to the parts, but so relates and determines them in their synthesis that their functions are altered; the synthesis affects and determines the parts, so that they function towards the 'whole'; and the whole and the parts therefore reciprocally influence and determine each other, and appear more or less to merge their individual characters: the whole is in the parts and the parts are in the whole, and this synthesis of whole and parts is reflected in the holistic character of the functions of the parts as well as of the whole."

"There is a progressive grading of this holistic synthesis in Nature, so that we pass from: (a) mere physical mixtures, where the structure is almost negligible and the parts largely preserve their separate characters and activities or functions: to (b) chemical compounds, where the structure is more synthetic and the activities and functions of the parts are strongly influenced by the new structure and can only with difficulty be traced to the individual parts; and again: to (c) organisms, where a still more intense synthesis of elements has been effected which impresses the parts or organs far more intimately with a unified character and a system of central control, regulation, and co-ordination of all the parts and organs arises; and from organism, again on to (d) minds or psychical organs, where the Central Control acquires consciousness and a freedom and creative power of the most far-reaching character and finally to (e) personality, which is the highest, most evolved whole among the structures of the universe, and becomes a new orientative, originative centre of reality. All through this progressive series the character of wholeness deepens; Holism is not only creative but self-creative, and its final structures are far more holistic than its initial structures. Natural wholes are always composed of parts; in fact the whole is not something additional to the parts, but is just the parts in their synthesis, which may be physico-chemical or organic or psychical or personal. . . ."

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Multi-discipline engineering

S. S. Kolodkin

Advances in technology and demands for more complex electronic equipments have brought together the talents of many engineers with various disciplines and points of view. As a result, many engineers have transcended the classical bounds established for their discipline and have become "multi-discipline engineers." This paper examines the reasons for this transition and cities two specific examples.

MOST ENGINEERS working in industry today, particularly those with more than ten years of experience are prepared in one of the so-called classical disciplines: electrical engineering, mechanical engineering, chemical engineering, metallurgy, or physics. Their formal training emphasized particular classical courses in each of these fields; thus, until they began their working career, they had little professional contact with engineers in other fields, since day-to-day classwork was with students of the same background. As their careers developed, however, they found that real problems required them to work closely with engineers trained in many varied fields. For example, complex electronic equipments (such as those produced at RCA) require the combined talents of many engineers with varied skills and points of view. More importantly, as their careers developed, advances in technology obsoleted their specific training but often bridged the gap between existing techniques and those considered state-of-the-art.

In recent years most universities have changed their philosophy with respect to engineering education. As a result they have drastically altered the framework of courses pursued by undergraduates and graduates alike. Eliminated or de-emphasized are courses such as synchronous motor design, vacuum tube design, and transformer design. These have since been replaced by more fundamental courses in AC field theory, 4-terminal network theory, and emphasis on physics and mathematics.

One recent advance in technology is the development of the laser. Today, there are many engineers who call themselves laser engineers, and yet when most of them graduated, not one knew what a laser was.

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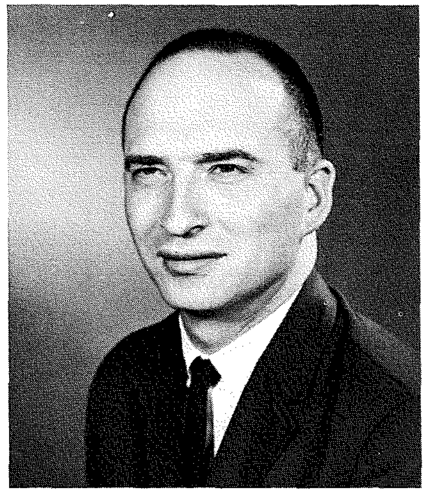
The design of modern electronic equipment for large systems and space requires a new approach towards the classical roles of the electrical and mechanical engineer. Recent experience in developing electronics for the Lunar Module (LM) did not allow the old and comfortable approaches of electrical engineers designing circuits, specifying parts, and releasing them to mechanical engineers who then proceeded to package them with more or less classic techniques. To achieve the stringent weight, reliability, and performance goals set by that program, a new awareness of each other's problems had to be faced and new organizational approaches evolved.

The use of digital computers as an engineering design tool has further forced the melding of engineering disciplines. Mechanical and electrical engineering problems, when reduced to the use of digital techniques required for their solution, are often more similar than different. Engineers are forced to think in those mathematical terms which make their art tick.

Past experience yields many examples of the multi-disciplined engineer at work; we can anticipate that future developments will require more of this broad skill. As engineers mature and develop, they must take active steps to increase their awareness of this important concept. The choice of specific after-hour courses can be significant, and an active desire on their part to understand will help. Additionally, this requirement presents its own unique challenge to engineering management. The specific engineering organization can either help or hinder technical interplay. The engineering manager must understand its importance when he organizes to do a specific engineering task. Even the categories that we attach to people, such as, "He is an electrical engineer, so what does he know about thermal design?", or, "Why is a mechanical engineer worry-



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received the MSEE from MIT in 1955 and has 15 years experience in Control Systems Engineering including 14 years with RCA. Mr. Kolodkin is responsible for the radars, stabilization and control electronics, and ground support equipment for the Lunar Module (LM). In addition, he supervises System Engineering and Program Managers for electro-optical systems for aircraft and space track, airborne radar and ECM, as well as missile electronics and optics programs. Prior to his present assignment, he was Manager, Electro-Optics & Control Engineering, and responsible for the total activities of the Electro-Optics & Control Skill Center. Since joining RCA, Mr. Kolodkin has worked on a number of electro-optic, control, and systems projects. He was responsible for programs related to guidance and control problems in the fields of missile and space systems and airborne fire control. He also served as project engineer for the SPANS lightweight inertial platform and associated digital digital differential analyzer. More recently, he served as Manager, Control Equipment Engineering, responsible for guidance and control equipment development and evaluation on the P706 Program and later served as Associate Study Manager for the P706 phase zero study. He is a member of AIAA, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

ing about the type of resistor we use?" are phrases which hinder the advancement of technology. We might well wish to re-title the person as the *multi-disciplined engineer*—one who can provide the maximum contribution to the creation of new products which bear the mark of many classical disciplines. This may be characterized with a few basic truisms:

1) No product we produce, no matter how simple, is the work of, or represents, a single classical engineering discipline;
2) Most major breakthroughs bridge the gap between the existing disciplines;
3) Isolated organizations (of electrical and mechanical engineers, for example) seldom meet the technical challenge—strong and continued interplay is needed to meet today's stringent requirements;
4) Every engineer's basic education becomes obsolete and can only be renewed by his own continuing efforts; and
5) Management action is required to encourage multidisclipline engineering.

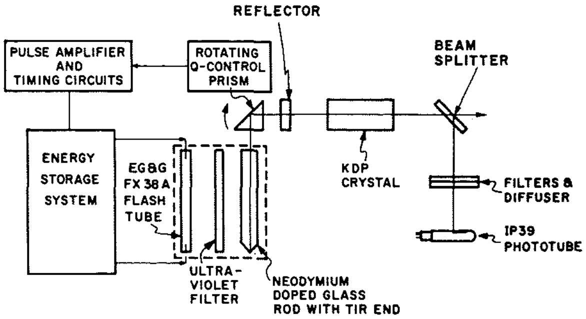


Fig. 1—Laser transmitter.

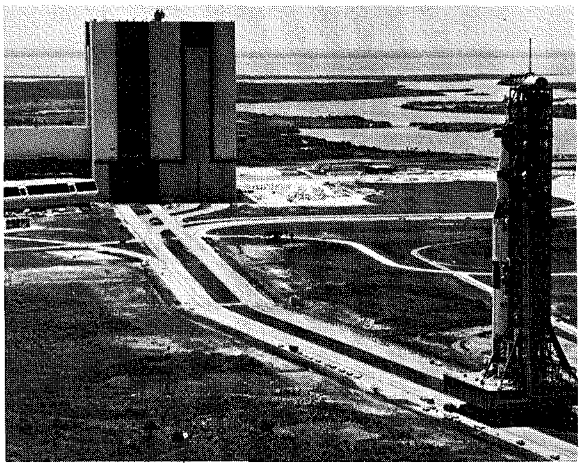


Fig. 2—The 363-foot-high Apollo-11 Saturn-V space vehicle towers over the crawlerway during its rollout from the Vehicle Assembly Building's High Bay 1, open doorway in background, to Launch Complex 39A.

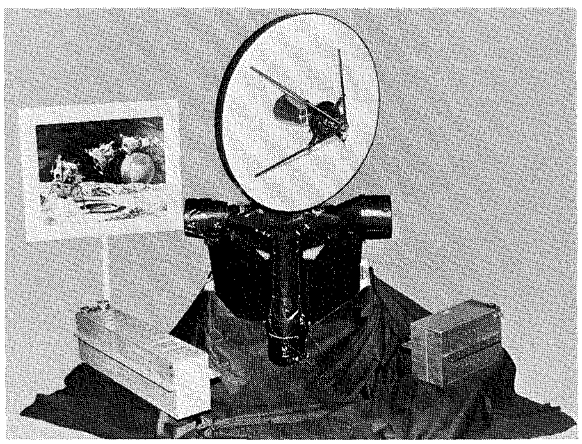


Fig. 3—Rendezvous radar/transponder system.

Multidiscipline engineering—a practical look

Two specific examples of multi-disciplined engineering at work, together with suggestions to encourage its development in the engineering work force, are described by way of examples showing how this can be done.

Laser devices

The first operation of a laser was reported only ten years ago; since then, hundreds of different materials in which laser action has been achieved have been reported. In addition, many devices covering a broad range of technical needs in which lasers are used have been developed. At RCA alone, for example, about 100 engineers are currently working on lasers and the Corporation garners well over 6 million dollars a year in laser business. Many engineers who specialize in this area now call themselves *laser engineers.*

It is interesting to examine a typical laser device, such as the range-finder, shown in Fig 1., highlighting the interplay of engineering disciplines in its development. A typical laser consists of an exotic material; in the example shown, a chromium doped sapphire or ruby rod in a precise optical assembly and the various optical elements are arranged to produce the desired laser light output. Normally, xenon flash lamps are used for optical excitation. These lamps are controlled through high voltage electronically switched power supplies. In the rangefinder shown in Fig 1, energy from the laser is received by a photomultiplier tube, amplified, and applied to digital logic to yield the desired range. Devices which combine all these functions typically are packaged in small, compact, hand-portable assemblies.

Some of the specific skills required in the design of such a package are:

1) Electronic circuit design,
2) Mechanical design,
3) Optical design,
4) Solid-state physics, and
5) Digital logic design.

At RCA, many people have mastered most or all of these skills to the extent required to design such devices. Often the devices are designed by one or two engineers. These men have clearly needed to learn new technologies, and this learning process was not automatic. It required work on the part of ambitious engineers. They read, studied, experimented, and consulted until they could call themselves experts!

It is only through the combining of engineering skills that we can economically compete in the development of laser devices. Every day, new developments requiring new skills take place; competition demands increased awareness of the multiple utility of engineering talent. In RCA, most of the work on laser devices is organized in groups containing all of the pre-requisite skills, thereby forcing a strong interplay of the engineers with classical backgrounds. After a while, engineers who might understand cavity design find themselves required to handle the digital logic, high voltage supplies, or mechanical problems. This is a multidiscipline environment and it makes us competitive.

System design

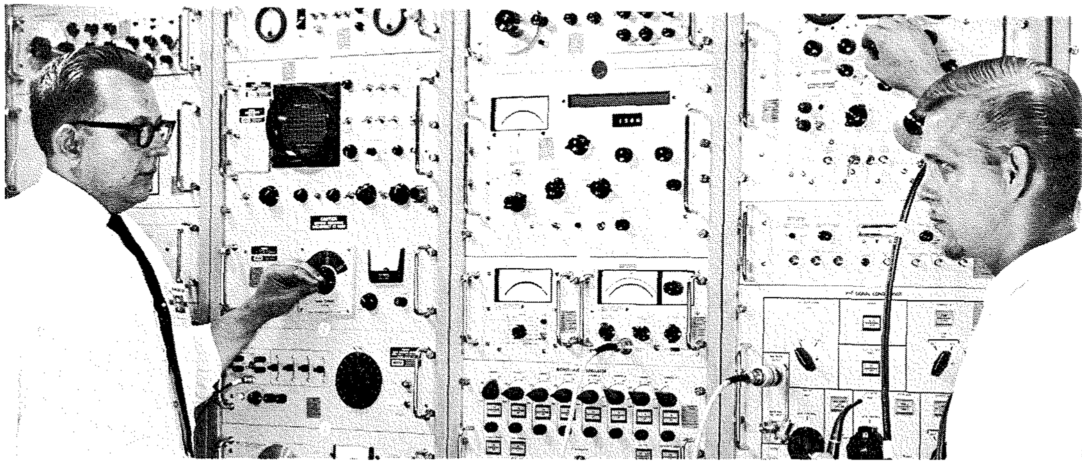
Perhaps the most significant, multidiscipline engineering development of the '60s was the Apollo program. When viewed in the perspective of RCA's participation, or on a national scale, examples of multi-discipline engineering abound. The management of the thousands of companies and the hundreds of thousands of people participating was the major technical management challenge of the 20th century. Within one program, we developed both the world's largest building (Fig. 2) and the smallest high performance radar (Fig. 3) with all possible variants in between. The vertical assembly building was not just a construction feat; it was a multi-discipline engineering challenge. The building's purpose was to optimally handle a large space system, so considerations unique to the construction art had to be understood. Engineers designing the building had to consider the requirements of their counterparts in space vehicle design. Electrical, mechanical, and aeronautical engineers had to understand the problems of the civil engineer, the structural engineer, and the architect.

The unique challenges of the Apollo program are more meaningful if we consider RCA's own participation. Examples of the results are shown in Fig. 4. Our major contribution was the development of electronics for the Lunar Module (LM). This design was one of the critical or essential requirements in the entire system. The weight saved by a one pound reduction in the LM autopilot (ATCA) was equivalent to one-half ton saving on the launch pad, and a corresponding reduction in the thrust requirements of the booster.

When the electronic equipment design for LM began, there were many alternatives available. The technical requirements were unique to our experience but the time scale of the program did not permit a long learning phase. To meet the challenges imposed by the stringent weight and power restrictions, new design approaches had to be evolved. Of utmost importance was the extreme reliability required by a manned mission. Attempts to move away from proven components and techniques were resisted by the reliability engineers—and rightfully so.

Packaging density had to be tighter than anything previously achieved. The derating policy was more severe than anything previously encountered. For example, no part temperature could go above 160°F. Classical economic perspectives relative to the design of electronics also changed in this program; cost was almost no object if weight savings or increased reliability could be achieved. Although a book could be written on the LM program, I will point out only a few examples of how some problems were handled by RCA's multi-disciplined engineers.

For electronic designs of the past, part selection was usually done by circuit designers. They arrived at a preliminary schematic and a list of parts designated by type number. This information was handed to the mechanical engineers who proceeded, with electrical assistance, to produce layouts. In the development of the ATCA an alternate approach was implemented. Mechanical engineers were given the responsibility for parts selection. This caused some consternation on the part of the electrical engineers, but it proved successful. The electrical engineers were told to specify their circuit and describe, in as much detail as they felt necessary, the *electrical* parameters of the part they required. Then the mechanical engineers with this information were to make selection of the part. Interestingly enough, the mechanical engineers found themselves, in a matter of months, learning more about electronic parts than they had done in all their previous experience. They researched transistors, capacitors, resistors, with respect to all of the important characteristics. They worked with parts vendors to develop new or modified parts when the design required. They questioned any circuit design if they thought it imposed restrictions. "Do you really require this amount of capacitance? Look at the size savings if reductions could be achieved." Through this tradeoff, we achieved a design which was truly re-



markable. This new role for the mechanical engineer increased his own status, and provided an important check on the electrical design of the equipment.

Another aspect of the Lunar Module Program was the requirement for exotic and new materials which had to be developed. The number of specialized requirements for conductive, thermal, or various resilient properties required an awareness on the part of our engineers of the chemistry of material they had previously used without question. Chemists and metallurgists had to work closely with electrical and mechanical engineers to achieve this development.

Concluding remarks

Innumerable examples of engineers working closely with other disciplines and enhancing their own skills could be presented. Let us consider briefly what steps should be taken to encourage this interplay. The first move has to come from the individual engineer, gently prodded by his management. Engineers should be encouraged to broaden themselves technically. They should be made aware of the other engineering requirements of the projects in which they work. Mechanical engineers should be involved in circuit designs wherever possible. The simple act of encouraging a mechanical engineer to take a transistor design course or an electrical engineer to take a fluid flow course as part of his after-hours educational program, encourages multi-disciplined thinking. Having taken this training, the engineer should not be frustrated, but encouraged to use this newly acquired talent. Engineering organizations must be structured to minimize the organizational gap between the different disciplines working on the same design or equipment; it is better to organize along product lines than along classical discipline lines.

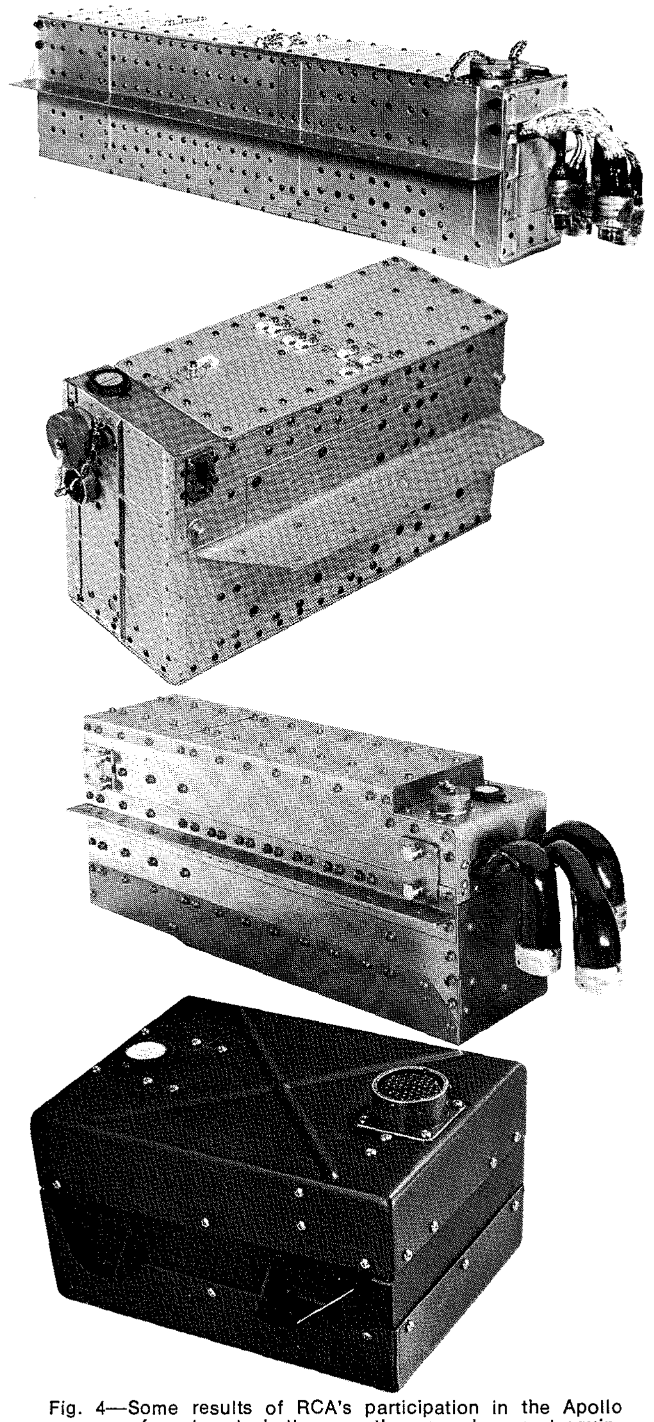


Fig. 4—Some results of RCA's participation in the Apollo program: from top to bottom are the ground support equipment, the rendezvous radar electronic assembly, the transponder, the attitude translation and control assembly, and the descent engine control assembly.

Interdisciplinary communication—do you speak my language?

Dr. N. E. Wolff

SOME YEARS AGO, when I had the dubious pleasure of ordering concrete for a walkway, I ran into the language barrier head-on. I was talking to the dispatcher who patiently took down the pertinent data for a well-timed delivery of a few yards of the gray semi-liquid mass. Then came the startling question: "What *slump?*" I hesitated for a few seconds and said, not to show my ignorance: "The usual, it's for a sidewalk." He came back by saying, "Then you want *slump two,*" and hung up.

This conversation bothered me. The dictionary was of no help. When the churning barrel truck finally came, I had a chance to satisfy my curiosity about *slump two.* It turned out that slump is a way of indicating, in a crude fashion, the viscosity of pouring concrete. The number indicates the decrease in inches of a one-foot-tall cone of the pouring mixture after its mold has been carefully removed. Now I knew. I had learned one term in the vocabulary of the concrete industry.

I picked this example because it is most likely outside the sphere of disciplines for most of us. But let us look at the problems of language around us in our work-a-day environment.

Same language—different concept

The great advances in electronics in the last fifteen years can largely be credited to an interdisciplinary effort. Physics, chemistry, engineering (of all kinds), statistics, mathematics, computer sciences—all these disciplines have found themselves working towards some systems goal through their representatives. Together, they represent a veritable tower of Babel when it comes to communicating.

Let us go through a "bilingual" conversation between two engineers that illustrates the need for speaking the other's language. (Refer to the discussion between the systems engineer and the device processing engineer illustrated on the facing page.) Perhaps we do not realize that we are conversing in different languages because we seem to use plain English to do it. The difference lies in the differing mental images and concepts arising in different minds exposed to the same verbal input.

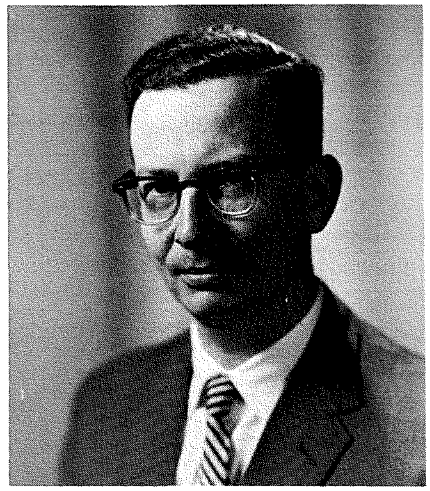
This brief conversation illustrates the point. The systems engineer approaches the problem from the applications point of view. He thinks in terms thoroughly familiar to him. He was trained in this environment. To him, the world of the device processing engineer is strange and foreign. The device processing engineer's world is solid state, the physical ramification of the systems engineer's engineering concepts. Both need to learn the other's language, that is, recognize the other's mental image, his association with the same English phrases. When this happens, they are ready to embark on a common project. It is bound to result in a creative contribution.

Same concept—different language

Historically, individual scientific disciplines have come to adopt certain "expressions," and particular units of measurement. Concepts and scientific facts are then expressed in this "sub-language." Scientists working in other disciplines talk about the same subjects using a somewhat different vocabulary and word association. A physicist, when talking about energy, prefers electron volts while a chemist tends to use kilocalories per mole. The spectroscopist, on the other hand, likes wavenumbers better. An electrical engineer, when looking at the change of light intensity through a piece of glass might talk about so many decibels attenuation, while someone in the photographic sciences would call it an increase in optical density. This tendency to express concepts in quite different ways hampers interdisciplinary communication to some extent. The many tables of conversion factors and the variety of units in various handbooks attest to the need of a dictionary. In fact, the handbook is the dictionary that should help us overcome this kind of language problem.

The mystery jargon

There are other language barriers. If a colleague tells you that he has just built a cross-mode pulse-clipping superplexer for the DNX Advanced Communications System, you are, more likely than not, baffled. We are



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RCA Laboratories
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received the BSc from the Institute of Technology, Munich, Germany in 1948 and the MA and PhD in chemistry from Princeton University in 1951 and 1952. During his graduate work, he was a part-time teacher at Princeton, becoming a full member of the faculty upon receiving his doctorate. From 1953 through 1959 he was associated with the Organic Chemicals Department, E. I. duPont de Nemours and Company, Inc. In 1959, Dr. Wolff joined the staff of RCA Laboratories, where he conducted research on the electronic behavior of organic materials. He has been active in the field of organic photoconductors, electrophotography, compounds of rare earths, luminescent materials, magnetic recording elements, and new thermoplastic recording systems. In the fall of 1963, Dr. Wolff helped to establish the Process Research and Development Laboratory and assumed responsibility for the Materials Processing Research group. In this capacity, he was concerned with materials problems related to new manufacturing processes for RCA products. In 1967 he was named Associated Laboratory Director, Process Technology, taking on the additional responsibilties of a newly established integrated-circuit facility, and a solid state device technology group. Dr. Wolff is a member of the American Chemical Society, the American Physical Society, the American Association for the Advancement of Science, the Society of Sigma Xi, and is listed in American Men in Science.

*Since writing this article, Dr. Wolff has left RCA and is now with Xerox Corp., Rochester, N.Y.

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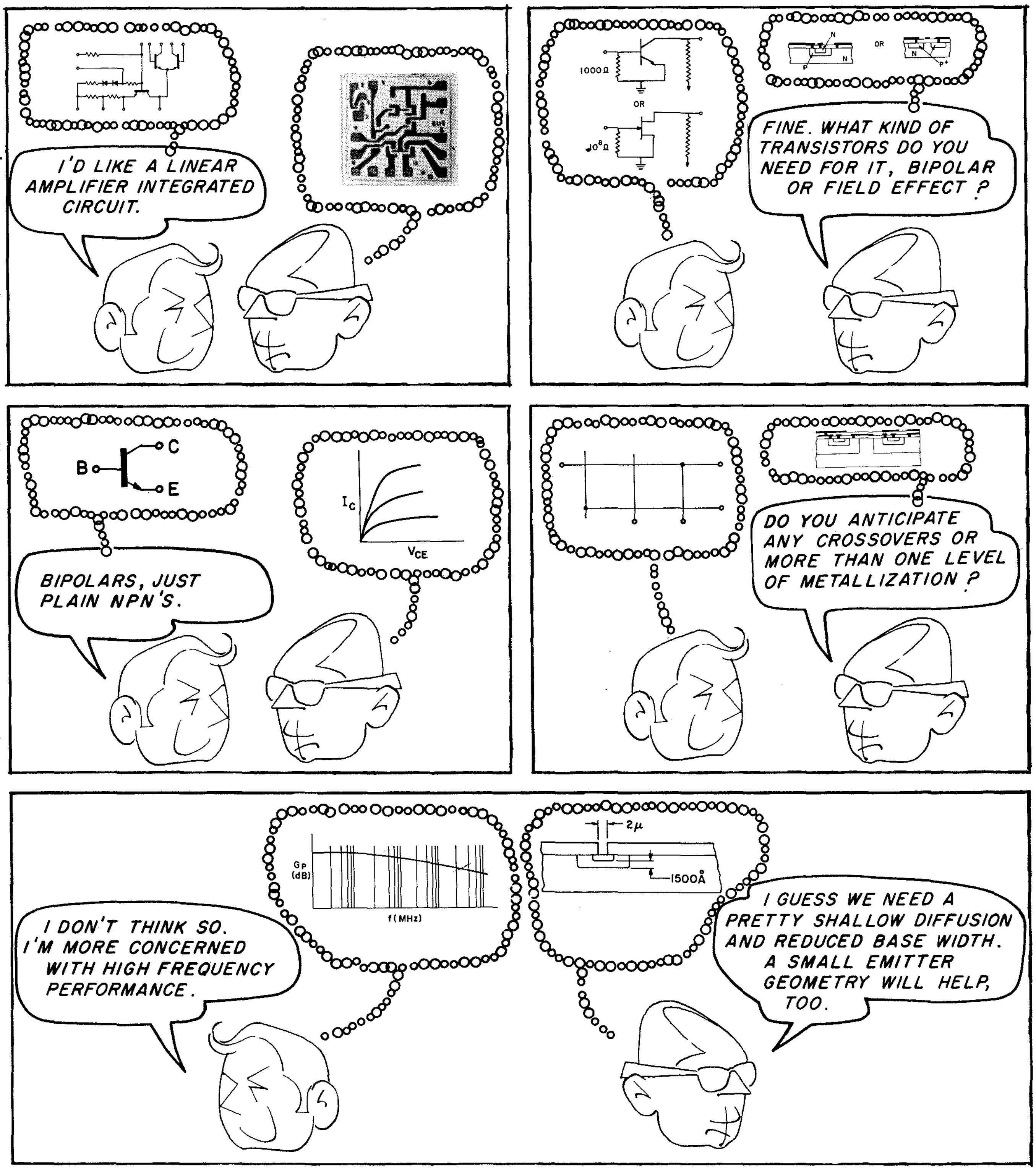
quick these days to coin new words and abbreviations that become household words in our own small world. Before long we talk to others and write reports in this highly personal lingo and can be misunderstood or ignored by those not "hep" to our word usage. Herein lies a danger of creating a communications gap.

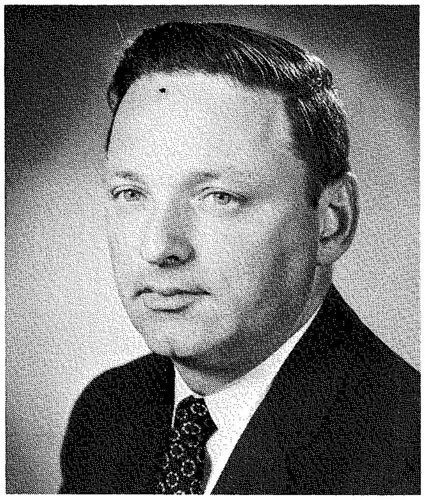
How then, do we avoid these pitfalls? It is not easy. There are no recipes or clear-cut methods. One extreme course of action might be to assume nothing and be explicit to the point of insulting the intelligence of the reader or listener. The other extreme would require all of us to learn and understand the entire vocabulary of those disciplines with which we have to deal in our professional life. That would require us to become quite some linguists, if not experts. Besides, we would have a hard time keeping up with the new vocabulary that appears weekly on the scene and do it all without the benefit of a dictionary. The best we can hope for is to become sensitive to the problems of language and communication, to clarify definitions when in doubt, and to attempt to match our mental images when we talk about a "common" subject.



The engineer in a manufacturing organization

E. B. Galton

The goal of the DEP enterprise is the delivery of a quality product, on schedule, within established budgets. This goal, so simply stated, can be attained only by exemplary performances by all elements of the enterprise. Most of the product business in DEP originates from our own research and development, which both provides opportunities and presents problems.



E. B. Galton, Plant Manager
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received the AB in Chemistry from Cornell University in 1947, the BEE (with distinction) from Cornell University in 1949, the MEE from New York University in 1956, and the MBA from Temple University in 1960. In 1956, Mr. Galton joined RCA and has been responsible for the design of the receiver/transmitter on the CF-105 ASTRA fire control system, company and government sponsored studies on ECM and penetration aids, preliminary design of an X-Band Paramp and a multichannel homing receiver (SLAP), delivery of an interim ECCM monitoring equipment on BMEWS, design of a multifrequency precision airborne instrumentation radar, design of low light level TV and laser products, and proposal effort on the LM radar. From 1962 to 1967, Mr. Galton was Manager, Systems Support Engineering, with total engineering responsibility for design, development, test, and acceptance of Multisystem Test Equipment, Depot Installed Multisystem Test Equipment, Preflight Test Set, Land Combat Support System, LM Test Benches, and Advanced Production Test Equipment. Since 1967, Mr. Galton has been responsible for Manufacturing and Test, Production Administration, Industrial Engineering, Material Procurement, Quality Assurance and Plant Engineering for Aerospace Systems Aerospace Systems Division.

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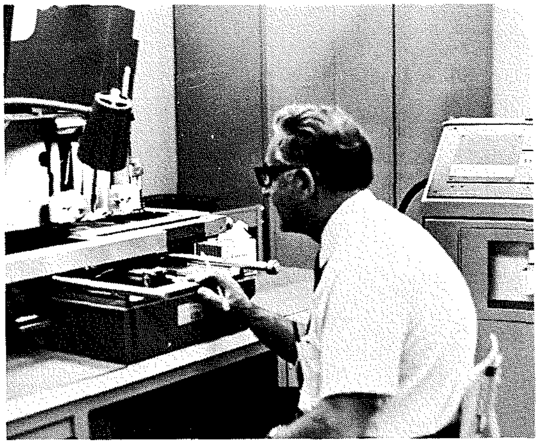
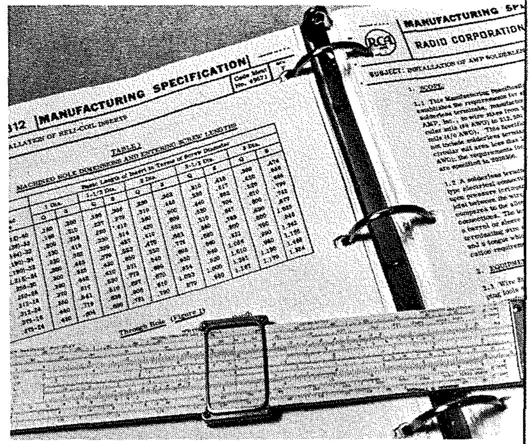
THE HISTORICAL ROLE OF MANUFACTURING has been to build a product to a released set of drawings. Recent experience in all divisions has indicated that restricting "plant" involvement to efforts *after* release does not result in optimum total performance. We cannot afford such a dichotomy of specialization: *engineering* responsible for *design*, and *plant* responsible for *manufacturing*. The participation of engineers from the plant, therefore, is more than a post-release effort. The need for conventional industrial and manufacturing engineering should not be minimized, but the need for advanced manufacturing technology and intimate involvement in the research and development process must be emphasized.

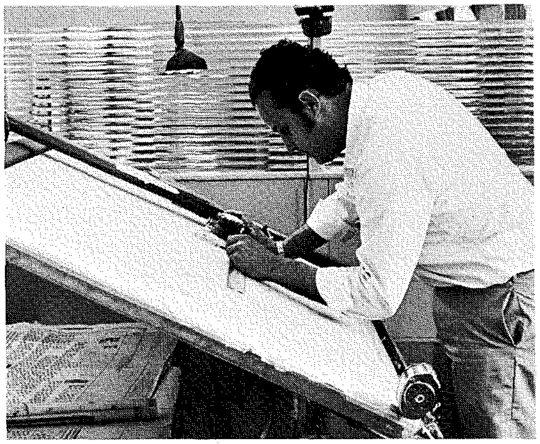
We will discuss both needs in some detail with a full recognition that the first is well understood and needs only clarification and the second is still lacking a full definition and implementation.

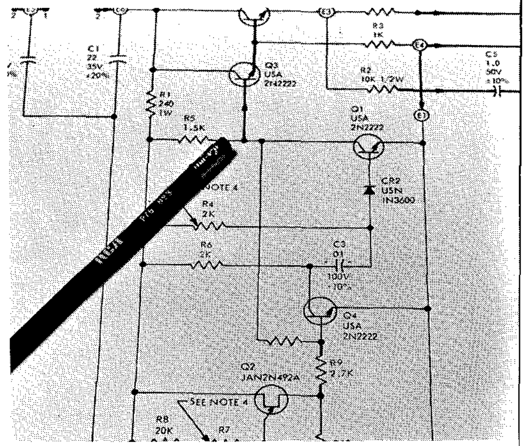
RCA prides itself in the quality of its product. This quality is a result of dedicated engineering efforts during the manufacturing cycle. Engineering judgements and expertise are required in a number of specified *technological* areas: process engineering, methods engineering, test engineering, and quality engineering. In addition, the analytical and *control* functions of production administration, cost estimating, and work measurement require a cadre of senior industrial engineers and business management personnel. It is self evident that even the control functions require a leavening with technological know-how, but most of the engineering efforts are in the technological areas.

Engineers and scientists of various disciplines are required in the *tech-*









nological areas: chemists and chemical engineers are required in printed board fabrication (whether double sided or multilayer), plating operations, potting and conformal coating processes, and solder analyses. Physicists are required in material analyses, failure mechanism investigations, hybrid manufacturing operations, and optical assembly and test methods. Mechanical engineers are required in the design, modification, and updating of automatic assembly and inspection equipment, improvement of the various methods and tools required in swaging, wirewrapping, soldering, welding, brazing, and crimping, and design of special-purpose material forming and fabrication tooling. Electrical engineers are needed in analysis of test equipment requirements, data analysis, vendor evaluation and administration, and design of test equipment for the modern factory with a weather eye toward unit cost reduction by automation and/or computer controlled operations. Programmers are required to utilize effectively the various types of numerically controlled machines in fabrication, assembly, and test. The numbers and uses of these machines have been growing in the industry and will continue to grow. It is essential that we continue to improve these conventional applications of engineering in the manufacturing cycle. But our opportunity for a quantum improvement in total performance is in early participation by manufacturing engineering in the design cycle. Instead of restricting our talents and energies to battling through a released design, manufacturing engineering must participate in the R&D phase to assure a product that is made up of items that can be purchased or fabricated expeditiously and economically, that can be assembled and inspected at a minimum expense, that can be tested easily to minimally complex acceptance criteria, and that is amenable to speedy fault diagnosis without undesirable probing, disassembling, or expensive troubleshooting tools and procedures. This quantum improvement in performance can be realized by the following steps:

1) Recognition by the design function that participation by manufacturing engineering in the design phase is, in the long run, cost and quality effective.
2) A reinforcement of manufacturing engineering skills to accept participation in the design phase. Concomitant with participation is responsibility; definition of this responsibility and evaluation of performance in this area must be refined.
3) Formalization of responsibility by determination of broad guidelines at divisional level and detailed implementation as determined by individual project and program managers.
4) Acceptance of initial costs in the R&D phase. It has long been accepted that design engineering effort is necessary during a production phase to resolve residual design problems. Factory follow costs are properly considered a necessary cost of operation. We similarly must accept manufacturing engineering during R&D phase of product development as an essential tool to minimize incipient and potential downstream costs.

We have lived with the concept of leaving "producibility" engineering to the design engineer. Our recent history indicates that the complexity and dynamics of our technology puts an undue burden on the designer. Our total DEP goals can be met only by early participation by the manufacturing engineer. With the continuous positive cooperation of engineering and manufacturing, we can significantly improve our total performance.

Field engineering

D. Koch

This paper discusses Field Engineering: what is it; how can it be a rewarding experience for the young and not-so-young engineer; what attributes are required to be a successful Field Engineer; and how do we accomplish it at the Electromagnetic and Aviation Systems Division.

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has attended Florida State University, Pennsylvania State University Extension, and several management symposiums. In his present position, Mr. Koch reports directly to the Manager of Engineering Support and Logistics. His responsibilities include configuration management, logistics documentation, spares and repair control, field engineering, customer training, and depot support. Previously Administrative Staff Assistant to the Manager of Engineering Support and Logistics, he was responsible for new business proposal coordination, including financial and manpower planning. He also held the positions of Leader in Editorial Services and as Test Director in the Environmental Laboratory. Prior to joining RCA, Mr. Koch was Manager of Field Support in Litton Industries Data Systems Division. He has also held positions as Supervisor of Service Engineering for General Dynamics Astronautics, and as District Manager of Field Engineerng for IBM. He was a Service Representative with Burroughs Corporation. During his professional career Mr. Koch has developed extensive experience in the supervisory, training, and technical aspects of product support engineering. Mr. Koch is a member of the American Ordnance Association and the Society of Logistics Engineers.

FIELD ENGINEERING is an engineering discipline covering the entire spectrum of many engineering disciplines. Throughout industry, Field Engineers are known by various titles: customer engineers, maintenance engineers, service engineers, and field support engineers, to name a few. Regardless of the title, Field Engineers have one thing in common: the work is performed in the field or, more specifically, on the customer's premises, whether it be in the field with the Army or Marines, or on board a battleship, bomber, or submarine.

Basic responsibilities

Now, if we look at the military's description of Field Engineering (the commercial version, contains some definite similarities), it would be as follows:

> The Field Engineer's primary mission is to Advise, Assist, and Train the military in the Operation and Maintenance of equipment in his inventory.

Advise

As the technical expert, it is the duty of the Field Engineer to advise the customer on how to operate and maintain his equipment to gain maximum utilization. Depending on the equipment, this can be a relatively small task when we are concerned with a black box or it can develop into a very large task if we are concerned with a large system. For a large system, the Field Engineer is obliged to understand the maintenance aspects of the equipment, and, by necessity, should thoroughly understand the complete operational characteristics. For example, some years ago I had the interesting task of acting as Field Engineer on the integrated weapon system for the B-52 aircraft. An assignment of this nature required that I thoroughly understand the operational profile of the system so I could advise the Radar Bombadier and Navigator on how to best use the system to gain maximum effect. This could only be accomplished by actually flying missions with them. There is an exciting and adventurous side of field engineering.

Assist

During the early introduction of equipment into the military inventory, the Field Engineer usually has the responsibility of actually troubleshooting the system with some assistance from the military customer. As time progresses, however, and the proficiency of the sailor, airman, or soldier increases, the Field Engineer steps back and assists the customer. Such assistance can be looked upon as "over the shoulder"; i.e., the military technician does the work and the Field Engineer provides guidance.

Train

The most important task of the Field Engineer is training. He has a responsibility to do everything possible to upgrade the military technician to the ultimate point where his services are no longer required. Stated differently: he should try to work himself out of a job. Fortunately, because of the turnover rate of the military, this utopian situation never arises.

Diplomacy

Advise, assist, and train . . . these are the basic responsibilities of the professional Field Engineer, but there are more. Working in the military environment requires diplomacy at its finest. The Field Engineer is looked upon by his military customer, not as an individual, but as *the company.* Whether he recognizes it or not, his company's logo is, figuratively, stamped on his forehead. His actions, his appearance, and his mannerisms determine, to a large degree, the company's image in the eyes of the customer.

We all recognize that equipment will fail regardless of design. In such instances, it is all too easy for the Field Engineer, out of sheer exasperation, to make uncomplimentary remarks concerning his equipment, his company, and those dumb engineers who created such a monster. To disclose such feelings could undermine the customer's confidence in the equipment and in the company. When equipment problems arise, the irate customer should be advised, as tactfully as possible, that problems exist but solutions are being sought and that all the resources of the company will be brought to bear, if necessary, to correct the situation.

Another area which requires diplomacy is what I call the thin grey line between the officer and enlisted man. The Field Engineer has an equivalent rank of Lieutenant in the Navy and Captain in the Air Force, Army, and Marines. Many times, the Field Engineer will take his newly-found rank somewhat too literally with the enlisted men. Such action is sheer disaster, because his effectiveness is

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determined, to a large degree, by the cooperation of the enlisted man. On the other hand, if he leans too far in the direction of the enlisted men, he will lose the respect of the officers. Again, he must exercise diplomacy and treat the officer and enlisted man with equal respect.

Marketing—another hat

The advantages of having a Field Engineer in the customer's operational environment is invaluable to a company. If he keeps his eyes and ears open, he can provide his company with marketing intelligence that may pave the way for a new product or a substantial engineering change. More important, however, is the image he projects. A Field Engineer can be a real asset to Marketing by merely doing a good job of keeping his company's equipment functioning and thereby maintain a satisfied customer. So. we can say he is on the firing line and his actions can make or break his company's reputation.

Characteristics of the Field Engineer

The Field Engineer is basically a gypsy. This can be considered an essential attribute. I have always informed my Field Engineers that they must be flexible. The very nature of the job requires immediate response. Consequently, it is essential that the Field Engineer be in a personal position to leave on a moment's notice and travel wherever his assignment is located. It is also necessary that he be prepared to go anywhere regardless of the location.

Most important, however, the Field Engineer must be technically qualified. We could have the best diplomat, a perfect marketeer, and a real gypsy, but if he doesn't have technical competence, he would be of little use to us. I might also comment that we could also have an exceptional engineer who would prove to be a disaster as a Field Engineer if he did not possess the necessary attributes required to work in the customer's environment. So, in the final analysis, a trade off is made in selecting Field Engineers. We measure all his strengths and weaknesses and decide whether he will satisfy the stringent requirements that must be imposed because of the importance of the assignment and the effect a bad decision will have on the company's image as well as the individual's.

Advantages

Working in the customer's environment exposes the Field Engineer to total systems engineering. He has an opportunity to see his black box merged with its related system, and he can see how it works in its true environment. He gains a good understanding of the customer's mission profile and how his equipment helps satisfy this mission. He will also gain a much better understanding of the intended use of his equipment and how it interfaces with other equipments.

Of necessity, he will become exposed, to a much greater degree, to the *-ilities* (e.g., Reliability and Maintainability). I guarantee that these most important disciplines will be considered in his future design work because he will have a much better appreciation of their importance.

As an ancillary experience not directly related to his engineering training, he will learn a great deal about spare-parts provisioning and its importance to the success of a mission. Those of us dedicated to Product Support realize only too well that a perfectly designed equipment will fail and, if adequate provisioning hasn't taken place, the equipment is not performing its intended purpose. He can also expect to become thoroughly familiar with technical documentation and the importance it has in the customer's environment. And, finally, he will gain a real understanding of the capability of the military technician, which he will certainly consider in future design work.

A field engineering assignment opens up the whole spectrum of the many engineering disciplines, and associated support disciplines, to the engineer and can prove invaluable to him in his professional advancement.

Field engineering at EASD

Field Engineering is a functional responsibility of Product Support Engineering and not part of the applicable Design Engineering Group. The role of Product Support Engineering is to support equipment after delivery. Such support encompasses not only Field Engineering, but training and spares. This support covers the entire life cycle of the equipment. Our task commences after the equipment has been designed and produced; whereas the design responsibility is short term, Product Support responsibility lasts for years. As a case in point: we are still providing a substantial amount of spares to the APS-42 Radar which was built in 1948, and we expect to continue supporting it for a number of years. Such support requires engineering evaluation to validate parts requested and, in certain instances, redesign has been necessary to correct illegible drawings or change parts because an original vendor went out of business taking his tooling with him.

Positive interface with provisioning, technical documentation, design engineering, and configuration management are essential when introducing new equipment into the field. Adding these considerations to the need for maintaining a diversified technical capability to satisfy the needs of equipment in the field, whether it be in or out of production, makes it entirely logical to retain this capability within Product Support. Another factor, which is of utmost importance, is having a single focal point within the company where the Field Engineer can communicate. His effectivity is directly related to the backing he receives from the company. The administrative function of Field Engineering has the fundamental mission of keeping the communication channels to the Field Engineer wide open, with the prime objective of seeing that the Field Engineer receives maximum support from all functions within the company.

Design Engineers move on to new ventures once they have completed designing an equipment. Their capability is no longer available on an immediate basis to out-of-production equipment. We have an obligation to our respective customers to maintain a technical capability; and, for this reason, Product Support maintains a nucleus of qualified, diversified individuals ready, willing, and able to satisfy the customers technical requirements, whether it be training, spares validation, or emergency field support.

Conclusion

Field Engineering offers the young engineer a rare opportunity for advancement in his chosen field, provides him with adventure, travel, and a real look at a fascinating business.

Technical disciplines in engineering service organizations

P. D. Strubhar* | J. M. Forman

Today's scientific discoveries and techniques demand that engineers quickly assimilate the advancing state of the art and apply it toward their product designs. Analysis of discoveries from other fields can result in innovation and uniqueness in product developments. Through a closer association with the many specialists in the field of material science, chemical processing, circuit design, environmental engineering, vacuum engineering, metallurgy, and equipment development, a greater awareness and utilization of all the plant skills should result. This paper emphasizes the need for a blending of the technologies and the need to maximize the use of all our engineering resources.

DESIGN ENGINEERS have to acquire knowledge in many technical fields and apply their know-how toward the design of their devices. With the enormous growth of science and engineering in the last quarter-century, it has become virtually impossible for an engineer to have adequate knowledge in every field. Therefore, he has been forced to depend more and more upon experts in diverse fields such as ceramics, metallurgy, chemical processing, materials science, and circuit engineering, to name just a few. The role of the specialist has, as a result, increased so significantly that he must now become part of the decision-making process before successful developments can be achieved and finished quality products can become a reality. The Engineering Service Organizations have many of these specialists in their wide-ranging operations and laboratories. These experienced and qualified engineers regularly assist design engineers on metallurgical, ceramic, and many other kinds of technical problems. Their very existence is completely dependent upon their constantly following the advancements of the state of the art in their specialties and upon their being able to provide improved solutions and understanding to design and factory engineers' problems. Their technical expertise in testing, processing, materials analysis, equipment design, ceramics, x-ray diffraction, etc., plays a vital role in the development and production of finished quality products.

Professional climate

Successful systems are usually structured to encourage mutual technical discussion, wherein the role of the consultant is strongly interleaved with the responsible design development function. Mutual respect and recognition of joint or partial contributions are encouraged, fostering a partnership-type interdisciplinary climate and an attitude that stresses company progress first and foremost. The major factor for consideration is the generation of better ideas and their implementation. Such a professional climate generates a rich blending of the technologies and a maximizing of all the engineering resources through a free flow of information, leading to improvements in communications and interaction while avoiding redundancy.

Conclusions

Today's complex technology must be interdisciplinary for company growth and survival. Because the scientific disciplines have attained such a high level of sophistication, it is necessary to stimulate closer cooperation and teamwork of all the experts before scientific developments can lead to practical innovations. The orderly and systematic tapping of creative ideas from all its sources must be of paramount importance to the company, because no one engineer can afford to ignore the potential contribution offered by the specialized disciplines. The cross-linking of the engineering disciplines will thus force the drawing together of engineers with specialized knowledge, while developing a new understanding and awareness of the value of each other's technologies towards apparently different but interrelated job functions. Sustaining such an interdisciplinary environment can be a great help in providing exposure to other fields and can be used as a growth medium to keep engineers abreast of the latest developments and technologies.

Several of the papers that follow this article are designed to give further insight into the various kinds of special engineering that are available at Lancaster. The papers also show some of the engineering disciplines that are used in the Lancaster plant and how these fields are related to other engineering functions.

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Special Engineering Services
Industrial Tube Division
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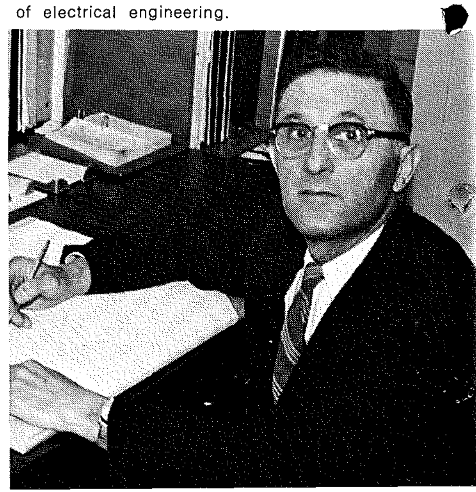
received the ME from Stevens Institute of Technology in 1940, was a teaching fellow at Stevens from 1940 to 1941, and did graduate work there from 1940 to 1942. He joined the Equipment Development Electrical Design Group at RCA Harrison in 1941; and transferred to RCA Lancaster in 1942, to the Special Equipment Engineering Group of the Life Test and Data Laboratory. Since 1942, he has designed numerous electromechanical electronic test sets, life test equipments, and has worked on the special application of electronic circuitry for small and large power, cathode ray, color, photo and image, and display storage electron tubes. He was promoted to Leader of Special Equipment Engineering in 1951. Since 1956 to 1962, his activity expanded to include Special Equipment and Environmental Engineering, having the additonal responsibility for environmental engineering evaluation and testing of all new and improved tube ruggedization. From 1962 until his recent appointment, Mr. Forman was Manager, Environmental, Special Equipment & Specifications Engineering in the Electrical Measurements and Environmental Engineering Laboratory. Mr. Forman is a senior member of the IEEE, a member of the Institute of Environmental Sciences, a member of NSPE, and is a Registered Professional Engineer in the state of Pennsylvania in the field of electrical engineering.



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*Mr. Strubhar's photograph and biography are given in another paper in this issue.

Metallurgical engineering

P. D. Strubhar

This paper describes the relationship of the metallurgical engineer to the various engineering and manufacturing functions of tube making. These relationships are illustrated by two actual case histories.

Metallurgy has been defined as the science and technology of metals. The scope of metallurgy covers the processing of ores after they have been removed from the earth by the mining engineer, the refining of metals, and making them into useful parts. As such, metallurgy is usually divided into two categories: process metallurgy and physical metallurgy.

Process metallurgy operates predominantly outside of RCA and concerns itself with the manufacture and shaping of metals into such forms as castings, strips, sheets, rods, and bars which can be further processed within RCA.

Physical metallurgy concerns itself with the physical and mechanical properties of metals. These properties are controlled by composition, mechanical working, and heat treatment, and constitute the area which operates within RCA. This phase of metallurgy deals with the applications of various metals in the tube-making industry and is therefore applied to the problem of defining the type, condition, and properties of the metals to be used for parts. The properties of the part are determined by the use to which the part will be put in the final tube.

In the Lancaster plant the metallurgical engineer is part of the Chemical and Physical Laboratory. His responsibility is to all phases of the plant operation, including design engineering, development shop engineering, tube factory engineering, parts works engineering, standardizing, and purchasing. He operates as a consultant to all of these areas of the factory when there are metallurgical questions to be answered. These questions usually arise when metals or parts do not function as expected. The metallurgical engineer must then review the problem and determine whether the difficulty is caused by properties of the metal which are either out of control or not sufficiently specified. This may require revising some of the process-scheduling internally in the plant, or it may mean going back and requesting of the vendor materials with different properties. In such cases, purchasing specifications must be revised. The metallurgical engineer also works with incoming inspection to see that the proper inspection procedures are followed and, when necessary, supervises the metallurgical inspection in the Chemical and Physical Laboratory.

As can be seen by the foregoing description of the type of work that the metallurgical engineer does at the Lancaster plant, the work is varied and covers a wide list of materials. Many metals—including steel, copper, copper alloys, nickel, nickel alloys, tungsten, molybdenum, titanium, and tantalum—are in use at Lancaster. In view of this wide variety of materials, and the manner in which the metallurgical engineer functions, his job is quite critical and useful. The feeling of this usefulness is what makes the job of metallurgical engineer very satisfying. As in many jobs, there is much routine work to be done. However, there are enough unusual requests and problems to make the job very exciting. One of the rewards of the job is the ability to see the results of decisions as they go through the factory. This ability is best illustrated by the two examples that follow.

Effect of calcium on thoriated tungsten

Thoriated tungsten is used for direct-heated cathodes in many power tubes.

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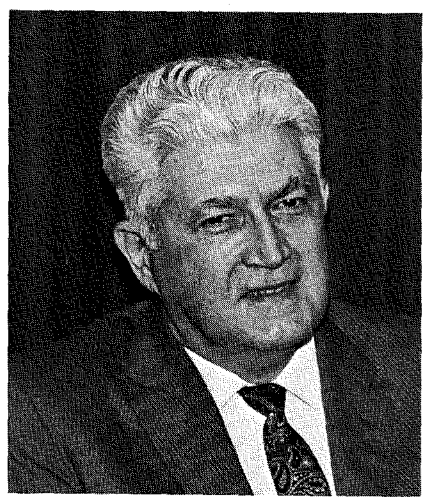

P. D. Strubhar, Mgr.
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Chemical and Physical Laboratory
Television Picture Tube Division
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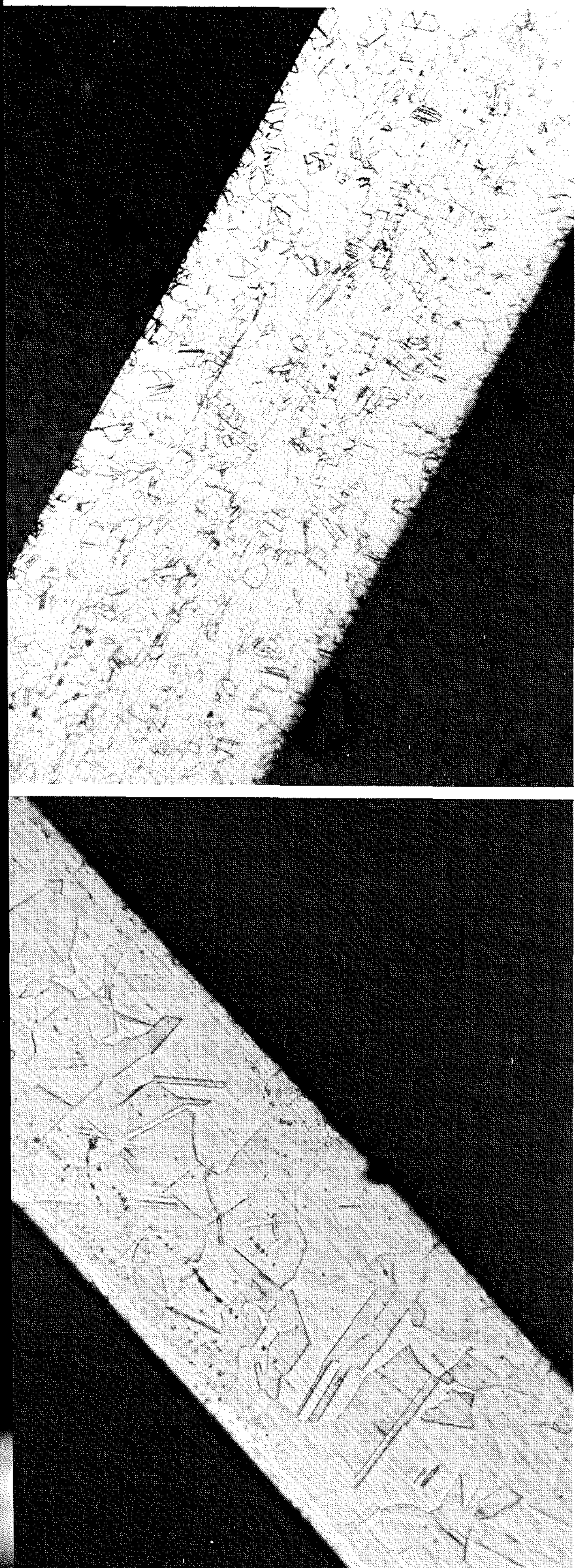
received the BS in Metallurgical Engineering in 1934 from Lehigh University. From 1935 to 1940, he was with Ingersoll-Rand, Inc. as a junior metallurgist. At Hyatt Division of General Motors he was a research metallurgist from 1940 to 1941. From 1941 to 1946, he was a metallurgist and superintendent of the heat treating department for Andover-Kent, Inc. With Remington-Rand Research Laboratory from 1946 to 1951, he was the head of the metallurgy department. Mr. Strubhar joined RCA in 1951 as a senior engineer in the Chemical and Physical Laboratory at Lancaster. He was promoted to engineering leader in 1959 and to his present position in 1962. Mr. Strubhar is a member of the American Society for Testing Materials and of the American Society for Metals.



The above photomicrographs of Stainless Steel were taken at 100X magnification. They show a comparison of the internal structure of the metal of two lots of material. The material shown in the top photo could be satisfactorily drawn into a cupped part, while the material in the bottom photo tore during the drawing operation. The primary difference between the two lots of material is the grain size: material at top is "fine grained" and bottom material is "coarse grained."

To control the emission characteristics, the thoriated tungsten is carburized (infused with carbon in a gaseous state). It is then put into the tube and a certain number of emission tests are run. The emission tests were going along fine, but it was noted that every now and then a particular lot of material seemed to produce slumping characteristics (decrease in emission as a function of tube operating life). This problem was called to the attention to the metallurgical engineer, and he was asked to investigate. There seemed to be no differences between the materials which showed slumping characteristics and those which did not. However, a lot of material came along in which the slumping was very severe. This lot of material was compared very carefully with two other lots of material, one which had medium slumping characteristics and one which performed entirely satisfactorily. After a very careful investigation of various characteristics of the material, it was discovered that the materials which showed slumping characteristics had varying amounts of calcium. The maximum calcium content was about 0.05%. Because calcium could not be detected in the material which performed satisfactorily and the only way in which calcium could be introduced was by the vendor, it was necessary to set up a series of meetings with the vendor through the Purchasing Department. At the first meeting the vendor maintained that calcium could not be in the tungsten. However, upon presentation of our data at a subsequent meeting, the vendor admitted that he had discovered by accident that the calcium, which was used as part of his processing and was supposed to be completely removed before the wire was made into final form, would give the material better drawing properties if small traces were left in.

The vendor further admitted that, over a period of time, he had been experimenting with allowing small traces of calcium to remain in the wire to determine its effect on the drawing properties. As a result of these meetings and the data which we had collected, it was finally agreed that a limit of 0.02% calcium would be put on the wire. This specification provided wire with satisfactory emission characteristics.

Effect of impurities in nichrome used in CRT's

The second example is that of a part which is called a cathode sleeve and is used for supporting the nickel cathode in a cathode-ray tube. This material is made of a nickel-chrome alloy which is 80% nickel and 20% chrome and is sometimes referred to as nichrome. While the main constituents of this material are nickel and chrome, there are numerous minor constituents present as impurities. In the past there was no necessity for having very close control over these impurities, because the firing of this material was always done on one schedule. However, subsequent work determined that different firing schedules were required, and there were therefore times when the sleeve material would become discolored. This problem was presented to the metallurgical engineer. After reviewing the data and collecting information on which lots showed this discoloration and which lots did not, he discovered that small fluctuations in the amount of manganese (say, between 0.05% and 0.2%) and the presence or absence of small amounts of zirconium (say, around 0.01%) were affecting the oxidation characteristics of this material. As a result of these findings, and after a series of meetings with the vendors, a new specification was instituted which called for the limiting of manganese and zirconium in this material.

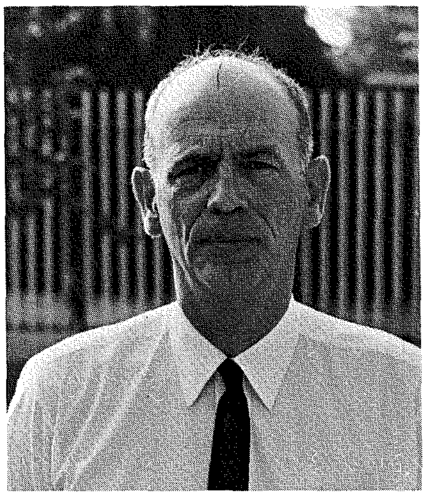
Concluding remarks

While the statements of the problems and their answers are condensed into a few sentences in this article, anyone who has ever worked with this type of problem can easily understand that the time consumed and the work involved in resolving these problems were not nearly so little. In both cases it was a matter of many months' work to track down the problem, collect the samples, and finally arrive at agreement with the vendors as to what would be done to correct the problem. It is hoped that these examples will give some insight into the way a metallurgical engineer works in the Lancaster plant, and will also give an indication of why the job is rewarding when you can see the results of your work.

Ceramic engineering

M. W. Hoelscher | J. L. Rhoads

Ceramics are essential to the fabrication of electronic devices because of their unusual material properties. They are used as envelopes, barriers, structural members, and substrates. The substitution of more desirable ceramics, the development of more reliable interfaces with other materials, and the application of more severe environmental conditions in operation of the devices are under continuing development. General considerations for, and progress in, the use of ceramics are discussed. Experience in the use of ceramics in one device often contributes to the development of devices in other areas.



M. W. Hoelscher
Chemical and Physical Laboratory
Television Picture Tube Division
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received the BS in Ceramic Engineering from Ohio State University in 1940. He was employed by the Seeger Refrigerator Company from 1940 to 1942 as Enameling Superintendent. From 1942 to 1946 he served in the Military, after which he returned to his previous position in industry. Mr. Hoelscher was employed by Murray Corporation of America from 1946 to 1952 as Supervisor of Enameling and later as Methods Engineer. He subsequently worked at Robinson Tube Fabricating from 1952 to 1953 as Superintendent; at Enamel Products Corporation from 1953 to 1959 as Methods Engineer; and at Westinghouse Electric from 1959 to 1962 as a Senior Engineer. Mr. Hoelscher joined RCA in 1962 as a Ceramic Engineer. Since then, he has been primarily engaged in the field of ceramic-metals, including applied reseach, development and production-reliability standards for ceramic-metal systems and general ceramics applications on all power tubes at Lancaster. Specific assignments have included: the development of high-reliability, high-strength seals for sapphire, ultrapure aluminas, commercial aluminas, and beryllium oxide; and methods of reliability testing of these systems. He also developed a ceramic-to-metal seal for travelling-wave tubes and microcircuits. Mr. Hoelscher also served as an advisor in the design of seals that incorporated uncommon capabilities, such as unusual ceramics, unusual methods, or unusual and special requirements of configuration. Mr. Hoelscher is a member of American Ceramic Society and Porcelain Enamel Institute.

J. L. Rhoads
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Converion Tube Engineering
Industrial Tube Division
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received the BS and MS in ceramics in 1952 and 1953, respectively, from Pennsylvania State University. Mr. Rhoads then joined RCA Lancaster in the Chemical and Physical Laboratory, to investigate criteria of ceramic-to-metal seals. His efforts included development of a reliable metalizing process for production use, development and construction of reliable furnaces for both metalizing, firing and brazing operations, evaluation of high alumina ceramics to obtain best ceramic bodies for seal construction, investigation of brazing materials and metals to produce optimum seals, and handling factory problems relating to the use of ceramic components and ceramic-to-metal seals. In June 1962, he joined the Direct Energy Conversion Department where he applied his knowledge and background toward the development of ceramic metal seals for use with thermionic converters at elevated temperatures. In addition, he worked on the development of fossel fuel converters and made substantial contributions in the development of a ceramic emitter casing for these converters to assure an adequate bond at the operating temperatures. In May 1964, he joined the Materials and Process Laboratory, assuming responsibility for the application of ceramics and ceramic-metal seals to the conversion tube line. Ceramic-metal envelope and internal tube structures were developed for image, photomultiplier, and vidicon tubes. Reliable seals were produced for both sapphire and Lucalox windows. Successful seal designs were developed to employ high expansion nonmagnetic metals to meet nonmagnetic tube requirements. Mr. Rhoads is a member of the American Ceramic Society, American Society for Metals, and Keramos.

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Ever since the discovery of the Edison effect, ceramics have constituted a substantial part of the structures of electron devices. High electrical and thermal resistance and the ability to transmit radiation are the main properties of ceramics that have made them uniquely useful in electron-device structures. Low tensile strength and high Young's modulus relative to metals, brittle fracture, varying electrical and mechanical properties, relatively low heat conductivity, and the problems of forming reliable interfaces with other materials are the major problem areas in their use.

The ceramic materials used in the 19th century and the first half of the 20th century were almost entirely from the glass category, or else natural minerals such as mica and lava. These materials are still used in large quantities, especially the glasses. The original glasses used were adapted from those available from the tableware, chemical glassware, and optical industries.

Naturally, the trend of development in every class of materials has been to maximize their useful properties and minimize their shortcomings. This optimization was accomplished by fabrication of glasses especially formulated for the electronics industry.[1] Development of new glasses, especially the devitrifying glasses, which are partially crystalline and partially amorphous, is still a very active area. The development of these glasses has in turn contributed to developments in the industries that were the original glass sources.

A similar pattern was followed in the use of crystalline ceramics. The original materials were obtained from the whiteware industries, such as the tile, insulator, and chemical porcelain ceramics. These materials, while polycrystalline, averaged 30% to 60% amorphous matrix and had few advantages over glass.

The first substantial interest in ceramics whose structure was 80% or more polycrystalline (for use as parts in electron devices) was generated by the Pulfrich sealing patents[2,3,4] and their use by the German electronics industry in World War II. The electrical porcelains, steatites, forsterites, and 85% to 90% aluminas, while still being used, have been supplanted in the area covered by this article mainly by the so-called "high-purity" ceramics, which contain 94% or better of the dominant crystal phase. Again, these specialized materials were developed primarily for the electronics industry (with the exception of the *BeO* ceramics). Not surprisingly, they have contributed to developments in the parent industries previously named.

In general, the features of this category of ceramics are better high-tensile strength, abrasion resistance, heat-shock resistance, brittle-fracture resistance, resistance to radiation attack, high deformation temperature, and better high-temperature conductivity and dielectric properties than the materials they have replaced. Properly used, these ceramics are much better both mechanically and electrically in "hostile" environments. Cost of fabrication, especially in limited quantity, and more complex processing for the development of reliable interfaces with other materials are still major problems in the use of these ceramics.

There are many other fields than structures where ceramic materials are used in the electronics industry. Ceramic technology covers not only the glasses, the polycrystalline materials, and the monocrystalline materials (such as sapphire) normally associated with structures, but also the titanates in capacitors, the metal spinels of the ferrite family, and the non-metal resistor materials. Micro-device substrates and packages, although structural and usually similar in composition to the larger structures for electron tubes discussed, are a specialized field in themselves. However, there has been a substantial tranfer of materials and techniques from the larger structures.

Lancaster ceramic engineering

The function of the ceramic engineers in the Chemical and Physical Laboratories and Development Shops in Lancaster is to act as general advisors to design engineers, development engineers, and production engineers in all areas where ceramics are involved. This function breaks down into three major areas of activity: 1) advice on ceramics usage and attendant problems from original design to production, 2) special development of materials and techniques common to all device types, and 3) assistance to the purchasing function in vendor contacts. The problems that arise are nearly always interdisciplinary in nature, and the team effort necessary for their solution requires a general knowledge of the other disciplines involved.

Normally, at the design stage, the original selection of specific ceramic materials is guided by past experience or the specification sheets of vendors. Because of special configuration conditions affecting availability or cost considerations, a source review may result in the ceramist's recommending alternative materials.

Once the final design takes shape, a careful review is made, especially of seal configurations. If past experience indicates a potential problem, prototype tryouts of subassemblies containing the seals are made and tested. In any case, a review of all the processing necessary—metalizing, plating, and brazing—is made to anticipate problem areas and provide for solutions.

Prototype models are usually made under laboratory conditions; if care was taken in the design analysis, adjustments are usually minor. The transition from prototype to pilot quantities is made gradually with a minimum change in equipment and personnel.

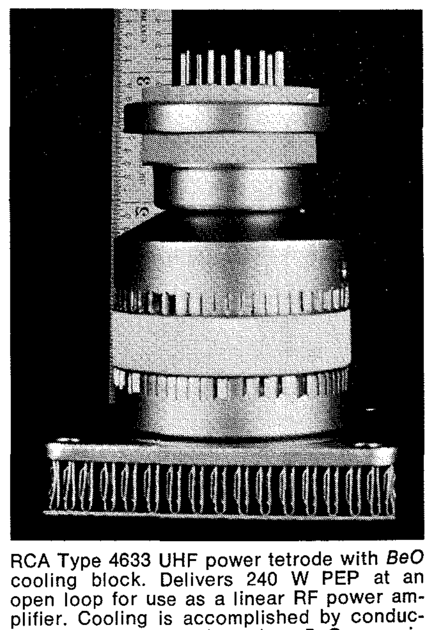
Release for production, however, is often a different story because equipment and personnel undergo a radical change, and it is the responsibility of the laboratory personnel to assist until all problems are solved, either by education, by processing changes, or by minor design changes.

Besides specific problems on individual device types, the general problem of the jointure of ceramics to other materials has been given continuous investigation. For practical purposes this problem has been divided into two areas: 1) the development of a transition layer between the ceramic and the joining metal and 2) the mechanical and metallurgical problems involved in making the whole jointure reliable and resistant to internal and external stresses. The transition layer on the ceramic substrate is usually referred to as the metalizing layer, and the process of forming it is known as metalizing. The whole jointure is normally called a seal.

Metalizing

The development goal in metalizing systems is to provide the highest strengths and reliabilities on the greatest range of ceramic substrates to give the design and procurement functions as much versatility as possible. A number of approaches are available, all based on the fact outlined by Pincus[5] and others that the transition layer, to be effective, must be cermet in character. An effective method to achieve this structure is to add ceramic material directly to a metalizing mix consisting mainly of refractory metal.[6]

The role of the ceramic engineer in the development of inks has been to find the interaction of the added ceramic materials with specific bodies in the presence of the metal components of the mix and to develop new additives. Not surprisingly, this successful combination varies not only with the composition of the ceramic substrate, but also wtih the thermal cycle to which the substrate has been exposed. By various techniques (such as strength-testing of the metalizing layers, metallographic examination, and electron-beam probe analysis)[7], it has been found that a good prediction can be made as to the reliability of a metalizing layer made with a specific combination of materials and processing.



RCA Type 4633 UHF power tetrode with *BeO* cooling block. Delivers 240 W PEP at an open loop for use as a linear RF power amplifier. Cooling is accomplished by conduction to the chassis through a *BeO* ceramic with a tube-chassis standoff of 4000 V. The flange mounting to the chassis is hermetic, and the radiator aids in cooling by forced convection. There are 14 flange-ceramic seals in the tube envelope. Note the cross-cuts in the copper members of the cooling block to permit the columnar stress relief in the copper-*BeO* seals.

As the materials are usually applied as a viscous ink, the rheology and method of application have an important bearing on the success in producing a reliable product. Developments in this area have been very rewarding. The interaction of plating and braze selection are also important factors because they may change the metallurgical structure of the metalizing layer.

Because the necessary skills are more closely allied to the ceramic field than to any other disciplines, the development of metalizing systems is usually delegated to ceramic engineers, with the cooperation of metallurgists, chemical specialists, and equipment designers.

Because of the fundamental nature and the complexity of the problems involved in metalizing and the new materials continually being introduced, metalizing development will probably be a continuous requirement and become more interdisciplinary in nature. Goals of long standing, such as high-strength metalizing below the creep temperatures (about 1250°C) of present substrates, are now under development on this basis and may be generally available in the near future.

Reliability, strength, and versatility of ceramic-metal seals has increased substantially in the last several years as a result of metalizing advances, but metalizing is still an exacting process, and limitations still exist on the use of potentially useful ceramics.

Seal-system development

Inasmuch as metalizing development is done by the ceramic engineer, the development and testing of new seal designs are done in the same area because the metalizing is a major factor of the seal system, and the testing methods and equipment are very similar.

Because every seal is prestressed at brazing beyond the elastic limit of at least one member and there is no known method of accurately testing brittle-ductile interface systems for strength, there are few calculations that can be made to predict the success of a seal configuration. This situation is complicated because, in a ceramic, the allowable shear stress is probably ten times the allowable tensile stress, and the allowable compression is normally thirty times the allowable tension.

Seal systems are, if possible, designed following the guidelines of successful past experiences, some of which have been resolved into useful empirical formulás.[8]

The material parameters governing successful seal configurations are well known. They are the strength of the ceramic (or its metalizing layer) and its thermal expansion and the strength of the mating material (usually a metal) and its Young's modulus, yield value, and permissible elongation. The plating and braze materials are sometimes a minor stress factor. Size and configuration of the components are also very important.

A balanced stack (i.e., a ceramic-metal-ceramic sandwich) is the most stable configuration because the stresses are nearly pure shear. An unbalanced flange or butt seal is more of a problem because there are more tensile stresses, and OD-ID seals must be very carefully designed because the tensile stresses are a very great part of the total stress.

The use in the intended device usually dictates the preferred seal design. Unless absolutely necessary, this design should not be radically changed, because such changes can become very costly and interfere with the optimum operation of the device.

Exact replicates or experimental build-ups are used in evaluation. If possible, destructive tests are performed to evaluate the residual strength numerically. If not, repeated thermal cycling, in conjunction with leak-testing, is a good means of evaluation because stresses generated by coefficient-of-expansion mismatch are usually the predominant stresses causing failure in seals. Thermal cycling at temperatures well above the temperatures encountered in processing or service is a quite reliable method of evaluating reliability. Analysis of failures by visual inspection, metallographic section, dye-check, and other means will usually pinpoint the causes of failure and indicate the corrective action necessary.

Corelative with seal development, attention should be given to brazing-fixture design and materials because these fixtures are very important to the successful duplication once the seal design is established.

Vendor contacts

The maintenance of vendor contacts in the ceramic industry is an important function of the ceramic engineer. New materials, new processing of extant materials, and new forming techniques are continually being developed and one cannot completely rely on routine purchasing-vendor contact, inasmuch as some relatively obscure technical changes can make a substantial difference in the usefulness of a vendor's offerings. Adjudication of specification disputes is another area where an engineer may be of service to purchasing. Strength—and metalizability—testing of new ceramics and periodic sampling of vendor materials not in production use have uncovered a number of useful materials.

The responsibility for technical assistance to design and production engineers in selection of materials and quality specifications requires knowledge of current vendor capabilities. This knowledge can prevent costly false starts, over- or under-specification, and the development of competitive sources of supply.

Summary

The utilization of the techniques described above has contributed to advancements in the use of high-strength ceramics in device structures in new designs and to increased reliability and reduced costs for extant designs. Many of the problems challenge the state of the art in ceramics; this feature, coupled with the interdisciplinary nature of the work, offers a great deal of technical challenge to the ceramic engineer in the electronic-device field.

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Cleaning and plating engineering

R. W. Etter | N. Seidman

Proper cleaning and plating merit consideration in the device design, process scheduling, and quality specification. Improved cleaning and plating techniques are tailored to costs for construction material and processing, to assembly and operation parameters, to appearance standards, and to the end use of the part in service under specified environment. Plating, both simple and alloy, can be customized not only for metals, non-conductors, and even powders but also for method (e.g. electrolytic, electroless, immersion, and for handling by rack or by barrel). Using the specifications, engineering must develop an optimum production cleaning and plating schedule to insure meeting the specifications in a practical and economical manner.

CLEANING is a reaction mechanism by which material is removed from surfaces so that they are altered or exposed in their intrinsic properties. *Plating* is a reaction mechanism by which material is added, in a controlled manner, to surfaces to allow, to control, or to prevent other reactions at those surfaces. In the narrower sense, it is applying a simple or alloy metal film or layer to another surface which is prepared to receive it for known reasons.

Product development

The Chemical and Physical Laboratory at RCA Lancaster, standing to serve between research, design, device development, and product manufacturing, plays a unique role in consultation and adaptation in relating new technologies to production. Frequently, there can be useful consultation either before a new device or process is designed and directed into manufacture or as soon as manufacturing difficulties are encountered.

Typical design problems

Most common examples are composite devices which may have designed-in galvanic corrosion of dissimilar metals. An example is a hermetic ceramic package having nickel-cobalt-iron alloy leads topped with aluminum, and a seal made of partially devitrified frit with many "wicking" capillaries reaching the embedded leads. The aluminum in contact with the ferrous alloy is a "built-in" galvanic cell, and the corrosion from it is aggravated by the remaining moisture from the frit. Also, the frit capillaries trap the acid etchant used to clean the oxidized leads. High scrap results from corrosion of the leads and from electrical leakage through the chemically contaminated capillaries. Prior to design, there could have been consultation with cleaning and plating engineers who could have cautioned against designing these sources of trouble into the device.

Again, incompatibility of materials operating at elevated temperatures can readily be designed into parts. An example is a basketweave cathode, woven of fine tungsten wire and requiring sufficient nickel plating at the cross-overs to allow sintering and bonding to reasonable strength. However, nickel, in contact with tungsten at the elevated temperatures which prevail during device operation, diffuses into the tungsten, swells the grain size, distorts the basket structure, and renders the tungsten quite brittle. A barrier layer of rhenium plating on the tungsten prior to nickel plating should have been designed into this part. Such information is within the purview of plating engineering.

Sometimes a design may require selective cleaning and plating without altering the major surface of the device or the assembly. An example is a metalized beryllia part to be brazed to a metal component of an electronic device. The molybdenum metalizing ink contains sufficient glass to allow strong bonding to the beryllia, yet must be plated to allow wetting by the brazing. To accomplish this, several processes had to be developed: 1) a chelated cleaner for removing all inking

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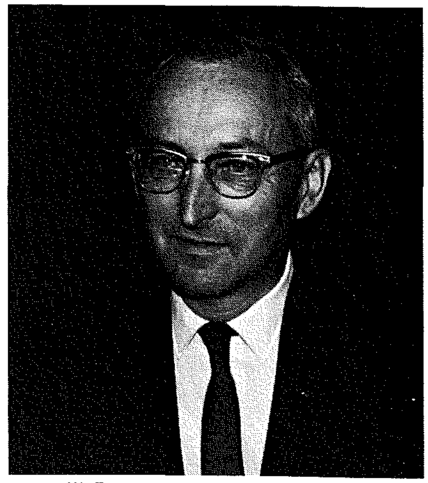

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smudges; 2) an etchant specific for the glass component without degrading the molybdenum; and 3) an activator specifically for the molybdenum, which will then accept an electroless plating adherently without smudging the beryllia.

Specifications

Plating engineering always needs to be alert to quality specifications for metal finishing, whether proposed by the industry or set by government-military standards. It needs to ask the questions:

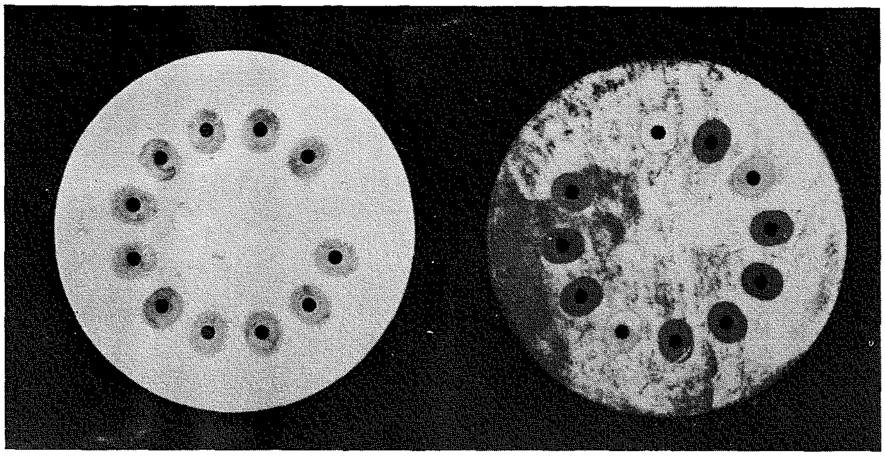
Is this specification realistic?
Is it attainable by present processing or by feasible modifications?
Is it related to the service requirements and life environment of the device?
Is cost consciousness kept in mind?

An example is a device having plated-wire leads. The initial plating specification required that the leads pass a bend test over a radius so small as to stretch the outside of the plating beyond the intrinsic elastic limit of the metal. Plating engineering ascertained that this subassembly would never experience such severe flexing of the leads. It pointed out how unrealistic the specification was and urged reasonable change.

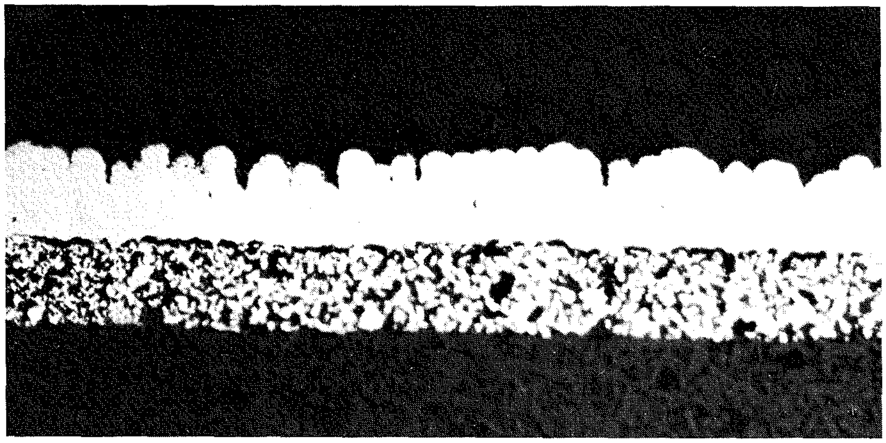
On the other hand, a specification can be made both cost conscious and quality up-graded by engineering application of intrinsic properties, e.g., the excellent oxidation resistance of rhodium. Rhodium is costly, but a very thin film of its plating goes a long way in assuring oxidation resistance at elevated temperatures. Therefore, the plating specification for a certain Cermalox tube in high-temperature service was changed from heavy silver plating to thin rhodium plating, resulting in both cost reduction and quality improvement in service.

Cleaning engineering

Cleaning engineering is directed to developing processes for removing machining lubricants, draining compounds, scale, oxidation, fingerprints, or any other surface contamination that detracts from assembling, plating, appearance, or use of the part or device. It considers all contaminating substances of the environment that the surface has already seen in the light of the intrinsic properties that the surface will have to manifest in all future environments. It is concerned that no previous process or handling has charged the surface with any soil which cannot be removed subsequently by ordinary means.



This photograph illustrates the effect of chelated cleaning. The electroless cobalt-copper-plated molybdenum-metalized ceramic on the left has been hydrogen fired only; the ceramic on the right shows the effect of chelated cleaning.



This microphotograph (X200) illustrates hard, high-tensile-strength, laminated-nickel plating from a conventional hydrazine nickel electroless bath—but using periodic interrupted current.

In the past, many devices required stepwise cleaning in three or four media, some of which were costly, required careful control, had short useful life, or had side effects, such as immersion plating by copper previously dissolved in hot hydrochloric acid pickle. Cleaning engineering has developed inexpensive composite media which at one and the same time chelate ionic contaminants and, by cathodic action, scrub the surface with effervescing hydrogen, removing solid soil and rendering the surface active to receive plating. Moreover, such baths have long, useful lives.

For more difficult cleaning, such as severely oxidized molybdenum, there are specific etchants which have accelerated action in dissolving all oxides and are yet mild toward base metal. It is difficult to descale high-chromium alloys and to remove all surface oxides. For such surfaces, there are available either proprietary materials or in-plant formulations of bright dips combining active blends of mineral acids with organic leveling agents and complexing compounds. In the past, preparing nickel-cobalt-iron alloy for adherent plating presented a constant challenge to the metal finisher. A recently developed bright dip resolved the problem.

Plating engineering

Plating can be customized in several ways:

1) Metals can be deposited on metals, on non-conductors such as plastics and ceramics, and even on powders, and controlled properties can be imparted to the plated surface.
2) Method of deposition (namely, electrolytic, immersion, or electroless) can be controlled. (Electrolytic plating can use racking, jigs, or barrels, of which a wide variety are available.);
3) Unique useful properties can be achieved.

Two recent developments

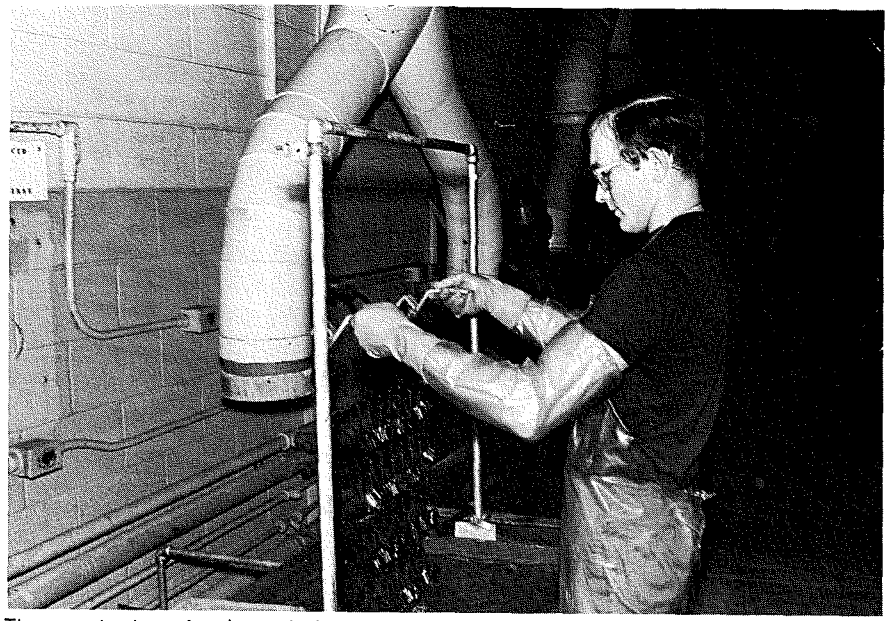
An electroless plating process for depositing an alloy of cobalt and copper from one bath has been developed. Composition of finished plating is controlled by the initial make-up of the bath and by the time of plating. The composition of the plating across the thickness of the film can be varied from the least amount of copper in the initial layer to the least amount of cobalt in the outermost layer. Among the many unique properties of this alloy plating is the readiness with which it improves brazing wetting on molybdenum metalizing of ceramic-to-metal seals. It enhances brazing strength and presents a barrier layer to prevent braze penetration through the metalizing to the base ceramic.

The second development is an electroless nickel bath having a hydrazine salt as reductant, used to achieve a strong, hard, high-purity deposit on ceramics. A new technique, namely periodic interrupted current, was used. During the off-current interval, the electroless process deposited its own distinct but strongly adherent layer. Each interface of this laminated nickel deposit contributed to the enhancement of its finished properties, such as strength and hardness. Variations were controlled by the number of cycles as well as by time ratio in each cycle.

New materials and processes

Important to cleaning and plating engineering is the evaluation and testing of new proprietaries constantly being developed in the field. Because of much company private know-how, realistic and reliable testing procedures must be developed prior to adoption in production manufacturing.

Such an engineering arrangement allows problems to be referred from initial manufacturing of a new device and allows consultation service in adapting research or design to productive manufacturing. The experience and know-how soon gained by this mutual relationship also provides the basis for consultation service to other RCA engineering disciplines, to other RCA product divisions, and even to vendors striving to meet difficult RCA specifications and to upgrade materials and subassemblies in the many aspects of metal finishing.



The operator is performing a rinsing operation. The stainless steel parts in the jig are the color shields (R9040) used in the 15-inch color tube. The specially designed jig is made of titanium.

Production aspects

The production plating department is all too often considered space on a flow diagram where raw parts, assemblies, or finished devices enter for such surface treatments as bright dipping, electroplating, or electropolishing. What happens in the box remains mysterious. Baths of various colors are steaming within and the area looks ominous and not nearly as antiseptic as a hospital sterilizng room. Perhaps alchemy is being practiced! Much of the mystery is because of the past when art dominated science. Without belittling art, which is an essential ingredient of any skill, science in the form of electrochemical engineering governs production plating at RCA Lancaster and most successful plating shops.

A plating shop may be anything from an automatic plant to handle high-volume work to a job shop in a basement. At Lancaster, we would classify the production plating department as a service organization primarily geared to the plating requirements of the power-tube, super-power-tube, and conversion-tube activities. Versatility is needed because of the many different processes involved, ranging from nickel-plating of ceramics to platinum-plating of molybdenum. Some are small batch operations handled on a bench scale and others are continuous volume processes of rack or barrel plating. Some processes are electrolytic, others electroless, and some are specific cleaning or descaling operations.

Electrochemical engineering is a distinct discipline that applies the principles of electrochemistry and chemical engineering together. Applied to production plating at RCA Lancaster, it generally involves the setting up and monitoring of a *controlled process* for cleaning and plating. The next step is toward process optimization and cost reduction. In addition, a certain amount of developmental work is done in conjunction with the plating laboratory because of the large-size facilities available. The striving toward an optimum process, which considers all factors of economics and technology, represents the challenge of production electrochemical engineering.

Functional plating . . . a need for control

It should be mentioned that there are two broad classifications of electroplating: decorative and functional specification plating. In the forefront of the latter is the electronics industry. The esthetic appeal plays a lesser role and is evident only in a finished device, such as the gold plating of a power tube primarily for skin-effect and temperature-corrosion-resistance rather than for ornamental purposes. A basic requirement for quality plating in electronics is virtually perfect adherence. It is not sufficient that a part, when removed from a plating bath, be free of peeling or blisters. It must not blister at elevated temperatures of brazing or thermal cycling or when stresses are imposed on the bonded plating. Sometimes this lack of quality knowledge because of the absence of quantitative checks of adherence and the necessity of relying essentially on a "use" test represents some frustration and emphasizes even more the necessity for controlling the process.

Disregarding the economics of the process, the type and method of plating, the size and design of facilities, etc., the most important criteria toward getting continuously reliable plating quality are 1) proper and sufficient cleaning and 2) strict total control of the plating baths.

Cleaning

Cleaning processes bear the burden of preparing the surface for optimum adhesion with a minimum attack on the surface. A metalized ceramic that can be cleaned satisfactorily by a certain method may later be found to have a weak metalizing bond because of chemical attack, although the plating is adherent. An assembly of dissimilar metals may not be able to be chemically cleaned because the brazing alloy will be attacked, and so will be mechanically cleaned. In another case, mechanical cleaning may impregnate the surface with contaminants that will not permit adherent plating. The purity of a material, previous treatments (such as firing), and even the vendor may play a role in how well a part can be cleaned and plated. In addition, the method of plating and the component design affect cleaning ability. It is obvious that cleaning in bulk, as in a plating barrel, is going to be more difficult than cleaning on a rack, and that both will depend on the many variables of equipment, part design, and operator technique or skill. Poorly brazed joints are often bad offenders and greatly hinder cleaning. Although not necessarily a cleaning process, rinsing steps are indirectly vital to good cleaning as well as to successful plating. The rinsing must be proper to prevent drag-in of contaminants to succeeding baths as well as adequate to thoroughly flush away any dragged material from the preceeding bath. Of necessity, the water must be extremely clean and hence de-ionized. Because this process is costly, it is necessary to limit the quantity used without adversely affecting the rinsing quality.

Plating

The total control of plating baths involves careful control of all the variables that can affect plating quality. Ideally, these variables should be constant from one plating run to another. The variables include such basic items as concentration, temperature, agitation, and the cleanliness of the bath itself. The last item is broad and covers anything from dirt to minute amounts of foreign metal ions. It is controlled by filtration, preferably continuous, and miscellaneous periodic bath-maintenance and purification steps. It is impossible to elaborate on all the trouble shooting that is involved in plating control. Skilled and observant operators are a tremendous asset.

This process control is an ever-continuing duty that pays off in a successful end product. However, plating production engineering must become involved with design and development as early as possible so that it can pave the way to setting up the process, procuring the equipment, and, in many instances, providing guidance and training to operators in performing new and unfamiliar plating operations.

Cooperation with other groups

The Plating Development group must be extremely close to production both during the development stage and later on as problems are encountered. Because material knowledge is vital, various sections of the Chemical and Physical Laboratory, from the chemical analysis group to the ceramic development group, are frequently consulted. Because a great variety of metals are handled, the metallurgy section becomes intimately involved with plating. In fact, metallurgy and electroplating are practically inseparable.

Production plating must continuously work with tube design and development engineers and factory engineers on new developments to provide technical plating knowledge on what can, can't, or might be done on a production basis, and also to provide assistance in solving problems on existing factory production problems. Plating production knowledge can be invaluable and should be exploited. Proper selection of a metal and its purity can eliminate subsequent galvanic corrosion and in some instances eliminate the need for plating entirely. If environmental testing is involved, the designer must make an early selection of the thickness and type of plating. The thickness aspect, of course, represents dimensional changes, and can affect parts-making, tooling, and gauges. Often overlooked is edge-plating buildup, which may be reduced considerably by specifying a larger radius or a more obtuse angle. If applicable, electroless plating may be recommended for greater uniformity, or perhaps special anodes or jigs may be needed to achieve the desired uniformity. With respect to the type of plating, a new bath and facilitation may be needed, for example, if there is a specific requirement such as a stress-free nickel layer or an unusually heavy deposit of copper. Knowledge of electrochemical deburring or of electroforming may be of great importance to a tube or tool designer. It may prove disastrous on a certain part if no provision is made for electrical contact, as by adding a tab to clip onto. On other hand, it could be just an expensive addition or hindrance if the part could otherwise be barrel-plated. Parts make assemblies, and if these assemblies are to be plated, some thought must be given to their plating requirements in a manner similar to the above procedure. Cases have been known in which a recommended change of brazing material has simplified cleaning steps, thus producing a better-quality end product.

Conclusion

The technology of cleaning and plating engineering is expanding rapidly and, with the cooperation of all disciplines concerned, new controlled processes will be utilized to RCA's fullest advantage and the present ones will be further improved.

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Process development

R. A. Alleman

The engineers of Advanced Process Development at RCA Lancaster might be described as "general practitioners" of engineering. Their background must be broad enough to allow them to become involved quickly in any process of interest to RCA. The challenge, the excitement, and sometimes the frustrations of trying to discover a new process or improve an old one are discussed. The article lists some past developments and describes one project in detail to illustrate the relationship of this group with the product designers, the production line, and with other engineering departments.

THE ADVANCED PROCESS DEVELOPMENT activity was established within Equipment Development at RCA Lancaster to assure that equipment designed for manufacturing use would be compatible with the process. Of course, there also are other equipment requirements—such as human factors, minimum equipment cost, reliable operation, and low maintenance—which must be considered. The cooperation of many disciplines is needed to achieve an equipment that makes products to meet the design specifications at a cost that is competitive in the marketplace.

The process engineer

The function of the process engineer is to provide assistance on material selection and process problems. The major part of this effort is devoted—either directly or indirectly—to support of the product lines in the Lancaster plant. On occasion, assistance is provided to other RCA plants whenever experience exists which might be helpful to them. Interplant cooperation is mutually beneficial; through contacts with other plants, techniques and processes are learned which help to solve problems at the Lancaster plant.

As implied by its title (Advanced Process Development) much of this group's efforts concern future RCA products. Less glamorous, but certainly no less essential, is the task of improving existing processes to achieve cost and scrap reduction. In addition to serving the product lines, the group serves as consultants to other parts of Equipment Development and the other service groups. They in turn, serve the process engineer as consultants in their fields. For example, the analytical services of the Chemical and Physical Laboratory are used constantly to identify materials involved in a process. A missing or added constituent or the wrong percentage composition often provides the clues needed to get a process under control or to re-establish control when a process becomes uncooperative.

Because of the extremely wide variety of the materials and processes used in the electronics industry, there are few limits to the types of problems encountered and the challenges presented. To that extent, each individual is a "general practitioner," although some limited specializing is done to cover certain fields more effectively. The education and experience backgrounds of the process engineers and technicians include chemistry, chemical engineering, mechanical engineering, mechanical design, tool-making, electronics, and industrial arts. Most of the individuals are "do-it-yourselfers" who have developed confidence that they can handle any problem. All that appears necessary is the ability to cooperate with others while retaining the right to think for oneself, an inquisitive nature, and the self discipline to pursue the desired goal while going through the maze of possible solutions.

Many times a rapid solution to a problem can prevent shutting down a process or other expensive delays. This group takes pride in providing fast reaction service when it is needed. In some cases, an immediate solution to get things running or keep things running is followed by a thorough search for a more permanent solution.

A broad general knowledge of processing is helpful in understanding problems quickly. The process may be unfamiliar, and the person stating the problem may be a specialist on the

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product involved. Samples, or a quick tour of the activity, may lend further insight into the problem. Depending upon the nature of the problem, hours —or even days—may be spent observing the process. Other problems require library study, trips to other RCA plants or vendors' plants, or experimentation on an improvised set-up in the laboratory. When necessary, prototype equipment is developed or a pilot production line may be established to prove the feasibility of a process.

Some general examples

Discovering the basic problem is not always easy. Sometimes the wrong problem may be presented, and further inquiries must be made to get to the heart of the situation. For instance, a request may be received to coat a metal pan with Teflon. [Teflon is a trademark of E. I. DuPont de Nemours & Co.] Questions about its use and what materials will be used with it may reveal that all requirements can be met by a 49¢ polyethylene dishpan. Such a pan, of course, can be procured immediately from the nearest "discount department store" (formerly known as the 5&10¢ store).

For other problems, there may appear to be no solutions within the present state of the art. These problems provide the challenge, the frustration of failure, and often the satisfaction of success in a difficult task. Unfortunately, the engineer may not be permitted to publish some of the most noteworthy accomplishments so that RCA may enjoy a period of advantage before competitors learn what is being done or come up with an equivalent process. Extensive work has been done on color-screen processing, ultrasonic cleaning, clean rooms, welding, laminating, salvage, application of plastics, and many other areas.

In the field of high-vacuum evaporation of thin films, sources have been designed or selected for a wide variety of materials. On high-production items, extending source life provides large savings. Improving the source holder in one case decreased gross scrap to 1/5 of the level it had maintained for years. Special fixtures and monitoring techniques have been developed for specific applications, such as evaporating a transparent gold electrode onto an electroluminescent speedometer drum.

Advanced Design and Advanced Process worked as a team to develop and debug the fixtures needed to fabricate the solar-cell modules which the Mountaintop plant supplied for Nimbus weather satellites. Mechanized soldering techniques were developed to attach the electrical interconnections for the module. The amount of solder used was controlled by the use of preforms.

In the production of photocells, Advanced Process worked in close cooperation with photoconductive-material experts and the factory to improve process control by changing from spray application to screen printing of the photoconductive layer. This approach entailed formulating the ink and establishing controlled printing procedures.

A specific example

Finally, one job should be described in detail. While it may seem inappropriate as an example of processing work, it illustrates the type of logjam sometimes encountered when use of a process depends upon first solving an equipment problem.

In this case, reliable 4-inch and 6-inch pneumatically-operated high-vacuum gate valves were needed to make a process practical for production use. Two valves of each size were needed per machine and would operate approximately every 2.5 minutes, three shifts per day, six days per week. Were there commercially available valves equal to the task? Inquiries were sent out to all known suppliers requesting information on their valves and any available data on how many cycles could be expected without servicing. Most manufacturers did not know, were in process of testing, or indicated their design was intended for laboratory use in ultra-high-vacuum systems where high numbers of cycles were unimportant. It was obvious that tests would have to be run. A test stand was prepared which would cycle the valve open and closed two times per minute. Three valves were obtained for test. Valve A was selected for test because hand-operated versions of the valve were being used in the Lancaster plant. Valve B was a later design made by the same manufacturer. Valve C was available in a hand-operated model only, but a pneumatically operated version was being designed. The latter valve was motorized for test purposes. Although neither of the manufacturers involved gave any encouragement that the selected goal of 100,000 cycles without any maintenance could be achieved, testing began with valve A. After only a few thousand cycles, the valve jammed and was disassembled. For all practical purposes, it was worn beyond use. Failure primarily was due to galling and seizure between the steel bellcrank used to move the gate and the cast aluminum housing used as its inner bearing surface. Ball joints used to lift the gate were made of brass and were mated with sockets machined into the soft aluminum. Galling and high wear were considered evidence of poor material selection, too high a load for the sizes used, or both. The sliding carriage which carried the gate was badly worn in many places, as were the corresponding parts of the valve body. There were so many design changes needed that correction of all of them appeared impractical.

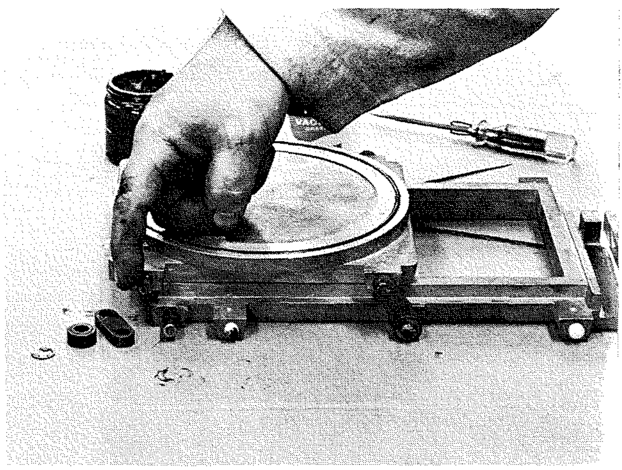


Fig.1—Lubrication of the gate-lifting links and carriage rollers of valve B.

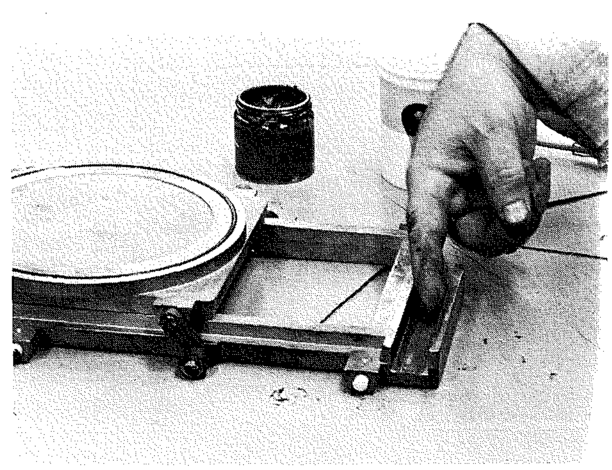


Fig. 2—Lubrication of the gate-carriage cam-roller slot of valve B.

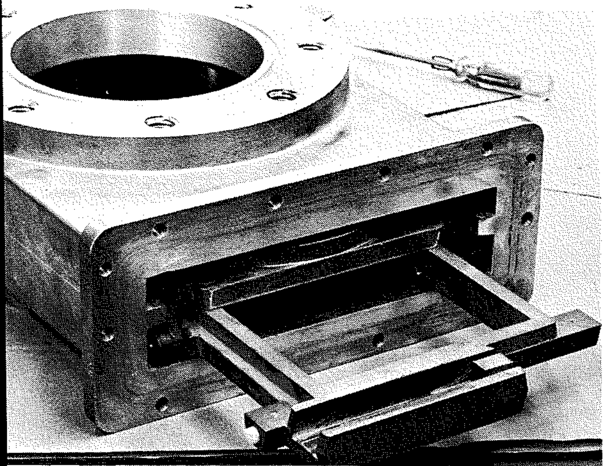


Fig 3—Gate end of valve B showing gate carriage in place.

Fig 4—Bellcrank end of valve B showing installation of bellcrank, bushings, and stem seal sub-asssembly.

Fig. 5—Guiding the cam roller into the carriage slot during assembly of valve B.

After the dismal failure of valve A, it was decided to dismantle and examine valves B and C before any more testing. Both were judged superior to valve A in basic design. Valve C was judged potentially superior in design but had many minor design and workmanship problems which indicated the vendor had not really inspected his product after the design was finished. A long list of deficiencies was dispatched to the vendor who suggested the valve be returned for exchange. Meanwhile, the few workmanship problems of valve B were corrected and testing was resumed. It soon became obvious that some form of lubrication was needed which would be suitable for use in the (10^{-4} torr) vacuum of the system. Molybdenum disulfide (MoS_2) was found to possess good lubrication properties for aluminum surfaces. Dow Corning Silicone High-Vacuum Grease was selected to serve as a carrier. A mixture of half MoS_2 and half grease by weight was prepared. Thorough mixing was found difficult, and the MoS_2 content was reduced to 35%. This mixture was checked for outgassing by comparing the pumpdown time of a bell-jar system before and after the addition of one square foot of aluminum foil coated with the mixture. No difference in pumpdown time was noted. The effect of thicker layers was checked by adding a two-ounce jar of the mixture to the foil sample in the chamber. Again, no effect could be noted in the pumpdown time. The grease mixture was used to coat the valve's gate-lifting links and the slot in the gate carriage which accommodated the bell-crank cam roller.

At the same time, the bellcrank stem-seal-bushing assembly was redesigned to correct its design weak points and to incorporate self-lubricating Teflon-filled Delrin bushings. [Teflon and Delrin are trademarks of E. I. DuPont de Nemours & Co.] The spring-loaded *O* rings used to seal the rotating ball-crank stem were coated with high-vacuum grease without the MoS_2 added. No lubrication was used for the bushings except that provided by the Teflon filler in the Delrin.

Testing was resumed. After each 10,000 cycles, the valve was carefully disassembled and inspected. The nylon wear plugs used to position and guide the gate carriage wore excessively and were replaced with the Teflon-filled Delrin material. The bellcrank cam roller was also similarly replaced with this material. Finally, the goal of 100,000 cycles without maintenance or excessive wear was achieved.

About this time the engineer working on the project visited a trade show and casually asked a salesman for the vendor if their valves would give 100,000 cycles of operation without maintenance. The engineer was assured that maybe someone else's valve would, but that definitely theirs would not. With a poker face, the engineer thanked the salesman for his honesty and moved on. The salesman will never know how much his answer bolstered the engineer's ego—which is needed occasionally to balance those days when everything seems to go wrong.

The equipment was built using the modified valve B and has now had several years of production use. Maintenance-free periods in excess of 100,000 cycles have been achieved in production service, but some earlier failures have also occurred. In most cases, they were due to mechanical blockages caused by small production parts being carried into the system and were not the fault of the valve.

Meanwhile, the makers of valve C had completed and debugged their pneumatically operated design. Because it was believed that their valve could be used with less modification than had been required for valve B, a C valve was procured. Tests were conducted on the test stand and in production service. After substitution of Teflon-filled Delrin for steel bellcrank cam roller and side-thrust rollers, the goal of 100,000 cycles without maintenance was again achieved. For new equipment, valve C is recommended to take advantage of the reduced costs of modification as compared with valve B.

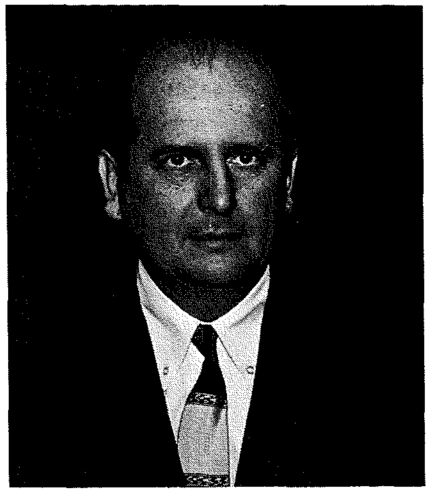
Conclusion

Some of the work described comprises more troubleshooting than the name "Advanced Process Development" would imply. As mentioned earlier, the group covers an extremely wide variety of problems which present real challenges and bring the satisfaction that comes with the achievement of a difficult goal.

Development and production of special materials

R. J. Blazek

Although the Advanced Technology Materials Laboratory operation is basically chemical in nature, many interdisciplinary relationships are associated with the development of new and improved materials. Ceramics, metallurgy, production engineering, equipment design, and industrial engineering are examples of disciplines which play an integral part in the development and production of conversion-tube materials.



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received the BS in Chemistry from the Polytechnic Institute of Brooklyn in 1948 and the MS in Industrial Engineering from the Stevens Institute of Technology in 1954. He was awarded a Gold Merit Key for high scholastic standing and meritorious service by Brooklyn Poly. Upon completion of his undergraduate studies, Mr. Blazek was employed as a Research Chemist at the Central Research Laboratory of the Allied Chemical Corporation. In 1957, Mr. Blazek joined the research and engineering staff of the Westinghouse Electric Corporation Lamp Divison. He was subsequently promoted to Senior Research Engineer with responsibility for a variety of projects related to electroluminescence. Mr. Blazek joined RCA's Chemical and Physical Laboratory at Lancaster in 1962. The following year he assumed responsibility for the operation of the associated materials laboratory that was established primarily for the production of antimony trisulfide photoconductor. During the intervening years he was instrumental in the development of many new and improved electronic materials currently utilized for conversion tube applications. As a consequence, the growth of what is known as the Advanced Technology Materials Laboratory has been rapid. Under Mr. Blazek's direction the output of the laboratory has increased over tenfold and its line of special materials expanded to include a wide variety of photoconductors, target glasses, photocathode materials and reactive alloys. He is a member of the American Chemical Society; has had four technical papers published; and has been granted seven patents relating to high polymers, electroluminescence and thin films.

The Advanced Technology Materials Laboratory at Lancaster, Pennsylvania, is responsible for the development and production of special materials used in the manufacture of conversion tubes. Materials synthesized by Laboratory personnel include a variety of photoconductors, electronically conducting target glasses, photocathode generator compositions, and reactive alloys. Because the application for each material is vital to the basic operation of conversion tubes, material purity is a factor of prime importance. Close control over the unusually stringent purity and uniformity requirements for electronically active materials is achieved through customized production in the Laboratory. Special purification procedures are utilized to remove from purchased starting materials impurities which would otherwise impair the functional aspects of the final product. All critical intermediate materials must pass rigid spectrographic analytical tests before being processed into special materials amenable to conversion-tube production. In many instances, these materials are weighed to an accuracy of five decimal places on a semimicro analytical balance to maintain the desired stoichiometry of the final compounds. Quartz reaction vessels and special plastic labware are expediently employed for averting the migration of impurities from standard laboratory glassware which would otherwise contaminate the product. In addition to purity considerations, many materials must be converted into a specific physical size or geometrical configuration before they can be effectively utilized for tube manufacturing applications. The transformation of special materials into a ready-to-use state is accomplished in the laboratory through various milling, pelletizing, and sieving operations.

Numerous control devices are employed to assure maintenance of high quality standards before materials are released to the factory. These controls include the use of emission spectroscopy, flame photometry, and chemical analysis for impurity-content determinations; metallographic examination for determining homogeneity and grain structure of alloys; thermal expansion and density measurements for synthetic glasses; and various special tests adapted for specific materials.

Photoconductors

The basic performance characteristics of a vidicon camera tube are determined in large part by the characteristics of its photoconductive target. Photoconductor evaporants are expected to yield surfaces which display proper spectral response, transfer characteristics, rise and decay characteristics, dark-current/voltage characteristics, and stability.[1] There is a high probability that one or more of these characteristics will be adversely affected by the inclusion of trace quantities of extraneous contamination in the photoconductor. To circumvent the deleterious effects of impurities on vidicon performance, special processing techniques are employed for the purification of starting materials. A zone-refining apparatus utilized for the purification of commercial high-purity antimony required for the production of SPS-type antimony trisulfide photoconductors is shown in Fig. 1. Completely different, but equally effective, chemical purification methods are employed for the synthesis of ultra-high-purity lead oxide photoconductors for

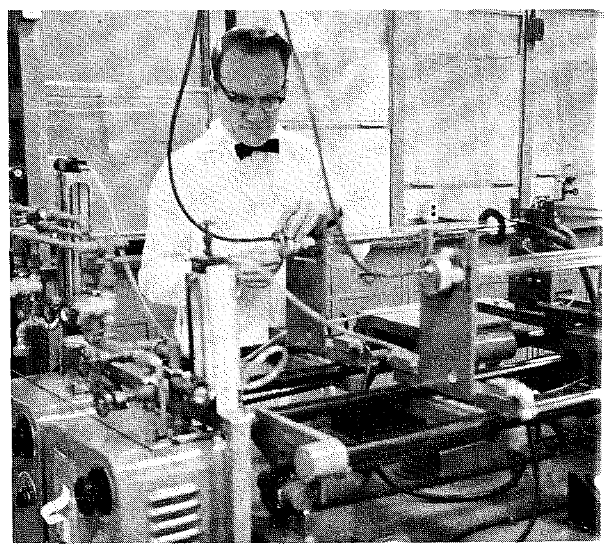

Fig. 1—Zone refining apparatus for purification of antimony metal.

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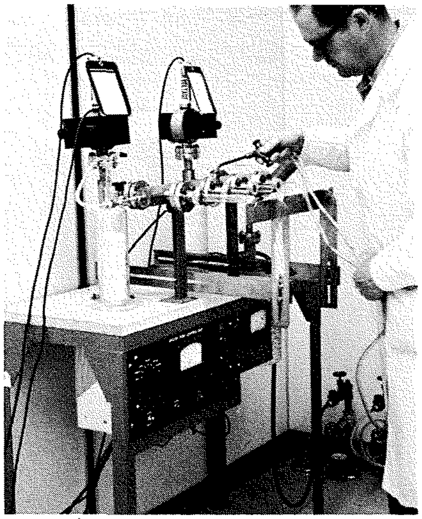

Fig. 2—Sputter-ion-pumped vacuum manifold for evacuating reaction tubes.

the Vistacon. Spectrographically pure lead oxide has been obtained through a process developed in the Advanced Technology Materials Laboratory. The performance characteristics of lead oxide and antimony trisulfide vidicons have been summarized in a recent issue of this publication.[2]

Additional types of photoconductor materials produced on a routine basis include antimony oxysulfide and PS-type antimony trisulfide. Antimony oxysulfide is utilized in comparatively small quantities for the production of high-sensitivity slow-scan vidicons and in other highly specialized applications. Near- and far-infrared-sensitive photoconductors are produced on a limited scale for military night-viewing applications.

Photoconductor materials are produced in specially designed equipment that permits precise control over processing variables. A sputter-ion vacuum manifold that was developed for the high-vacuum evacuation of reaction tubes in a back-streaming free environment is shown in Fig. 2.

Many problems associated with the development of new materials and processes have been resolved through the joint effort of specialists trained in divergent engineering disciplines. A typical problem solved through the interdisciplinary team approach involved the development of a new process for producing PS-type antimony trisulfide photoconductors. The photoconductor material was previously manufactured outside the laboratory by a somewhat hazardous and uncontrollable process. Production was subsequently curtailed after a critical material used in the process was discontinued by its sole supplier and an acceptable substitute material could not be found. Because vidicon manufacturing urgently needed additional quantities of PS antimony trisulfide, a coordinated program was established to develop a new process utilizing existing laboratory equipment. Personnel trained in purchasing, operations planning, analytical chemistry, and production engineering participated in the developmental program. The purchasing agent procured samples of substitute starting materials which were considered to offer the best chance for success. The analytical department of the Color Tube Division performed essential analytical work, and with this assistance the Materials Laboratory was able to prepare photoconductor samples which were similar in composition to the original PS material. Operations Planning personnel coordinated material-evaluation tests and maintained open lines of communication between all participants of the program. Production engineers performed all tube tests and inspections necessary for evaluating tube performance and accumulating yield data. The ultimate result was that all program objectives were met within a relatively short period of time. A safe and reliable process was developed for the production of PS-type antimony trisulfide from commercially available starting materials.

Photocathode materials

High-purity chemical compounds are synthesized in the laboratory and subsequently formulated into alkali metal generating compositions. Generator powders are utilized extensively for the preparation of photocathodes in phototubes, image tubes, and image orthicons. The application of RF heating to a pelletized generator composition is the most common method for introducing a photocathode-activating alkali metal into a tube. A probable reaction for the liberation of free cesium from a cesium chromate-silicon generator mixture heated to temperatures in excess of 700°C is[3]

$$4Cs_2CrO_4 + 5Si \rightarrow 8Cs + 2Cr_2O_3 + 5SiO_2.$$

Trace impurities in any of the constituents of a generator mixture can be highly detrimental to photocathode sensitivity and result in an undesired shift in spectral response. The production of generator powders is further complicated because the particle size of each constituent must be very carefully controlled. Particle size influences the rate of reaction for alkali-metal liberation and critically affects the flow and pelletizing properties of generator powders.

The development of a process for the synthesis of photocathode-grade cesium chromate presented a challenging problem to the Advanced Technology Materials Laboratory. The circumstances surrounding the problem were similar to that described previously for PS antimony trisulfide. In the past, all generator materials were purchased from chemical specialty manufacturers and the generator mixtures formulated by RCA production personnel. This mode of operation continued until the only available supplier of factory-approved cesium chromate was no longer able to meet RCA standards, for some unknown reason. As a consequence, it became imperative to avert the shutdown of a number of tube lines because of lack of cesiation material. A program was established to cover the following courses of action:

1) To locate a new potential source of supply for photocathode-grade cesium chromate.
2) To develop a method for the purification of nonstandard cesium chromate and transform it into high-quality material suitable for tube applications.
3) To develop a process for the synthesis of photocathode-grade cesium chromate directly from raw materials.

The Advanced Technology Materials Laboratory was given the responsibility for the investigation and development of a cesium chromate process by either of the latter two alternatives outlined above. Early in the program it became evident that conventional purification techniques such as recrystallization and solvent precipitation are not effective for the removal of rubidium and other alkali metals from cesium chromate, owing to isomorphism. Effort was therefore directed toward the development of a synthesis whereby undesirable impurities would be removed prior to cesium chromate formation. As a result of this work a stop-gap method was developed which afforded acceptable-quality cesium chromate in sufficient quantities for uninterrupted production of tubes. The synthesis involved the formation of an intermediate cesium alum compound for separation of associated alkali metals. Subsequent regeneration and neutralization reactions produced high-purity cesium chromate, but the product was costly because of the complexity of the process. Further investigative work led to the development of a considerably more efficient process based on a thermal interaction between cesium nitrate and chromic anhydride.[4] Cesium chromate is currently being produced by the thermal method in a higher-purity state at approximately half the cost of cesium chromate synthesized by means of the earlier cesium alum process. Internal production of photocathode-grade cesium chromate now assures absolute control over the quality of this vital material.

Electronically conducting glass

Electronically conducting glass targets utilized in the long-life image-orthicon line are characterized by high stability, resistance to "burn-in", and the absence of granular structure. The basic glass compositions and related glass-ring glazing frits are produced in the laboratory by reacting metallic oxides and other chemical constituents at high temperatures. Platinum or platinum-rhodium crucibles containing the glass-forming materials are heated in a specially designed furnace capable of sustained operation at 1650°C. Only high-purity reagents are employed for the preparation of target glasses and frits. In certain instances, an intermediate compound is first transformed into a high-purity raw material such as that achieved by the thermal dehydration of chemically pure silicic acid to provide high-purity silicon dioxide, an important target-glass constituent. The purity of the raw materials is determined primarily by emission spectroscopy. Quality-control measures established for synthetic glasses include density measurements and the determination of thermal-expansion coefficients.

The glass-formation process and the subsequent fabrication of the resultant glass into a physical form amenable to the manufacture of image-orthicon targets are operations which fall predominantly within the scope of ceramic engineering.[5] Other engineering disciplines play a relatively minor role in the production of target glass and ring-glazing frit.

Special alloys

The great majority of the alloys produced in the laboratory are utilized either as evaporants for photocathodes or for the deposition of thin-film semiconducting image-orthicon targets. Platinum antimonide and silver-bismuth are important photocathode alloys used for the production of image tubes, image orthicons, and phototubes. The S-10 (Ag-Bi-O-Cs) photocathode is the most commonly used type for image orthicons because of its wide panchromatic response. The S-10 photocathode is prepared by evaporating silver-bismuth alloy to a given light-transmission value, then oxidizing the film to a second specified transmission value, and then following up with cesiation.[6]

Magnesium-aluminum and magnesium-indium alloys are typical semiconducting target-forming alloys which are employed in the manufacture of high-resolution-image and image-intensifier orthicons. Both photocathode alloys and target-forming alloys are highly reactive and oxidize rapidly at elevated temperatures. As a consequence, all alloying operations must be performed in an oxygen-free environment. Because alloy purity is a particularly important consideration, the metal constituents are individually purified to a high degree by zone refining, single-crystal growth, or some other appropriate method. Homogenization, quenching, and annealing processes are representative metallurgical techniques employed to achieve structurally uniform alloys. Metallographic examination provides a useful quality-control tool for monitoring the grain structure and homogeneity of custom-produced alloys.

Miscellaneous materials and services

Miscellaneous materials produced in the laboratory include filming lacquers, conductive paint, modified TIC solutions, and resistive-coating compositions. These materials are formulated with great care by experienced chemical technicians to maintain the high quality standards required for tube-manufacturing applications. Filming lacquer is the most widely used conversion-tube material in the group.

The laboratory augments the discharge of its responsibilities for special-materials production by providing a materials-and-processes consultation service for development-and-production-oriented personnel. Technical assistance is rendered to help resolve chemical problems arising in certain phases of tube manufacturing. Specific salvage procedures are developed for the recovery of valuable parts or materials, and those operations requiring implementation by technically trained personnel are usually performed in the laboratory. Salvaging operations for tantalum target-mounting rings and stem-aluminizing wires are currently being performed in the laboratory for the image-orthicon manufacturing section. As previously indicated, developmental programs are established between laboratory personnel, application engineers, and production engineers.

Concluding remarks

The problems associated with the development and production of special conversion-tube materials are unusually challenging and diverse. Materials which are otherwise unattainable commercially because of their exceptionally high purity, unique stoichiometry, or critical quality-control requirements are synthesized on a routine basis. Reduction in material costs may be accomplished either by process simplification or by increasing product yield, provided there is no impairment of material quality from the tube-manufacturing standpoint. The development of new and improved materials involves the application of a wide variety of scientific and humanistic disciplines. Chemistry, physics, metallurgy, ceramics, equipment design, electrical engineering, industrial engineering, operations planning, and production engineering are among the various disciplines which play a vital role in advancing the state of the art for conversion-tube materials.

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Spacecraft environmental testing

E. L. Meyer | P. C. Wise

In spacecraft environmental testing, an engineer must be conversant in many engineering disciplines—corresponding to the various environments which the spacecraft encounters through launch, orbit, and re-entry. Although usually of a mechanical engineering background, the environmental engineer must be familiar with such diverse fields as optics, infrared technology, hydraulics, dynamics, vacuum technology, and thermal analysis. This paper illustrates some of the interdisciplinary considerations of the environmental testing role.

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THE OBJECT of environmental testing is to verify the capability of a spacecraft system design to withstand the environmental stresses to be encountered during a mission. Therefore, one of the major requirements of the testing program is to simulate the critical environments or their effects on spacecraft in as rigorous and controlled a manner as is economically possible.

Test methods may be grouped into the following:

1) The reproduction of the environment, and
2) The production of the effects of the environment.

Both methods have been utilized extensively and successfully at AED. However, each approach has its major advantages and disadvantages. The former approach, if performed in a rigorous manner, results in a large degree of confidence in test results, but usually involves complexity of test equipment with resultant high costs. The latter approach, while allowing for relatively simple test equipment and procedures, may require extensive analysis for prediction of the response of the spacecraft to the environment.

The mission environment

To the environmental engineer, the spacecraft mission begins with the transfer of the spacecraft from the manufacturing and testing facility to the launch site. Stresses encountered during this phase include low-level and low-frequency vibration (both sinusoidal and random), shocks during handling, high and low temperature, and low pressures (as would be experienced in an unpressurized aircraft compartment.) Due to the location of our major launch facilities, the spacecraft, prior to launch, may be exposed to high humidity, high temperature, sand and dust, and salt fog.

The next phase of the environmental profile is that of the explosive and/or flammable environment. Fueling of the launch vehicle and the spacecraft presents the hazards of the explosive atmosphere, especially during final operational check-out. With manned spacecraft missions, the danger of the oxygen-enriched atmosphere is present, as was made tragically apparent on the Apollo program in 1967.

Perhaps the most severe environmental stresses occur during the spacecraft launch or boost phase. Launch operations subject the spacecraft to high level broad-band random vibration, acoustical noise (during both the lift-off and transonic periods), static acceleration, and staging shock loads. Sinusoidal vibration loads may also be impressed upon the spacecraft due to bending modes during launch.

Once in flight, the spacecraft, dependent on its particular mission and design, may be subjected to severe thermal cycling while in the vacuum environment of space. This cycling may be caused by the crossing of planetary shadow zones, the relatively slow rate of rotation of a spacecraft about its own axis, the cyclical nature of a spacecraft's power profile, or (most often) by combinations of these. The thermal stresses on a spacecraft are due, in part, to the lack of an air envelope which, if present, would more evenly distribute heat energy by convection. This lack of convection may lead to troublesome hot spots and mechanical stresses due to thermal gradients. Again dependent on the orbit or trajectory, the spacecraft may encounter particulate and electromagnetic radiation (for example, Van Allen belts and ultraviolet rays).

Finally, spacecraft which are intended for recovery are subjected to the severe high temperature environment of re-entry, landing shock loads, and possible water immersion.

Environmental testing facilities

At AED, spacecraft testing is conducted in a variety of simulated environments utilizing some of the most advanced test facilities presently available to the environmental engineer. To simulate the orbital environments, these facilities range from a 26-foot diameter by 20-foot high thermal-vacuum chamber to 2-foot diameter by 2-foot high, ultra-clean titanium sublimation, ion-pumped Bell Jars. The climatic environments are simulated, in part, by an assortment of thermal-humidity facilities ranging up to a 17 x 14 x 14-foot chamber. Electro-dynamic vibration exciters are employed to simulate the dynamic launch environments with capabilities up to 28,000-pound force sinusoidal or random vibration

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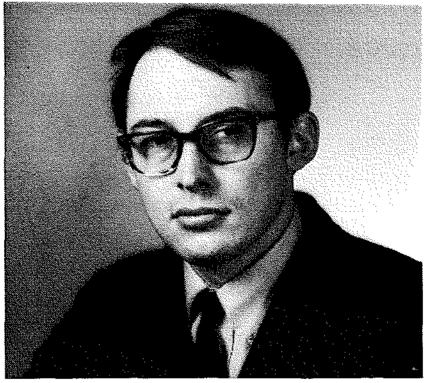

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and spectrum shock testing. Static acceleration testing is performed using a centrifuge facility with a peak load capability of 100 g on test items up to 100 pounds in weight.

Environmental engineering disciplines

The interdisciplinary challenge of the environmental engineer is broad indeed. To serve his most useful function, he should first be thoroughly familiar with the spacecraft configuration. He should be aware of the functions of the various spacecraft subsystems, their criticality to the mission goals and their major failure modes.

Secondly, the environmental engineer should have an intimate knowledge of the mission environment during each phase of the spacecraft life. The environmental engineer may then proceed to designing those test configurations that most economically and reliably serve to point out any spacecraft weaknesses.

However, given the complexity of the typical spacecraft configuration, its mission objectives, and sophistication of on-board equipment, coupled with the multitude of possible environments, it is obvious that the environmental engineer is faced with a task that crosses many disciplinary lines. The variety of challenges facing the engineer in the critical task of experimentally proving spacecraft reliability may best be appreciated by considering some specific disciplines of the science of environmental engineering.

Heat transfer technology

As mentioned above, the effects of heat transfer by air convection are usually absent in the orbital environment, leaving radiation and conduction as the remaining modes of distribution of heat energy. The test equipment involved in presenting orbital thermal environments to spacecraft therefore include vacuum chambers and radiative sinks and sources to simulate solar and planetary thermal fluxes. These radiative sources range from isothermal, high-emissivity tube and fin shrouds, to hot-wire and lamp arrays and carbon arc solar simulators. When testing subsystems or component parts of a spacecraft, conductive heat sinks and sources are usually required to simulate the more massive elements of the spacecraft.

One spacecraft subsystem particularly susceptible to extremes of temperature cycling is the solar-cell array. The critical function of these arrays, of course, is to absorb solar energy and transform it into electrical power for use by the spacecraft. Due to weight constraints on all spacecraft elements, the arrays normally possess a relatively low thermal mass (product of mass and specific heat); and, due to the necessity of gathering large amounts of solar radiation, the arrays tend to have large surface areas. Because of these two design requirements, an array subjected to a varying solar input, will undergo large excursions in temperature as governed by the following basic equation:

$$\Delta T/\Delta\theta = Q/mc \qquad (1)$$

where, Q is the heat power being stored or given up, m is the solar array mass, c is the solar array effective specific heat, and $\Delta T/\Delta\theta$ is the rate of change of temperature with time.

The solar cell array responds to these large temperature excursions, of course, by repeated expansions and contractions. The repetitive nature of these deformations is analogous to the reversed bending of beams wherein a

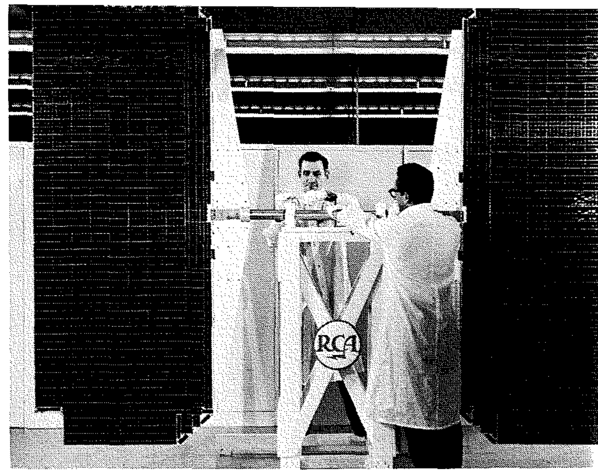

Fig. 1—Nimbus spacecraft solar-cell arrays.

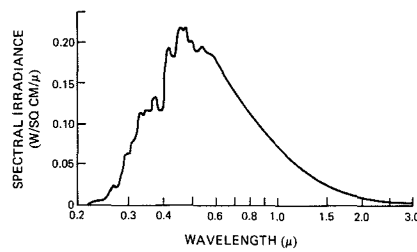

Fig. 2—The Johnson solar spectral irradiance curve.

fatigue failure mode is common. Complicating the thermal response is the abundance of dissimilar materials present in the array construction (aluminum honeycomb structure, silicon cells, glass filter covers, adhesive agents, and intercell wiring). The effect of materials having different thermal coefficients is to present localized stresses due to nonuniform deformations. Therefore, if an array such as that shown in Fig. 1 is destined for a planetary orbital environment, the test conditions should include rapid cycling of the array between its extreme response temperatures. A rigorous approach to such a test is the exposure of the array to a carbon arc or xenon arc-lamp solar source. These sources have the advantage of possessing a good spectral match with the Johnson curve, which describes the spectral distribution of solar energy (Fig. 2). Thus, the use of either a carbon arc or xenon arc-lamp would result in a rigorous simulation of the amount of thermal power absorbed by the array. However, offsetting the spectral desirability of these sources is their relatively large expense both in initial installation and operating costs.

Efforts to provide an adequate simulation of the solar-array orbital thermal environment at reasonable cost has resulted in the design and manufacture of an infrared hot tungsten wire test facility. The wires, each of which are 104 inches long, are con-

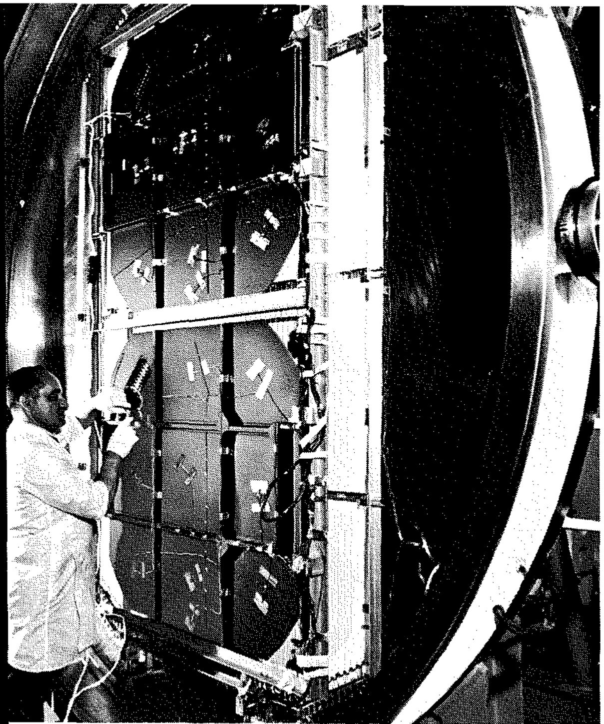

Fig. 3—Lunar Orbiter solar arrays in T/V test facility.

figured into a plane array 66 inches wide with wires spaced one inch on centers. With wire temperatures of 1500°F to 2000°F, temperature uniformities of 5°F to 6°F have been experienced on flat solar-cell arrays under test. In addition, the tungsten wires possess a low thermal mass, thereby allowing for rapid temperature cycling.

However, the use of any infrared thermal source (with a correspondingly poor spectral match to the Johnson curve) necessitates a knowledge of the so-called α/ε ratio of the solar array surfaces. Here, α is the solar absorptivity of the surface (the ratio of incident solar energy to that absorbed) and ε is the total infrared emissivity (the ratio of emitted energy of a surface at a temperature to that of a black body at the same temperature). Given the ratio α/ε, the following equation must be satisfied for a valid infrared source test:

$$Q_t = \frac{\alpha A_p}{\varepsilon A_s} S \qquad (2)$$

where, Q_t is the required radiative power incident on the solar array during the test, A_p is the projected solar array area normal to the sun vector, A_S is the total solar array surface area, and S is the solar constant (0.9 watts/in^2 in the vicinity of the Earth).

To determine the required voltage input to the tungsten wires, several factors must be considered, such as, the spectral emittance of the wires at the given wire temperature, multiple reflections within the test chamber, and the tungsten wire variable resistivity with temperature.

Completing the hot-wire test facility was the design and manufacture of liquid-nitrogen shrouds (to simulate the coldness of deep space), of the attendant nitrogen pumping and piping equipment, of the vacuum chamber, its pumps, and of the control console. The completed system is shown in Fig. 3. This test facility has been successfully used for the testing of the Nimbus, Lunar Orbiter, and TIROS spacecraft solar cell arrays.

High-vacuum technology

The production of a high-vacuum environment is a major consideration of environmental engineering. Vacuum levels in near earth orbit are in the range of 1×10^{-7} to 1×10^{-10} torr, whereas interplanetary space levels may be as low as 10^{-15} torr (760 torr = 1 atmosphere). However, unless one is interested in investigating cold-welding and similar surface effects, laboratory vacuum levels of from 1×10^{-15} to 1×10^{-7} torr usually are sufficient to satisfy test requirements. These requirements commonly include the elimination of heat transfer by air convection and conduction and the allowance for outgassing of absorbed materials and loss of volatile lubricants.

There are a number of basic pumping mechanisms to consider when designing a vacuum system. The pressure range between one atmosphere and approximately 1×10^{-2} torr is usually handled most effectively by positive displacement mechanical roughing pumps. Examples of this type of pump are the rotary oil-sealed pump and the Roots blower. These pumps mechanically isolate the gas from the vacuum system, compress it and exhaust to the atmosphere.

Sorption pumps may also be used to evacuate from one atmosphere to approximately 1×10^{-2} torr. This type of pump employs a sponge-like material such as zeolite, which, when cooled to liquid nitrogen temperatures, has the ability to absorb large quantities of gases.

Vapor stream pumps are used for reaching vacuum levels better than those achieved by either mechanical or sorption pumps. In this application, gas molecules are forced to a higher pressure level by gaining momentum through collisions with a velocity jet. For high-vacuum applications, the jet is composed of a condensable vapor with a high molecular weight, such as oil or mercury, whereas water vapor is used when only a rough vacuum is required. Examples of the vapor stream pump are the well known diffusion pump and vapor ejector.

Chemical pumps and ion pumps are used to produce relatively clean vacuum environments at pressures of 1×10^{-8} torr and better. In the chemical pump, the gas is chemically combined with an active getter, such as barium or titanium, to form a low vapor-pressure compound. In the ion pump, the gas molecules in the system are ionized and electrically accelerated into an anode in which they are buried or chemically trapped. The sputter-ion pump is an application combining both a chemical and ion type pump.

Cryogenic pumping removes gas molecules from the system by condensation of the molecules to a low vapor pressure state on a cold surface. Cryogenic shroud temperatures below 77°K are required to pump gases such as nitrogen and oxygen.

To enable maximum gas pumping efficiency throughout the pressure spectrum, most vacuum chambers employ various combinations of the pumps.

The basic equation describing the pumpdown of a chamber is:

$$-V\frac{dp}{dt} = SP - Q_L \qquad (3)$$

where, V is the chamber volume (liters), P is the pressure (torr), t is time (seconds), S is the system pumping speed (liters/second), and Q_L is the gas load which includes chamber leaks and spacecraft and chamber outgassing (torr-liters/second).

It may be seen that the chamber pumpdown is comprised of two separate stages; the first stage is the evacuation of the initial air that fills the chamber, which, as explained above, is usually performed using mechanical roughing pumps or sorption pumps. This stage is described by the first term of the right hand side of Eq. 3 such that,

$$-V\frac{dp}{dt} = SP \qquad (4)$$

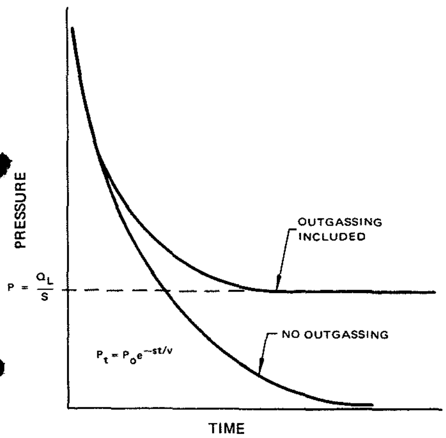

Fig. 4—Evacuation curve.

This equation may be rearranged and integrated to give:

$$P_t = P_o \exp(-St/V) \qquad (5)$$

Eq. 5 allows for computation of the pressure at any time t where P_o is the pressure at time zero. When plotted, Eq. 5 results in the familiar evacuation curve shown in Fig. 4.

In integrating Eq. 4, the assumption was made that the pumping speed, S, was a constant. This is approximately true for mechanical and sorption pumps down to a range between 5×10^{-1} and 1×10^{-2} torr depending on the particular pump. Below this range, the speeds of the mechanical pump and sorption pump fall off rapidly and other types of pumps such as diffusion or ion pumps are required.

Eqs. 4 and 5 are only applicable during the period that $SP >> Q_L$, that is, when the speed-pressure product is much greater than the leakage/outgassing term. Fig. 4 shows that eventually the slope of the evacuation curve approaches zero such that,

$$SP = Q_L \qquad (6)$$

Eq. 6 describes the second stage of chamber evacuation, that of a steady-state equilibrium condition between the pumping speed of the chamber and the gas load. Therefore, by computing the leakage and outgassing quantities and using appropriate safety factors, one may determine the system speed required to reach a desired ultimate vacuum level.

Many other considerations are necessary in the selection of a proper vacuum pump which are beyond the scope of this article. Such factors as the reduction of effective pumping speeds by interconnecting piping and valves and inability of some gases to be handled by certain types of pumps are of primary concern to the vacuum engineer and are treated in detail in Refs. 1 and 2.

Infrared/visible optics

Most of the spacecraft produced at AED contain subsystems of an optical/electronic nature. These subsystems are stimulated by incident radiant energy and respond by providing information in electrical form which is stored, transmitted, or used to control other spacecraft subsystems. Optical devices currently in use include television cameras for daytime scene imaging, infrared radiometers for mapping cloud cover at night, and horizon crossing indicators to provide position references for camera triggering or attitude control.

Whether responsive in the visible or infrared spectral regions, these devices have a common requirement of being directionally oriented with respect to a set of spacecraft reference axes. This requirement is satisfied by special test equipment which incorporate optical techniques to align the device and scene simulators to verify performance during mission simulation environmental testing.

A typical example of such an optical device is the horizon crossing sensor of the ITOS meteorological spacecraft. This sensor possesses a narrow field of view which sweeps 360 degrees by means of a rotating mirror. When the spacecraft is in earth orbit, this field of view scans across the sky-to-Earth horizon line and after traversing the Earth, scans across the Earth-to-sky horizon line. The sensor responds to the change in incident infrared energy as the field of view crosses the sky-to-Earth horizon line (4°K to 200-300°K).

Spacecraft attitude is referenced to these horizons which, at a given orbit altitude, provide a positional reference for the attitude control subsystem. The attitude control subsystem maintains the spacecraft oriented with its television cameras facing the Earth along the local vertical.

For alignment and testing purposes, dynamic stimulation of the sensor is provided by two infrared targets which fill the field of view of the sensor as the scanning mirror rotates. The two targets are sections of circular cylinders and simulate the radiance characteristics of the Earth and sky respectively. The target cylinders are individually temperature controlled and overlap to produce a well-defined, accurately positioned horizon. The target fixture is shown in Fig. 5.

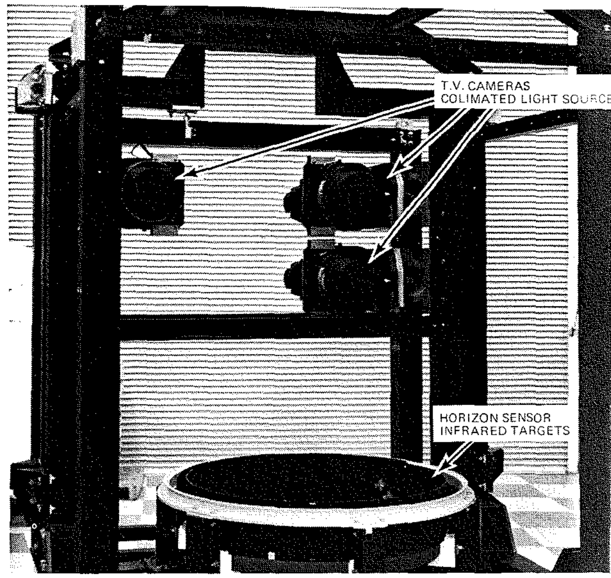

Fig. 5a—ITOS spacecraft T/V test fixture.

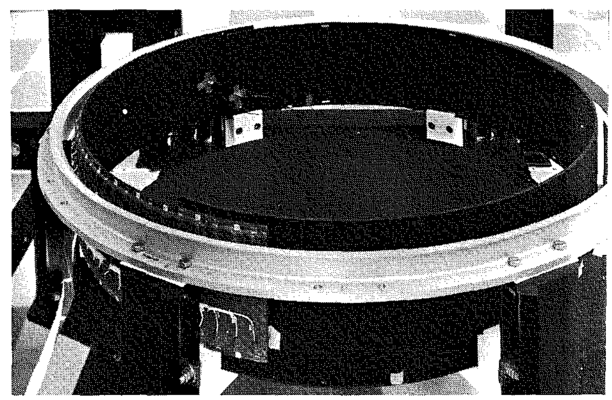
Fig. 5b—Close-up of ITOS horizon sensor targets.

Target design criteria should incorporate all of the radiometric and geometric characteristics of typical sensor operation. These characteristics include sensor aperture and field of view, mirror scan rate, sensor focusing, and parallax effects produced by finite target distances. Simulation of horizon radiance changes involves determination of the allowable temperature gradients along the target surfaces, emissivity of the target surface coatings, precise target temperature measurements, and means of providing thermal control. Target fixture design is further constrained by the geometry of the thermal-vacuum chambers in which alignment is verified in the simulated environment.

The extensive use of the assembled target fixture is illustrated by the following horizon-sensor alignment and test program sequence:

1) Optical alignment of sensor in subsystem.
2) Calibration of sensor electronics utilizing infrared targets.
3) Thermal-vacuum testing of subsystem to verify performance and alignment utilizing infrared targets.
4) Optical alignment of subsystem in spacecraft.
5) Thermal-vacuum testing of spacecraft to verify performance and alignment utilizing infrared targets.

Vibration data analysis

Vibration data analysis plays a major role in the formulation of any dynamic test program. The main objectives are to analyze vibration data recorded from the launch environment and to determine the dynamic characteristics of the spacecraft structure.

Analysis of the launch environment is necessary for the design of a simulated test environment while determination of the spacecraft dynamic characteristics from test data is used in verifying the analytical design. The following paragraphs present some of the more important aspects of each.

Launch data analysis

In most launch environments, the vibration, as viewed from an acceleration time history, seems to be all random in nature. However, as mentioned earlier, structural bending modes of the launch vehicle may introduce superimposed sinusoidal vibration. The contribution of each type of vibration is then required in order to formulate a simulated test environment.

The first data analysis technique that is employed is the evaluation of the power spectral density (PSD) function. This function, having units of g^2/Hz and usually plotted on log-log paper, measures the power (based on an electrical analogy) in the frequency domain. A typical plot would reveal at what frequencies the major part of the vibration is contained. Also, the area under the curve provides a measure of the total mean-squared acceleration. However, use of the PSD function does not provide any information on the composition of the launch data. For this evaluation, an autocorrelation function measurement is used. Physically, this establishes the influence of the signal to that of the same signal delayed in time. The evaluation of this function then determines whether or not a periodic waveform exists within a random signal.

When the launch data is analyzed in this manner, the sinusoidal motion due to the launch vehicle's bending modes are extracted since they possess a periodic waveform. If no periodic waveform exists, then the autocorrelation function diminishes to zero for large time delays. Figs. 6 and 7 show autocorrelation function plots of random noise and sine wave signals respectively.

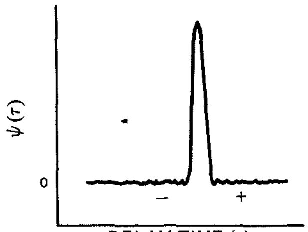

Fig. 6—Autocorrelation function for random noise.

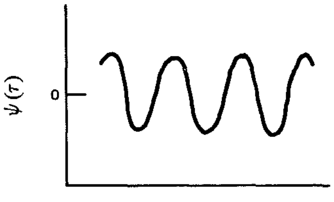

Fig. 7—Autocorrelation function for a sinewave.

With these results in mind, it is then possible to establish test criteria for a simulated environment.

Spacecraft dynamic characteristics

A parameter which is used extensively in the evaluation of a structural design is transmissibility. In this context, transmissibility is defined as the ratio of the response acceleration to the input acceleration for all frequencies of concern.

Transmissibility is obtained by measuring the response of a structure being subjected to a controlled input, usually a pure sinusoidal motion. Traditionally, the sinusoid has been used since most of the service environments up to the last decade were of this nature; also, it simplifies the analytical work when the classical methods of differential equations are used to describe the motion. The main disadvantage in using a sinusoidal input is that it requires a low level of excitation if the life of the structure is not to be shortened by fatigue. Since the transmissibility function is generally non-linear, errors in the magnitude of the transmissibility can be introduced.

The measured transmissibility function can only be meaningful if both input and response wave shapes are sinusoidal and exhibit no distortion. In an actual test, these conditions can be satisfied if the servo control signal to the vibration exciter is passed through a tracking filter to remove any distortion present. Also, the response signal must be passed through a similar filter before the ratio is obtained.

An alternate method of obtaining the same transmissibility function is the use of a random noise excitation instead of a sinusoidal excitation. This method has the advantage of allowing the test to be conducted at full level and therefore eliminates the error due to non-linearity. This advantage is due in part to the greatly reduced number of fatigue cycles since the test duration need be only on the order of thirty seconds, and also, since the total energy is distributed over a bandwidth of usually 2000 Hz instead of one Hz which is characteristic of a sinewave. A complete description of random vibration testing is given in Ref. 3.

Shock analysis and testing

During a mission, various types of shock are experienced by the spacecraft. These include engine ignition, staging, engine cut-off, pyrotechnic, and re-entry. Each type of shock presents a different signature such as a one-sided pulse for re-entry (Fig. 8) or a decaying transient vibration as in engine cut-off (Fig. 9).

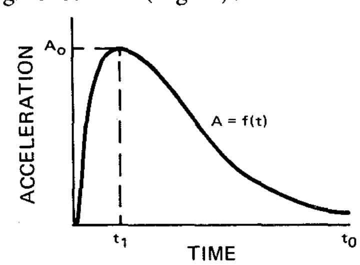

Fig. 8—Single-sided re-entry shock pulse.

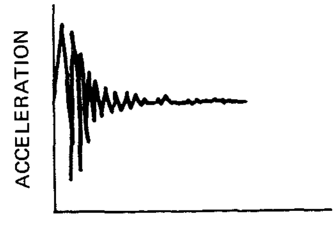

Fig. 9—Decaying transient from engine cut-off.

Since the shock environment can produce loading conditions which cause structural failures, a practical method is needed which can be used to predict the structural responses to this environment. In addition, a technique must be employed to define the shock in such a manner as to readily lend itself to testing with available equipment.

One concept which can satisfy both these requirements is the Fourier Transform[4]. The usefulness of this concept can be seen by inspection of the following equation:

$$R(\omega) = F(\omega) H(\omega) \qquad (7)$$

where, $R(\omega)$ is the response Fourier transform, $F(\omega)$ is the shock pulse Fourier transform, and $H(\omega)$ is the complex transmissibility function.

As seen from Eq. 7, the Fourier transform of the shock input and the complex transmissibility must be evaluated. Data analysis equipment for determining the transform can be obtained from a number of manufacturers.

The Fourier transform can also serve as the definition of the shock pulse much the same way as the standard shock spectrum. However, it possesses one additional advantage over the shock spectrum in that the phase relationships between input and response are retained. Shock testing using an electrodynamic machine is then accomplished by obtaining the energy density function (in decibels) of the transform for programming of a standard multi-channel random system.[5] It should be noted that this approach subjects the spacecraft to a frequency spectrum of the shock input instead of the standard waveshape excitation. The frequency spectrum approach is extremely useful if the actual shock pulse is not defined by a single waveshape as shown in Fig. 9. An application of the Fourier transform approach is presented in the following example. Fig. 10 presents a typical structure transmissibility plot.

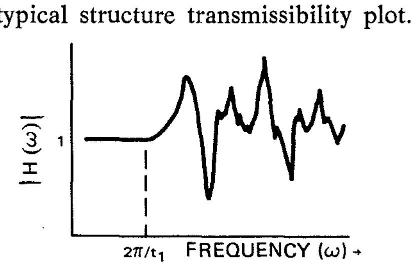

Fig. 10—Typical transmissibility plot.

This structure is subjected to the aperiodic pulse as shown in Fig. 8. The transform of this pulse is obtained by evaluating the following equation:

$$F(\omega) = \int_0^{t_0} f(t) \exp(-j\omega t)\, dt \qquad (8)$$

Following integration, this equation, when plotted, will yield the curve shown in Fig. 11.

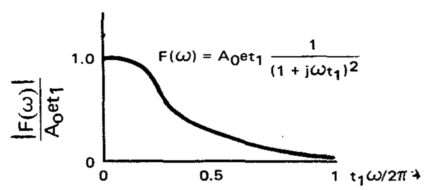

Fig. 11—Fourier transform of the re-entry shock pulse.

If the above result along with the complex transmissibility function is substituted into Eq. 7, the response transform of the structure is obtained. Since the results are in the frequency domain, the inverse transform must be taken if an acceleration time history presentation is desired. The inverse transform is defined by the following equation:

$$x(t) = \frac{1}{2\pi} \int_0^{\omega_0} R(\omega) \exp(j\omega t)\, d\omega \qquad (9)$$

Inspection of Fig. 10 reveals the rigid-body characteristic of the structure (a one-to-one ratio of input to output) below $\omega = 2\pi/t_1$. Beyond this point, the structural response is dynamic in nature. A study of the expressions shown in Figs. 10 and 11 reveal that the transmissibility function does not influence the response transform beyond $\omega = 2\pi/t_1$ since the input transform approaches zero. Also, since the transmissibility function exhibits a value of unity below $\omega = 2\pi/t_1$, the response and input transforms will be equal in magnitude. Physically, this means the shock pulse will be transmitted through the structure without producing any dynamic effects and, as such, a static acceleration test level equal to the peak shock pulse amplitude would provide a good simulation.

Concluding remarks

Today's space environmental engineering efforts involve a wide spectrum of disciplinary challenges. Moreover, as aerospace missions grow more ambitious and sophisticated, so, too, must the supporting function of the environmental testing program. As a result, environmental engineering evolves as a dynamic and expanding technology. There are many other engineering disciplines in which the environmental engineer must, at times, be conversant, which are not discussed in this article. A partial listing of these disciplines includes:

Fluid mechanics, required for the design of heat exchange test equipment;
Vibration fixture design analysis, used to predict dynamic performance of vibration fixtures;
Structural analysis, required for the design of all spacecraft handling and support equipment; and
Cryogenics, the science of ultra-low temperatures.

For further investigation in the various disciplines of environmental engineering, the reader is directed to the Bibliography at the end of the article.

Acknowledgment

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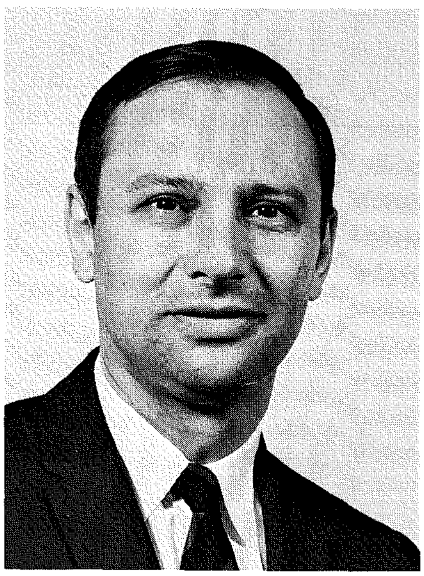
Mechanical engineering in electronic equipment design

Dr. M. Weiss | I. D. Kruger

The continued growth of the electronics industry has created new and exciting opportunities for the mechanical engineer. As the most versatile member of the engineering team, he participates in nearly all phases of the design and production effort. His tasks generally consist of 1) assuring that the electronic black box concept can be incorporated into useful and reliable hardware, 2) producing the designs and analyses of all mechanical components, and 3) producing the final product at a competitive price. To meet these responsibilities, the mechanical engineer must combine a sound practical approach with comprehensive theoretical knowledge and modern analytical techniques, such as numerical methods and computer solutions.

Examples of the wide ranging activities of the mechanical engineer in the electronics industry may be found in the design of large precision radars and of light-weight space hardware, in the computer analysis of complex thermal systems and of large redundant structures, and in the interfacing of mechanical and electrical design activities. In these, as in many other instances, the mechanical engineer remains indispensable in translating new ideas into desirable and improved products.



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graduated from the University of Vienna, Austria, with the MS in Mechanical Engineering and obtained the PhD from the same institution in 1950. He has taken additional post-graduate courses at the University of Pennsylvania. Dr. Weiss joined RCA as a mechanical design engineer in 1959. In his present capacity, he is involved in the analysis and design of mechanical aspects of communication and radar antenna systems. He has specialized in thermodynamics and was responsible for the thermal design and mission analysis of the LM rendezvous radar.

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received the BSME degree from Newark College of Engineering in 1940, and the MSME degree from Drexel Institute in 1959, and has taken additional post graduate work in electronic subjects. Mr. Kruger has had 29 years of engineering and engineering leadership experience at RCA, joining as a student engineer in 1940 and working in design, development, and manufacturing liaison of antenna structures, pedestals, mechanical aspect of servos and equipment integration. He had key responsibilities in design of such equipments as the AN/UPS-1, AN/FPS-16, MIPIR, and the BMEWS and TRADEX Antenna Pedestals. He now is a senior engineer in the Mechanical Design Skill Center at M&SR. He is a licensed professional engineer in New Jersey, a member of AIAA and ASME, Tau Beta Pi, and is an instructor in Machine Design at Drexel Institute.

The role of the mechanical engineer in electronics has expanded into exciting new areas, as products have grown steadily more complex and sophisticated. The ME's contributions were discussed several years ago by Greene and Harrison[1] and by Jacobs[2]. Then, as now, electronic and systems engineers lay the groundwork for the design and development of new products. However, the former image of the electronic engineer, who would design the black boxes and convert them to "production release" hardware, taking care of the mechanical details with his left hand, has completely disappeared. Instead, the ME's responsibility of establishing the physical concept and creating useful and reliable hardware has been firmly established.

Participation by the Mechanical Engineer is necessary because of the increasing need to provide only the best in new, competitive product design. As Jacobs[2] pointed out:

> "In the new field of electronics, frequent changes are to be expected. A new product could hardly compete in today's market if it did not include many ideas that are basically new. Not only must new arrangements be provided, but frequently new concepts are necessary, new materials must be developed, and new techniques discovered. It is in facing these hitherto unsolved problems that the mechanical engineer assumes the

initiative in furthering development work."

This call to creativeness has changed the outlook of young ME's towards the electronics industry. In the past, many of them felt that knowledge of mechanical subjects they had assimilated in college, or accumulated in their early years of engineering practice, could never be sufficiently applied in the electronics industry; as a result, many people with excellent potential refrained from entering the field. The increasing complexity of the industry has now led to the demand that the ME 1) apply all phases of his knowledge, 2) acquire an education in areas he would not normally cover, and 3) reinforce his grasp on theory.

To succeed in the electronics industry, the ME must have a firm grasp of the basic subjects such as physics, statics, dynamics, stress analysis and vibrations. His work may lead him into structural design where nuclear blast or ship, airborne, or missile launch vibrations are encountered; into fluid dynamics and hydraulics for design of air or hydrostatic bearings or servos; into dynamic analysis of aperture antennas and pedestals; into thermal analysis where space environment exists; into heat transfer or the related field of cryogenics for cooling of densely populated generating sources or of large transmitters; or into design; and process application where new materials, refractories, light high-modulus metals or plastics, and various forms of epoxies are considered.

The need for compatibility, tradeoffs, and optimization of a system prior to its entering the hardware stage has increased the importance of mathematical analysis. This not only requires the ME to have a strong mathematical background but also to be able to use modern tools. The "rule of thumb" has given way to the venerable slide rule, and that instrument has been augmented by electronic programmable desk calculators and computers. As a result, the ME has acquired the capability of accurately predicting equipment performance, provided he has mastered the process of mathematical modeling, the application of numerical techniques, and, where necessary, the use of Fortran in writing his own programs.

Table I—Mechanical engineering contributions to specific projects.

	Phased Arrays	*Mechanically Steerable Antennas*	*Packaging*	*Miniaturization*	*Transmitter*
Configuration studies	X	X	X	X	X
Structural design	X	X	X		X
Shock and vibration	X	X	X	X	X
Thermal design	X	X	X	X	X
Bearing design		X			
Materials selection	X	X	X	X	X
Stress analysis	X	X	X		X
Mechanical systems	X	X	X	X	X
Electrical/mechanical interface	X	X	X	X	X
Computer usage	X	X	X		
Cost analysis	X	X	X	X	X
Design review	X	X	X		X

In addition, the ME must attain some degree of electronic background, depending on his assignment, so as to be more effective in interrelating his work with that of the electronic engineer. This takes the form of some formal University courses, company sponsored courses, or his own personal technical reading. For example, a mechanical engineer who is working on design of a microwave system is far more effective if he has some understanding of transmission modes in waveguides, electrical vs. mechanical length of waveguides, impedance matching, phase shifters, monopulse feed theory, and similar topics. This is true since there are always alternate approaches to the mechanical construction of microwave devices and the ME is in a better position to contribute valuable suggestions based on mechanical needs with some degree of knowledge as to effect of his suggestions on the desired electrical properties.

The success of the electronic design is thus intimately dependent upon the degree to which the various engineering skills can effectively interrelate their work. The mechanical engineer becomes the key individual who ultimately translates the electrical need into a working cost-effective device. The ME must therefore be highly versatile in the present day electronic industry, not only having a deep physical and mathematical ability in his own field, but an understanding of the basic electronic requirements and sufficient technical background in the various related fields, to efficiently carry out his function.

As the ME progresses in scope and stature, he can also contribute highly to certain aspects of the systems engineering effort—formulating concepts for new systems and carrying out related studies. This is particularly true where alignment of many sensors or weapons is required, and the ME's working knowledge of the allowed error budget for each subsystem and its contribution to total error, as well as his understanding of optical instrumentation required to carry out system alignment, can be applied.

Specific examples

The remainder of this article highlights certain mechanical engineers and the techniques they have applied to a number of programs at the Missile and Surface Radar Division. The discussion is about the engineer's work and in quite broad terms; other technical papers or reports prepared by the engineers would have to be reviewed to gain more depth in the specific techniques. Obviously not all of the efforts can be covered, and the small portion reported herein represents a part of the total work, with no intention of slighting the fine efforts accomplished or underway in other areas.

However, from these examples and the summary in Table I, it can be seen that the mechanical engineer's contributions range across a very broad spectrum, indeed—his areas of competence affecting all aspects of the hardware.

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Phased arrays

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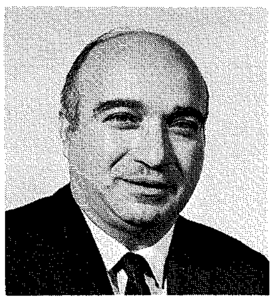


J. Ninfa

Although the phased array concept dates back some 25 years, it is only lately that the development of high-power solid-state devices has made this type of radar practical. Paradoxically, although the electronic steering of the radiated energy has eliminated such items as drive motors, bearings, slip rings and rotary joints, the involvement of the mechanical engineer is deeper than ever.

In essence, the ME is faced with densely packed feeds forming the face of the array, backed up by even more densely packed phase shifters, power dividers and amplifiers, and last, but not least, a large number of power and control cables.

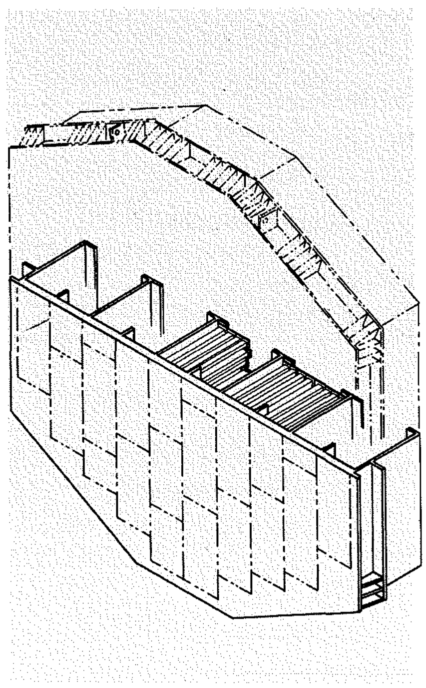
These components must be designed and grouped in a logical manner that not only will produce the required electrical performance, but will be easy to manufacture and assemble, and will permit access for servicing and replacement. The active electronic elements must be integrated with the supporting structure; in addition, space must be provided for cooling, since the compactness of the design entails high power densities.

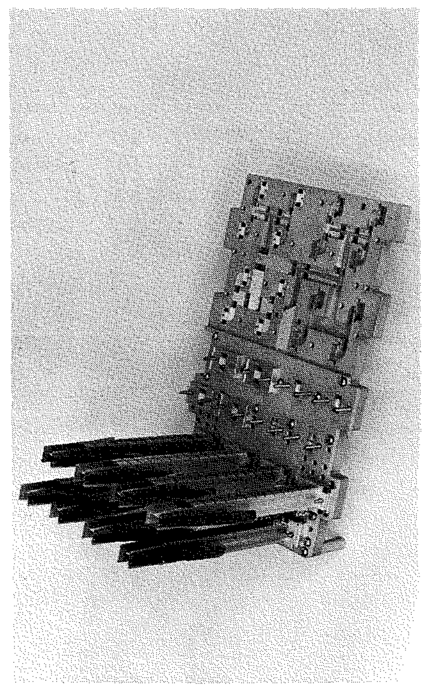
The initial approach to this design problem is necessarily of a systems nature. Given initial overall data as to physical size, desired configuration, power dissipation, operating temperature ranges and environmental conditions, he must make decisions that determine the main hardware concepts:

Should the array be built as a self-supporting piece of hardware?
Does its size permit construction in one piece or should it be made up of modules?
What kind of structure is required to sustain the array under specified loading conditions and to assure adequate relative alignment of radiating elements?
What cooling medium should be employed and how can the array be boresighted?

These, and a host of other questions, must be answered in principle before detail design to establish feasibility, configuration, and dimensions can begin.

For military applications, the operating environment may include shock and overpressure conditions resulting from conventional and nuclear blasts. In this case, the load-bearing structure of the array may become highly stressed, justifying a detailed analysis that not only accounts for static stress levels, but also for dynamic stresses and deflections. Weight and structural volume must both be minimized. The detailed computations are performed on the computer, modeling the array as a multi-mass system, where the interconnecting springs represent the tensile, bending, and shear properties of the load-carrying sections. Material selection is an important aspect of the overall design. It not only determines applicable manufacturing methods and costs, a point of obvious interest where thousands of elements are concerned, but also sets the temperature limits within which proper operation of the array is possible. Such temperature limits turn out to be quite narrow when compared with the range of environmental temperatures, requiring a detailed thermal analysis and provision for the removal of internally generated and absorbed heat.





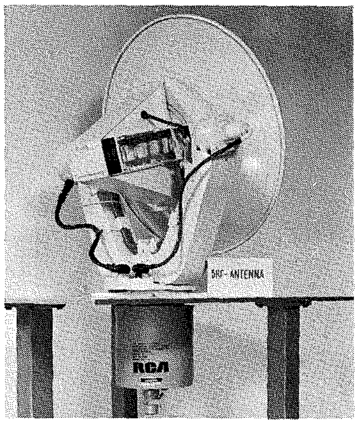
Lightweight antenna pedestals

The LM rendezvous radar antenna assembly marked a high point in the design of precision tracking radar antennas employing extremely lightweight fabricated structures. The experience gained on this program was carried over into the design and development of the SHF antenna series, which are intended for communication between large aircraft and orbiting satellites. These antennas were designed as elevation-over-azimuth pedestals capable of hemispherical coverage. They employ direct drive DC motors and on-axis gyro stabilization.

W. Harmening

The challenge to the ME consisted of applying elements of the LM radar to the design of the new antenna and coming up with an economical, simple, and reliable configuration that could be put into production in the shortest possible time.

Particular attention had to be paid to the vibration environment in which the antenna would have to operate. Analysis and test data of aircraft vibrational characteristics were reviewed to establish a satisfactory mounting location. The antenna structure was laid out to produce a maximum amount of damping; it was then modeled as a multi-mass system and subjected to computer analysis to assure that the antenna structure was not resonant with aircraft imputs. Extensive vibration testing on the prototype unit confirmed the result of the calculations and the adequacy of the antenna structure. Computer analysis and thermal shock testing supplemented the design effort, assuring that the antenna would operate under worst case ground and altitude conditions.



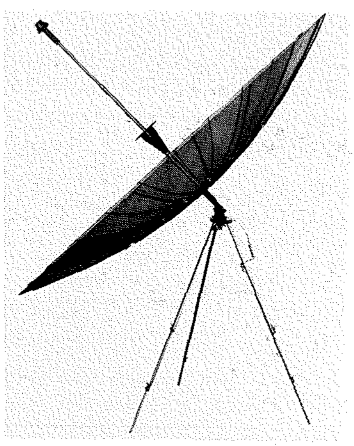
D. Sackett

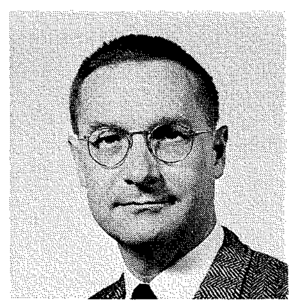
Lightweight space erectable antennas

Space continues to challenge the ME for improved hardware to meet new mission requirements—the new design being of an evolutionary nature where possible.

A. Kline

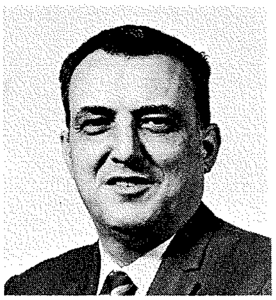
The current design of the Project Viking Mars lander communications antenna is a case in point. Feed and reflector were taken from the LM antenna program used for transmissions from the moon to earth. The gimbal system represents a new design that, after landing and deployment, must be capable of pointing the antenna toward earth and maintaining this line of sight for up to three months with minimum power consumption. The ME is finding ample scope for his talents in the design of a lightweight two-axis mount that has to operate through wide temperature extremes in a storm-driven dust environment. It is a tribute to past mechanical engineering achievements in space that the ability of the hardware to stand up to sterilization and month-long inactivity during the flight to Mars is almost taken for granted. Success in this venture is being sought by painstaking attention to detail, comprehensive analysis, extensive testing, and, before all, by drawing on the fund of experience accumulated on previous space projects.





T. Clarke

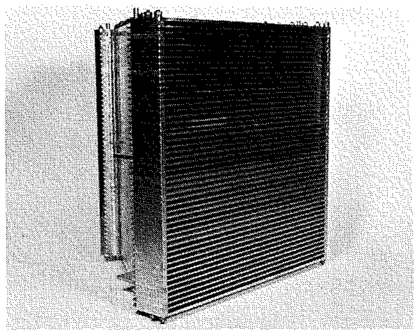
Miniaturization

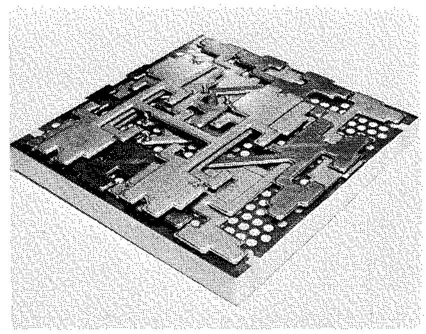


J. Boyle

A challenging, hardware oriented area has opened up for the ME in the field of miniaturization of various microwave components. Here the ME must work closely with his electrical counterpart to eliminate all possible inactive structure. Thus stripline replaces waveguide, a groundplane is not a solid piece of sheet metal, electroformed conductors my be supported in a foam matrix, the result being compact, extremely lightweight circuits with a large number of potential applications.

To produce such assemblies the ME must pioneer new production techniques and become familiar with chemical processes as well. While he has the choice of all the newly developed exotic manufacturing tools, the criteria of feasibility, simplicity, low cost and reliability must still be applied. Where necessary, the layout of production fixtures and processes must be specified in detail, since their importance for the viability of the final product may overshadow the choice of a possible technique.



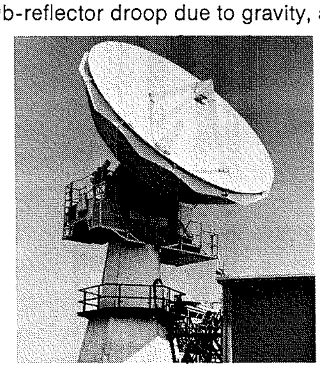


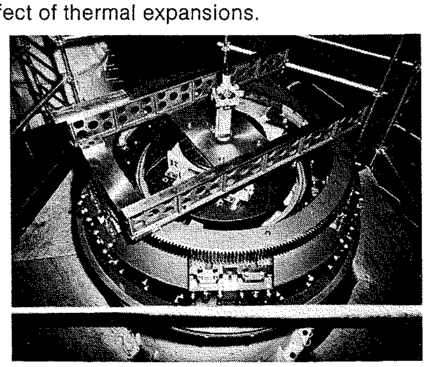
Precision antenna pedestal design

G. Robinson

The application of precision antenna pedestal mechanical engineering continues as an important aspect of the M&SR programs directed mainly to instrumentation radars. The design activity has taken the form of in-house design of equipment as well as the concept and specification efforts where such equipments are produced from contractors specializing in antenna pedestal fabrication.

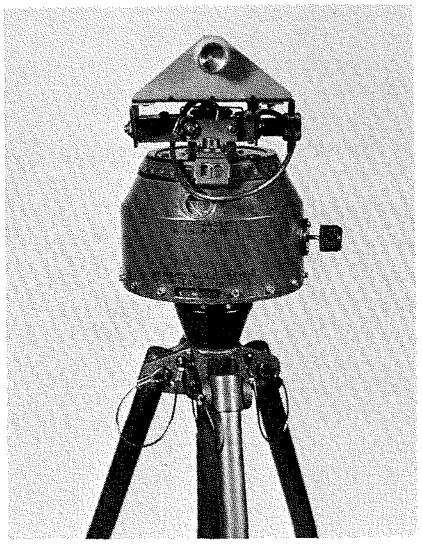
An example of pioneering work in this area was the design of a hydrostatic bearing for the MIPIR radar,[3] which was conceived, designed, and tested to solve stiction problems inherent in bearings required to move intermittently or at very low rotation rates. The initial design criteria (derived from theory) were augmented by analog simulation and laboratory testing so that considerable confidence was built up prior to implementation of the first production unit. Other areas of this antenna assembly were investigated in detail to meet the accuracy requirements (0.1 mils) for this radar. These investigations included a search for an adequate and economical foundation design, the calculation of sub-reflector droop due to gravity, and the effect of thermal expansions.

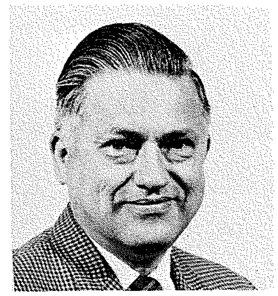




Mechanism design

Positioning and scanning requirements of antennas often produce a need for special actuators or mechanisms. The design of such equipment may be constrained by space and power limitations, and, due to its effect on systems performance, may be required to perform unattended, for long periods of time, and with extreme reliability. The figure shows a small scanner mechanism that posed a number of unusual design problems. It had to be a completely self contained unit, adjustable to variable scan angles, and providing for angle read out and manual over-ride capability. The unit had to operate on minimal power of approximately 1/10 watt, including dial illumination which was provided by miniature light bulbs of 0.094-inch diameter. A scan angle variable by single knob adjustment from 10° to 270°, is traversed at a rate of 5°/second. The mechanism had to be designed to allow immersion in water and had to stand up to MIL spec shock and vibration requirements. A low weight of approximately 3 pounds was achieved using aluminum alloys as the main structural materials, by avoiding unnecessary structural joints, and by designing for direct load paths. The mechanism itself was laid out as a planetary gear assembly, permitting the introduction of required direction change and override functions.





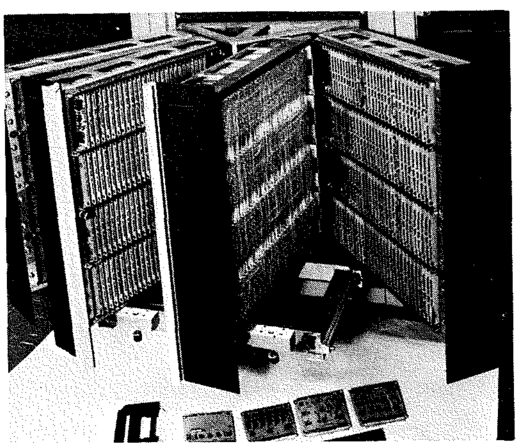
W. Carter

R. Schirmer

Packaging

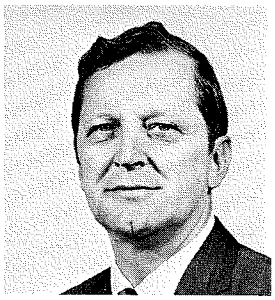
The ME specializing in equipment packaging has to contend with constantly changing building blocks and a continuing need to contain more power-dissipating components in smaller volumes. He has gone through the vacuum-tube/transistor evolution, has seen the advent of integrated circuits, and has witnessed the gradual replacement of mechanical-control devices by solid-state circuits. The individual chassis of former days have largely given way to printed circuit boards. All this has resulted in a drastic shrinkage of the space required by radar circuitry, which now is housed in assembly line stacks inside a few control cabinets and consoles.

To provide a well balanced design, where all components operate within their design temperature levels, where convenient access can be provided, and where the hardware can be produced at reasonable cost, the packaging ME has to investigate many suitable configurations and make a choice that meets the major requirements of the job. Cooling considerations are critical for the success of the design, as is the need to make the equipment capable of surviving in often severe shock and vibration environments. Working closely with electrical engineers, the ME addresses himself to component locations, connecting harnesses, shielding requirements and electrical parameters, so that adequate electrical performance of the packaged circuits is guaranteed.



C. Rosenblum

General analysis



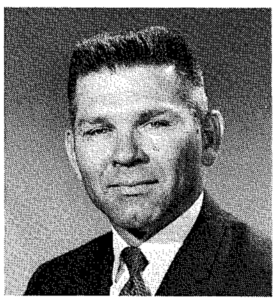
R. Pschunder

The design of a suspension system for a large dipole-type log-periodic antenna is a good example of an off-the-beaten-path application of mechanical engineering knowledge. Here the ME had to interface with structural[4] and electrical engineers to provide the analysis for a practical approach combining cost effectiveness, rigidity, and compatibility with high electric fields.

The basis suspension system element is the catenary whose general design equation was rather unwieldy; this equation was subjected to a series of transformations to allow it to be expressed in power-series form suitable for computer analysis. The suspension system (part of which is shown in the Figure) consists of a large number of catenaries which are subject to concentrated loads, wind, ice and their own weight. These catenaries form a non-linear spring system, whose stresses and deflections depend on the interaction between different parts of the system. A rational design approach, allowing reasonable safety factors and moderate cost, depended on the generation of a number of computer programs. These were designed to not only calculate the loaded configuration of the system but also to provide the unstressed length required for cutting individual strings to their correct length and to perform the required bookkeeping functions for keeping track of all the parts.

The behavior of the catenary system is intimately tied to the design of the supporting towers, which had to be modeled into the overall program. Tower design let to the investigation and analysis of buckling stresses. Additional work was required to verify the erection procedure making sure that erection stresses would not damage the system.

High power transmitter design

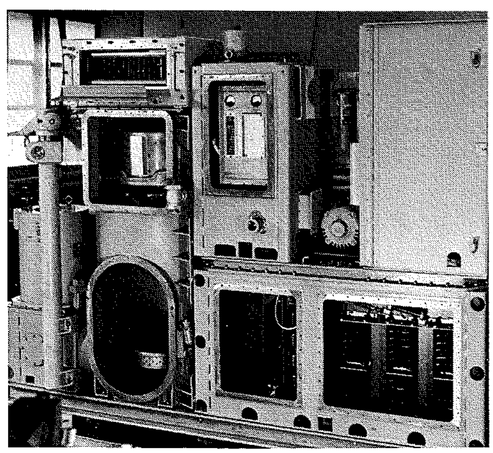


P. Scully

The design of transmitters for radar use, where peak power in the order of 5MW and a broad range of frequencies are considered, provides demanding and interesting work for mechanical engineers. The principal disciplines are thermal analysis and heat exchanger design; equipment enclosures and packaging considering the high voltage arcover effects; and shock and vibration analysis, particularly for shipboard applications.

The ever-present economic and space utilization problem demands that the ME determine means for reducing the size of components and increase packaging density, which in turn increases the severity of the high voltage arcing effects. Resorting to liquid dielectric immersion for cooling and arc supression creates problems in handling and sealing of large tank structures and introduces problems of access and maintenance.

The hard tube modulator for a shipboard radar program is a typical example illustrating a combination of employed techniques. The Figure highlights the compact design of the enclosures, the problems encountered in liquid sealing and RF shielding, and the general ruggedness of design. Note the configuration of the ceramic insulators (left); this compression arrangement overcame some particularly difficult mounting problems with the modulator tube.



Thermal design

Design trends in modern electronics tend toward higher power, greater packaging density, and better performance predictions. Coupled with new design environments, such as space, these trends have resulted in the emergence of thermally oriented ME's as major contributors to the design of complex hardware.

A typical example of work performed in this specialty is the LM rendezvous radar. Thermal design decisions contributed to establishing the overall configuration and provided guidelines for finishes, insulation, interface treatment, and critical sections. Verification of antenna thermal capability also dictated thermal vacuum test requirements and instrumentation. Compliance with specified mission capability was assured by an extensive analytical effort that produced a test-correlated mathematical model of the rendezvous radar antenna, as well as the system of computer programs that permits rapid mission analysis.

The mathematical model of the antenna was established as a thermal network of about 170 nodes, approximately one third of which represent antenna surfaces. A general thermal analysis program was expanded to meet the requirements of the radar.

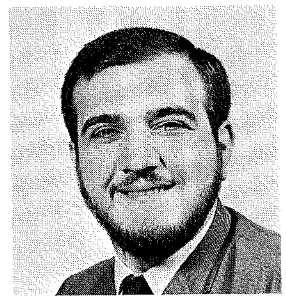
Among other features, the program accounts for the operation of thermostats controlling antenna heaters; it is able to program component power dissipation as a function of temperature and it provides for automatic plotting of the temperature history of selected modes.

Calculation of heat-input tables for the thermal analysis is performed by machine computation using a number of interlocking programs. The proper evaluation of the various heat inputs required theoretical involvement in such areas as gray surface radiative heat exchange; absorption of solar flux by interacting, diffusely reflecting surfaces; and the properties of thermal control finishes.

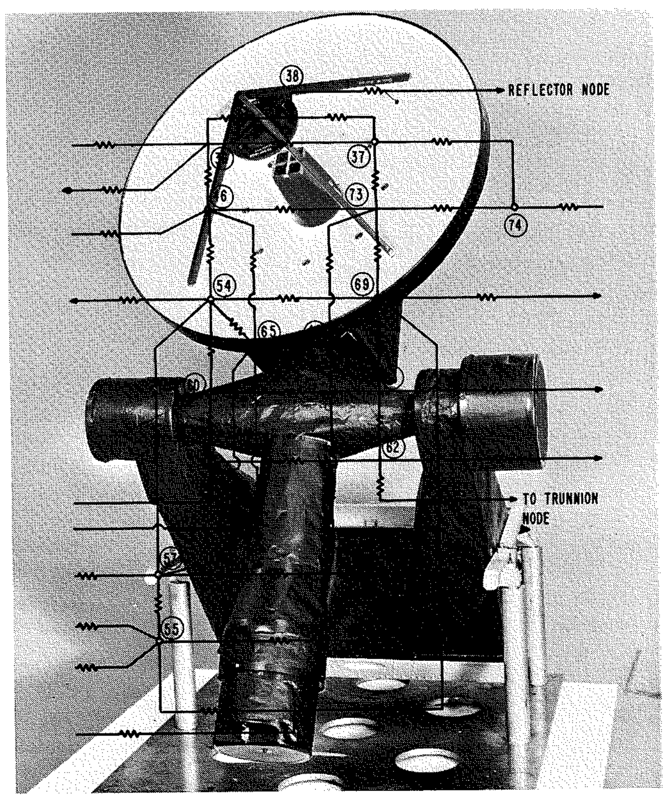
Thermal finish measurement became an important part of acceptance testing. Special procedures had to be worked out to achieve precision measurements with portable equipment.

Mission data provided an important test of the accuracy of the performed analysis. Experience so far has shown that calculated antenna temperatures generally fall within 10° F of telemetered data.

F. Gorman



S. Mucciacciaro



Interdisciplines of integrated-circuit research

Dr. W. A. Bösenberg

The annual cost of industry-wide research and development of integrated circuits is in excess of $100 million. Such an investment poses complex management problems. For the successful team, the financial rewards and, even more so, the future potential rewards in a rapidly growing market are great. In this article only one aspect, i.e., the value of a good interdisciplinary technical team, is discussed. Other factors such as low manufacturing costs and effective marketing are also needed for success.

VARIOUS FUNCTIONS in integrated-circuit research are listed in Fig. 1 along with the suggested appropriate backgrounds for people performing those functions. It is not implied that persons with different backgrounds are incapable of engaging in a particular function and of being successful in it. However, the suggested background training makes for a natural fit of knowledge and function. Furthermore, since the whole area of integrated-circuit research and development is highly complex, it is very unlikely that any single individual could handle effectively all aspects of a project. The endeavor calls for teamwork.

System design

Most obvious is the role of system design in, for example, complex digital equipment. In this area, system designers think of logic gates as building blocks, and concentrate on the use of them to achieve a system function, rather than on the particulars of the logic gate design or of how the active element functions. Electrical engineers almost exclusively handle the system design function. With large-scale integration of semiconductor devices, the system designer will have to learn more about the device design and the present gulf between him and the circuit/device designer will narrow.[1]

Circuit design

The function of integrated-circuit designer supersedes the former function of applications engineer in a laboratory where circuits were built with transistors, diodes, resistors, or other discrete elements. Since integrated circuits depend highly on technology, the circuit designer has to be very close to device design. The majority of circuit designers are electrical engineers by training, and who have learned to master device technology. Good understanding of solid-state physics is important when a new class of circuits is being developed. Somewhat less is required when existing rules are followed for new circuit layouts.

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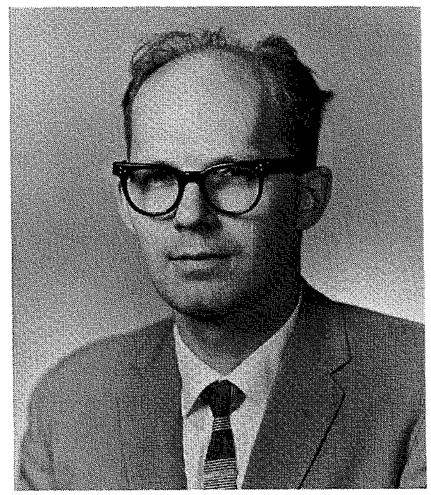
Device physics and device design

Optimum implementation of a given circuit function may require a wide spectrum of solid-state devices. Most commonly used are bipolar integrated circuits with N-P-N transistors, resistors, diodes and capacitors; see Fig. 2 for a typical fabrication sequence for bipolar integrated circuits. More recently P-type, N-type, and complementary MOS transistors have been widely used for MOS integrated circuits. In Fig. 3, the basic fabrication steps are shown for complementary MOS integrated circuits. A good understanding of the device physics and the device design parameters is needed for achieving the optimum high-frequency response, a low storage time, etc. The list of basic devices is getting longer every year. Schottky barrier diodes and MOS bistable storage transistors with silicon nitride dielectric have recently been added. Other devices such as tunnel diodes and Gunn-effect devices are not compatible with planar silicon technology and can be used only in hybrid integrated circuits. Microwave generation by overlay transistors or avalanche diodes evolves large amounts of localized heat. This condition coupled with transmission line circuitry again necessitates a hybrid integrated circuit technology.

It is quite clear that this whole area is in the domain of the solid-state device physicist. Since the electrical engineering schools offer more and more courses in this area, the younger EE's very often are also quite successful in the area of device physics and device design.



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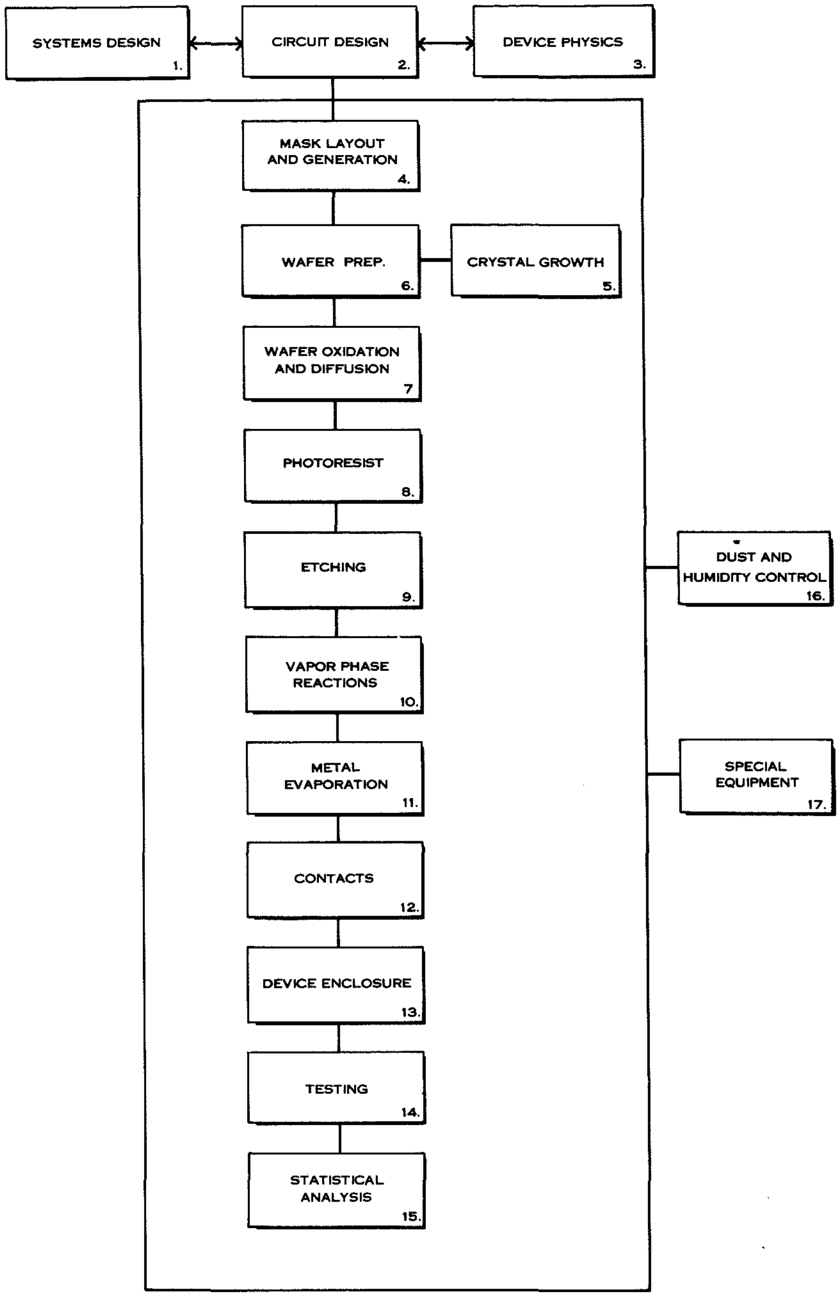
RCA Laboratories
Princeton, N.J.
attended the Technical University, Stuttgart, Germany and received a Dr. rer. nat (PhD) degree in 1955. He has worked in the field of solid-state physics and technology since 1949. From 1952 to 1957. Dr. Bösenberg worked for Standard Elektrik (SAF) at Nuremberg, Germany. In 1957, he joined the RCA Semiconductor and Materials Division at Somerville, New Jersey. He became an Engineering Leader in 1958, an Engineering Manager in Advanced Development in 1960. In 1963 Dr. Bösenberg transferred to the RCA Laboratories as a member of the Computer Research Laboratory. He worked on integrated MOS circuits for driving, sensing and decoding of large capacity monolithic ferrite memories. He also conducted a study of the effects of neutron irradiation on the electrical properties of MOS transistors. In 1966, he was named to his present position, and was instrumental in setting up a centralized integrated circuits facility at Princeton. At present he supervises a number of advanced programs for MOS and bipolar integrated circuits. Dr. Bösenberg has published a number of papers on solid-state devices and solid-state technology.



1. Systems design
   Electrical Engineer
2. Circuit design
   Electrical Engineer
3. Device physics and device design
   Physicist/Solid State Electrical Engineer
4. Precision mask layout & generation
   Optical Expert, Chemist, Computer Specialist, Mechanical Engineer
5. Crystal growth
   Crystallographer, Physicist
6. Wafer preparation
   Ceramist, Chemist
7. Wafer exidation, diffusion
   Chemist/Physicist
8. Photoresist
   Chemist, Optical Expert
9. Etching
   Chemist
10. Vapor phase reactions
    Chemist, Physicist
11. Metal evaporation and sputtering
    Physicist
12. Contacts
    Metallurgist, Mechanical Engineer
13. Device enclosure
    Metallurgist, Ceramist, Polymer Chemist, Mechanical Engineer
14. Testing
    Electrical Engineer, Computer Specialist
15. Statistical yield analysis
    Statistician
16. Dust and humidity control
    Environment Control Engineer
17. Special equipment
    Mechanical Engineer, Chemical Engineer

Fig. 1—Major technological steps in integrated-circuit fabrication, along with a breakdown of the various disciplines involved in each step.

Table I—Various phosphorus and boron diffusion sources.

Source	*Chemical symbol*	*State at room temp.*	*Source temperature (°C)*
Phosphorus pentoxide	P_2O_5	solid	200 to 300
Mono-H-ammonia ortho-phosphate	$(NH_4)_2\ HPO_4$	solid	450 to 1200
Phosphorus oxychloride	$POCl_3$	liquid	2 to 40
Phosphorus tribromide	PBr_3	liquid	170
Phosphine	PH_3	gas	25
Boric acid	B_2O_3	solid	600 to 1200
Boron trichloride	BCl_3	gas	25
Boron tribromide	BBr_3	liquid	10 to 30
Methyl borate	$B(OCH_3)_3$	liquid	10 to 30
Boron nitride	BN	solid	900 to 1000
Diborane	B_2H_6	gas	25

Precision mask layout and generation

Once the circuit to be integrated has been breadboarded with parasitic components, a mask layout must be done. This is still mostly a trial-and-error proposition to obtain minimum lead lengths and minimum number of crossovers in a minimum silicon area design. Fig. 4 shows an example how complex integrated circuits have become these days. In the last few years, a lot of work has been done on design automation for mask layout and mask generation. In the near future the cutting of a Rubylith master and its reduction will be eliminated by a photo-composed master recticle.

The combined efforts of a circuit (electrical) engineer, device (electrical) engineer, optical expert, computer specialist, mechanical equipment designer and specialist in wet photo-processing are required to fulfill the function of precision mask layout and generation.

Crystal growth

The growth techniques that were de-

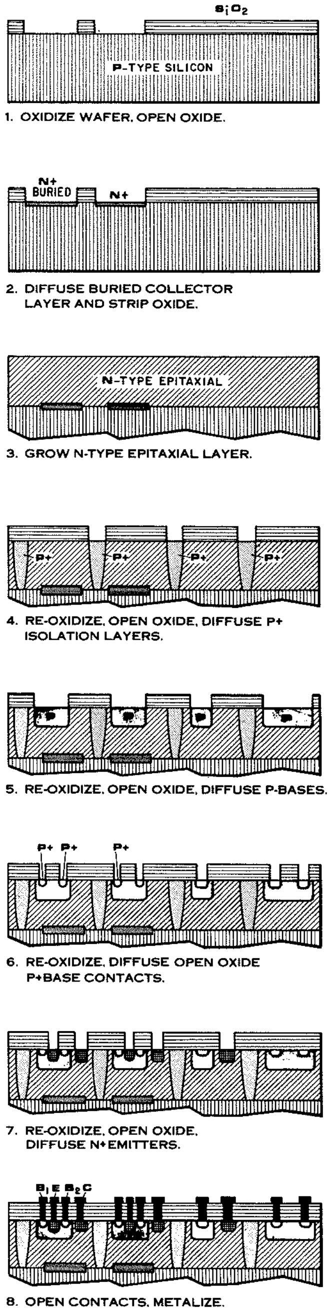


Fig. 2—Major processing steps for bipolar integrated circuits.

veloped for germanium and silicon crystals have revolutionized crystal growing for other materials. Single crystals have oriented lattices. Silicon wafers have to be cut according to one or two preferred orientations (as determined by X-ray diffraction techniques). The single crystal wafers have to also be doped electrically to a specified resistivity with small resistivity fluctuations across a slice. The dislocation count has to be low. The lifetime in the finished material often must be controlled from extremely short for one type to extremely long for other types.

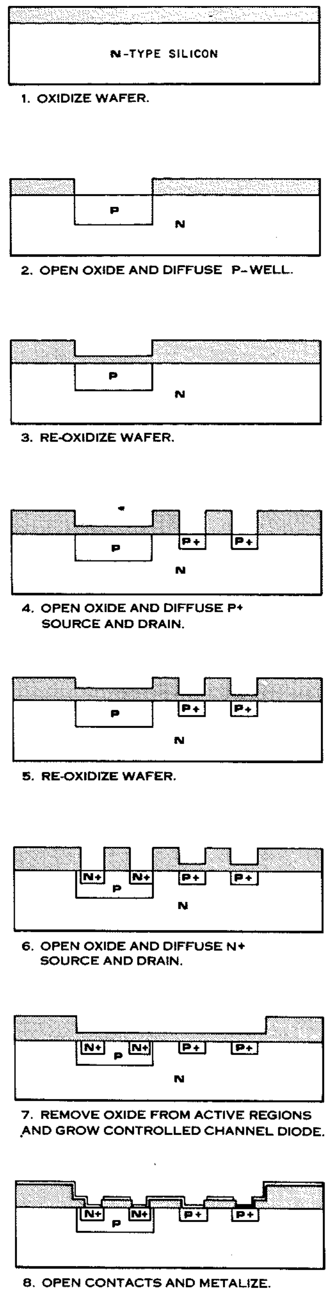


Fig. 3—Major processing steps for complementary MOS bipolar integrated circuits.

A crystallographer, most often a physicist by basic training, is the best man for the job. For making floating zone material by vapor phase reaction a chemist will do very well.

Wafer preparation

A silicon single crystal is cut into slices by a diamond saw. Afterwards both sides of the slice are lapped and polished. These techniques are very similar to ceramic metallurgical technology. After the polishing, the slices have to be cleaned chemically.

Therefore, either a ceramic metallurgist or a chemist will do well in this area.

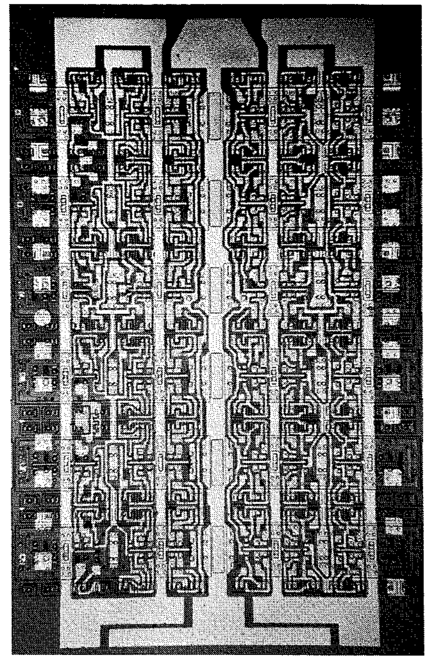


Fig. 4—72-gate emitter-coupled logic (ECL) arithmetic register array fabricated for the LIMAC computer. A string of three such units (selected by pre-testing) has been mounted in a single package. (Photograph courtesy of A. G. F. Dingwall, RCA Somerville)

Wafer oxidation and diffusion

The planar silicon technology relies on the masking properties of silicon dioxide against vapors of elements of group III (acceptors) and group V (donors) of the periodic table. The silicon surface can very accurately be oxidized in steam or wet ambient (fast growth) or in dry oxygen (slow growth) at temperatures between 1000°C and 1200°C. Clean oxides are needed for drift-free transfer characteristics in N-type MOS transistors and for large current gains at low emitter currents in bipolar transistors. The thickness of the oxide layer has to be maintained within ±100Å for the gate insulation of MOS transistors.

The diffusion technology has been worked out to a point where submicron base widths in bipolar transistors can be achieved. The complexity of the work is shown in Table I, where the various phosphorus and boron diffusion sources in common use are listed. There are, however, some other subtle factors, such as a large number of dislocations underneath the emitter, that may influence the emitter diffusion length and the transistor current gain. Also, diffusion pipes may be generated that short the emitter to the collectors; see Fig. 5. They are easy to detect electrically but difficult to show in a metallurgical cross-section, since both the pipe and the cross-sectioning plane have to be identical. Chemistry or physics background is ideal for this area.

Photoresist

A fantastic amount of progress has been made over the last ten years in precision photolithography. Line widths of 0.0001 inch or 2.5 microns are quite common, with laboratory work progressing into the 1-micron region or less. The line widths are becoming comparable to the wavelength of light and diffraction becomes dominant. Extremely fine lines can neither be printed nor observed by conventional techniques. Electron-beam exposure has been used for sub-micron lines in silicon dioxide on silicon, but the complexity of equipment needed does not seem to make this approach a very practical one.

The chemistry of photoresist is still more an art than a science. Low pinhole concentrations are needed for high device yields. Ragged edges may cause shorts in the successive processing steps. Some photoresists require low relative humidity in the room for good adherence. Most of these characteristics are experimentally optimized by trial and error.

This is a very highly specialized area calling for a combination of chemist, optical expert and mechanical fixture designer.

Etching

After a photoresist layer has been exposed, it has to be developed. For positive photoresist, such as Shipley, the exposed portions will be removed; for negative photoresist, such as the Kodak photoresist series, the non-exposed regions will be removed during the development. After baking, the photoresist mask serves as an etching mask to remove part of the silicon dioxide layer on top of the silicon wafer. Special etches are being used to have steep edges left over when the wafer is to be diffused afterwards. Tapered edges are left when the silicon wafer is to be metallized subsequently. Sometimes overhanging cliffs or deep

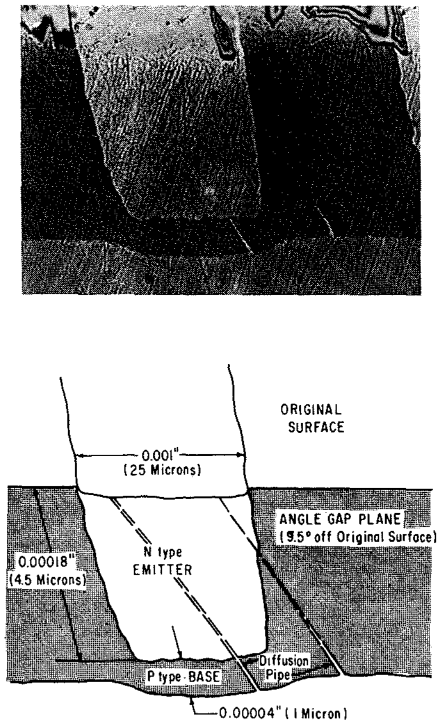


Fig. 5—N-type spikes from the emitter stripe of a N-P-N transistor through the base into the collector. Dimensions and explanations on drawing below. (Photograph courtesy of J. Olmstead, RCA Somerville)

cuts in a composite silicon dioxide layer occurs, see Figs. 6 and 7. This area is clearly the domain of the chemist.

Vapor-phase reactions

Vapor-phase reactions to deposit metals on insulators are used more and more in integrated circuit technology. The reactions are selected in such a way that a deposit occurs only at elevated temperature. Table II gives a partial listing of materials used in vapor-phase reactions. The control and optimization of these reactions leaves the chemist a wide field of technology all to himself. The characterization of these layers for dielectric perfection is usually done by a device physicist.

Metal evaporation and sputtering

Most integrated circuits use evaporated aluminum contacts. Commercial evaporation equipment is highly automated, and its operation does not require a deep understanding of the operating principles of mechanical and diffusion pumps. The workhorse for integrated-circuit metallization are evaporated aluminum layers that are delineated by photolithography. A number of metals such as chrome-

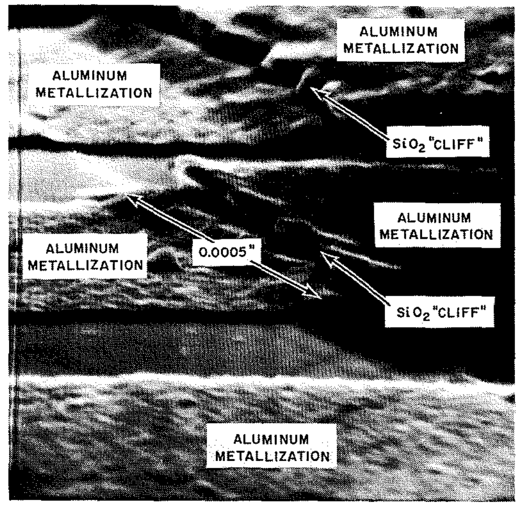


Fig. 6—Faulty aluminum metallization over silicon dioxide "cliff" in MOS integrated circuit. (Courtesy of D. W. Flatley, RCA Princeton.)[2]

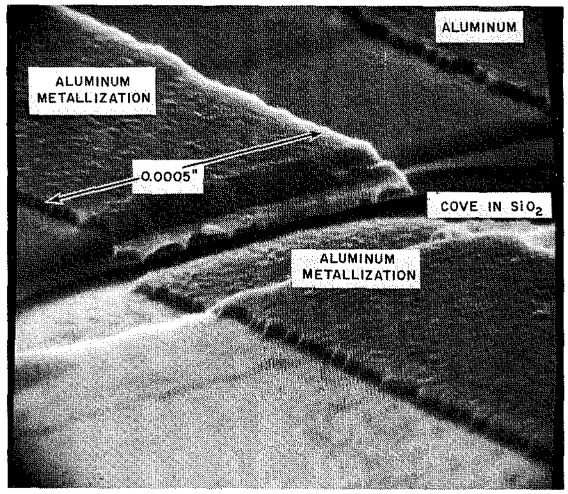


Fig. 7—Faulty aluminum metallization over silicon dioxide "cove" in MOS integrated circuit. (Courtesy of D. W. Flatley, RCA Princeton.)[2]

silver, chrome-gold, tungsten-nickel, and molybdenum-gold have been tried but are not in widespread use at present. The beam-lead approach as developed by Bell Telephone Laboratories is getting more and more acceptance. A low ohmic contact is formed by alloying platinum with silicon (platinum-silicide). Adhesion to the silicon dioxide layer is achieved through the use of titanium, followed by a platinum barrier and capped by a gold layer. Platinum is difficult to evaporate. Therefore, sputtering systems are used. A physicist or a metallurgist seems to do well in this area.

Contacts

Superficially, contacts seem to be a minor part of integrated circuits. This is true only for ohmic contacts to highly diffused silicon regions. Contact

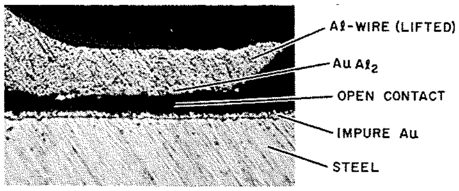


Fig. 8—Faulty bond of aluminum wire to gold pad. This was previously attributed to purple $AuAl_2$ compound formation presumed to be of high resistivity. Recently this was related to impure gold plating. (Courtesy of C. Horsting, RCA Somerville.)

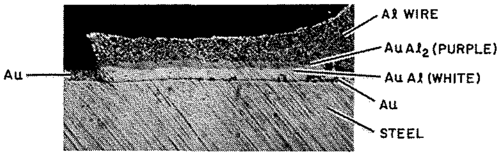


Fig. 9—Good bond of alumium wire to gold pad. The formation of purple $AuAl_2$ (purple plague) does not impair bond strength if pure gold plating is used. (Courtesy of C. Horsting, RCA Somerville.)

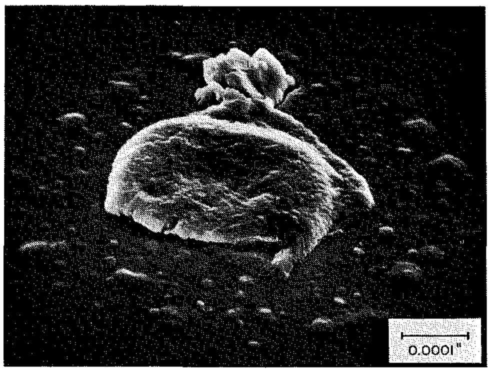


Fig. 10—Hillock in evaporated aluminum layer after 500°C micro alloying step that is typically used in integrated circuit fabrication. The hillock will pierce the insulator in two layer metallizations. (Courtesy of E. Ham and R. Soden, RCA Somerville.)[2]

resistances to small areas can be several ohms and tend to insert significant ohmic voltage drops which shift the operating point in the circuitry or degenerate the transconductance and the power gain of the devices. Also, for the high current densities that are present in integrated circuits, the formation of voids or hillocks can occur. The "purple" plague is a classical example of a metallurgical problem. Between aluminum (either wire or wafer metallization) and gold (either post or wire) there forms an intermetallic compound which was believed to be high resistivity, see Figs. 8 and 9. Open connections very often resulted. Recently it has been traced to impurities in the gold that are responsible for this problem.

Fig. 10 shows a 45° view of an aluminum metallized silicon surface. To obtain low resistance contacts, the wafer is heated to 500°C. With pure aluminum hillocks occur that pierce through a dielectric layer into the upper aluminum layer of a two layer metallization. The hillocks can be avoided by the evaporation of aluminum with a small percentage of another metal, i.e., an aluminum alloy. This area is the domain of a metallurgist.

Device enclosure

Device enclosures have the purpose of mechanically protecting the device and to remove or dissipate heat that is generated inside. If the enclosure is hermetic it also maintains the ambient, most often dry nitrogen, around the integrated circuit. Plastic encapsulated integrated circuits have become more and more important. They need surface passivation and a vapor barrier before the plastic can be applied. Since the packaging cost of integrated circuits is a substantial portion of the total integrated circuit cost, plastic encapsulation and/or attachment of integrated circuits to babyboards on 0.010″ centers will become more and more popular. Clever teamwork by a mechanical engineer, a metallurgist, and a ceramist or polymer chemist will minimize this cost.

Testing

Testing an integrated circuit is testing of a "black box" with from 10 leads or more up to several hundred. When the number of contact leads increases, the number of tests increases very rapidly. Manual testing is much too time consuming. Rapid progress has been made during the past few years in computer-controlled testing technology, while finished devices are subjected to GO/NO-GO testing by the manufacturer before shipping. For engineering purposes it is more important to obtain the distribution curves of the actual integrated circuit parameters. Diagnostic software programs are quite helpful to help determine why a particular integrated circuit does not work. This area is the domain of an electrical engineer and a computer specialist.

Statistical yield analysis

Statistical yield analysis is very important when device processing is to be optimized. The diffusion cycles for emitter and base of a transistor, for example, have pronounced effects on some parameters that are interrelated. For optimization one processing step at a time is changed. Other previously optimized processing parameters may have to be changed again for an even better optimum. Since some of the changes may be small enough to be overshadowed by the scattering of the parameter values, statistical methods for averaging may reveal significant trends.

For high reliability devices, an enormous amount of life testing is required. Semiconductor devices are so reliable these days that it may take 100,000 device hours [for around 11.3 years] for one device failure to occur. Confidence levels can only be assigned by statistical methods. This is an area for a statistician.

Dust and humidity control

Clean working areas are a must for integrated-circuit fabrication. Dust counts of less than 100 particles (over 0.3 micron in size) per cubic foot are commonly specified. Normal laboratory dust counts are in the area of 1 million per cubic foot. Special laminar flow benches are available commercially. Whole laminar flow rooms have been built by a number of companies.

Most photoresists have adherence problems in humid weather. Baking prior to photoresist application removes adsorbed water. A rigid humidity control in the photoresist area is still very important. Environmental control engineers can handle these problems well.

Special equipment

The integrated-circuit technology is constantly changing due to the need of faster and faster switching speeds, for example. Larger and larger portions of a system are integrated in one piece requiring multi-level metallization schemes. These tasks cannot be done if special equipment is not developed at the same time. The feedback loop between the equipment developer and the process developer has to be very short.

Reference

1. Kihn, H., "The Impact of Integrated Circuits in Engineering," reprint PE-375.
2. The photographs in Figs. 6, 7, and 10 were taken using the Scanning Electron Microscope.

Quality assurance engineering

T. I. Arnold

To examine the interdisciplines involved in Quality Assurance, we should first define the areas in which the Quality Engineer operates. Basically, his responsibilities include such activities as developing training programs, production inspection, tool and test equipment calibration, process capability, visual aids to production, and generally insuring quality conformance. The responsibility of this engineer for quality of design is less well defined, but equally essential to the achievement of optimum quality.

THE QUALITY ENGINEER deals across the entire spectrum of shop quality and becomes involved with contracts, customers, and design engineering as well. Due to this wide variety of interfaces in which he participates, a good quality engineer, should be first a businessman, second an engineer, and lastly a quality man.

Quality costs

The total costs attributable to quality are normally segregated into costs associated with

1) *Detection or appraisal*—such as vendor incoming or in-process inspection;
2) *Prevention*—before-the-fact design for quality, design reviews, process control, etc;
3) *Failure*—including in-plant failure and rework as well as failure in the customers hands, including repair and warranty expense.

This satisfied customer/profit picture must, of course, be viewed in the long range; for example, better, more reliable, and more expensive components may be selected because the reduction in the quality costs of failure far outweigh the short-term costs of appraisal and prevention. Even if he cannot reduce the total cost of quality, an astute Quality Engineer may, at the early stages, provide for better and more easily maintained quality without a corresponding increase in cost.

The design phase

The participation of the Quality Engineer may well begin by close liaison with the Design Engineer. The Quality Engineer, for example, may contribute statistically designed experiments which lead to a level of parameter optimization that could be achieved in no other way. Such optimization, in addition to providing a better product, reduces the difficulty of properly manufacturing and inspecting the product while in production. This process need not cease when design is complete; the Quality Engineer may deliberately vary known parameters (usually within pre-established process control limits) during the manufacturing cycle and then evaluate the resulting data to determine whether the resulting changes were statistically significant. It is interesting to note that it is not necessary to hold all parameters constant and vary only one at a time, but quite the reverse. In many instances, the only way to determine the significance of a parameter is to experiment with several characteristics varying simultaneously. Obviously, to accomplish these ends, the Quality Engineer must be sufficiently knowledgeable to span the activities of the Design Engineer, Manufacturing Engineer, and Line Supervisor. Through it all, he must maintain a spirit of friendly cooperation and contribute to the solution of problems rather than serve as a roadblock with reasons of why it "can't be done" or he will never succeed in implementing changes desirable from a quality point of view.

The aid provided by the Quality Engineer in the design cycle, including constructive participation in design reviews, is the first step in maintaining a good relationship with a satisfied customer and thereby contributing to corporate profit.

An important—too frequently the only —contribution of the Quality Engineer during the design phase is his familiarity with military process specifications and newer manufacturing techniques. Significant examples of this familiarity on the part of the Quality Engineer, as well as cross-pollination which he introduces daily, are seen when a Design Engineer describes such a fundamental item as a single-sided printed-circuit board. The Quality Engineer will contribute the necessary manufacturing familiarity with processes which will insure that the pads are oriented and sized to permit later acceptance of the board when it is judged by the requirements of a soldering specifications. (See Fig. 1.)

Process control

By the time a product idea has reached the "drawing board," the Quality Engineer, has already supplied an intimate knowledge of specifications, participated in design reviews, and has coordinated the quality effort among design engineers, program administration, marketing, contracts, manufacturing engineering, and the customer. It is already apparent that an engineer trained in one discipline only is now in deep trouble. At the time of design

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earned both the ME and MS in Industrial Engineering from Stevens Institute of Technology and has more than 18 years experience in Quality Control of electronic, aircraft, and space products. He is responsible for Quality Assurance requirements, both interpreting specifications and assuring compliance with the specifications, developing quality plans, specs, preventative Q. C., etc. His duties have included responsibility for all phases of Quality Assurance of commercial, DOD, and NASA procurements.

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Fig. 1—During the design phase, the Quality Engineer can contribute valuable advice on manufacturing and process requirements.

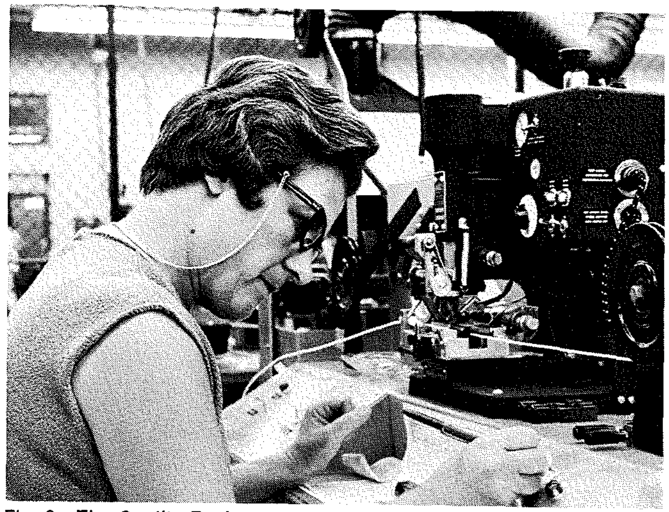

Fig. 2—The Quality Engineer maintains a close vigil over all phases of a process so that even the simple operations, such as the wire-marking step pictured above, do not present problems.

review, the Quality Engineer must not only reflect the obvious points of quality which will result from the released design, but must also take into consideration how a broad spectrum of specialties (including not only the mechanical and electronics, but human factors as well) will affect the quality designed into the product and the quality which it is possible to build into the product.

Once the part is released for production, the Quality Engineer will have to measure accurately the obvious parameters of quality as well as the other characteristics which, if changed, will result in better quality. To do this he must deal with both mechanical and electrical engineers in order to ascertain which characteristics should be most closely monitored. Further, he must have an accurate picture of the inner relationship of all aspects of the material when establishing the classification of the characteristics which serve as a basis for sampling inspection. This inspection, in turn, must not only insure that the quality of the product delivered by RCA is in keeping with the standards expected by the customer, but must also minimize those costs of appraisal incurred at purchased material inspection.

As the parts progress throughout the manufacturing cycle, the Quality Engineer who is knowledgeable about the various disciplines will adjust processes and controls based on data in order to develop various breakthroughs into better ways of designing or manufacturing the product while still maintaining control over the process. The simplest of processes which normally cause little problems can, in fact, be the most expensive mistakes and cause the greatest impact on profit. Typical of these are such simple operations as painting, iriditing, plating, welding, soldering, and wire-marking. (See Fig. 2.)

When any of the aforementioned items is determined to be defective by an inspector, it is the Quality Engineer who is called upon to isolate the cause and determine how the problem occurred, determine what corrective action is to be taken, and to convene a Material Review Board composed of the Quality Engineer, the Design Engineer, and the customer. In addition, he must also determine, in the light of his investigation of all aspects of the problem and its cause, what disposition is to be made of the discrepant pieces on hand, and such other similar pieces as may have already passed the critical operation and are therefore unavoidable. This investigation frequently finds itself in the operations of design engineering, manufacturing engineering, manufacturing line supervision, etc.

The quality plan

Each of the points discussed above will normally be incorporated into a quality plan which is established before the company undertakes to manufacture the product. Such a quality plan will define the elements which will be monitored or controlled by quality throughout the life of the contract. There are many cases where quality has (through a quality plan) brought to the attention of management the necessity for certain special requirements such as controlled atmospheres, positive pressure, high reliability parts, certified operators, etc. These requirements are frequently hidden in secondary specifications and, were it not for the quality review prior to manufacture, would come as a surprise at the time that manufacturing began. In addition, the quality plan normally specifies those reports which will be prepared and the action which will be taken as a result of the information which they supply. This information is important to the customer and manufacturer so they can evaluate what benefits quality will be giving them, and so that they will know what information is available for use during manufacture or (should any undesirable circumstance occur) for an analysis of what conditions went into manufacture.

It is important that all reports which are prepared for both management and those activities outside of the manufacturing operation are simple and clear, that they establish trends, and that they establish measurable characteristics rather than supply a mass of data which should first have been reduced by the Quality Engineer. To prepare such a plan, the Quality Engineer must have had sufficient interface with the customer to establish those levels of quality which the customer is interested in obtaining and paying for. He must also know any special requirements which the customer has, and possibly some which did not appear in the information given for design. Further, he must establish those criteria which will be used to evaluate all of the quality parameters of the product, and the test and inspection plans which will be used to serve as grounds for acceptance or rejection. Throughout this process, he must bring to bear his knowledge of previous similar products and of the requirements of quality for the group with which he is dealing. Possibly the most important part of this plan will be a thorough review of all of the specifications which are to appear in the contract. This will avoid the hidden impact of an unknown quality requirement but, even more important, will provide information to engineering, manufacturing engineering, and manufacturing regarding the actions which they must take in order to comply with the specifications when the job is placed in the manufacturing cycle. In those instances where the requirements are such that it is impossible to measure them directly in the manufacturing cycle, it is incumbent upon the Quality Engineer to develop a method of controlling the process which performs the operation in question. Typical of these are plating and soldering.

Other responsibilities

Monitoring performance

The Quality Engineer will often participate in the preparation of visual aids for both manufacturing and inspection operations. These visual aids will be designed to interpret workmanship specifications, and will frequently be the basis from which quality practices are prepared for the inspector's checking operations. It is also the responsibility of the Quality Engineer to measure and post the results of day-to-day activity. The method selected for this can contribute tremendously to the positive motivation of the employees for better output or, conversely, a dejected atmosphere which considers success impossible and leads to poorer and poorer quality. It is therefore important that the Quality Engineer consider the motivational effect of the information which he elects to publish to the personnel performing the work.

Training

Frequently, the Quality Engineer is called upon to participate in the training of personnel. This is still commonly done both on the job and in short classes. However, the tendency for Quality Engineering to operate the training school used for indoctrination of new employees is gradually giving way to the increased utilization of Manufacturing Engineering as the instructing agency, with the Quality Engineer retaining only the examining and certifying responsibilities. This permits the Quality Engineer to objectively review, based upon his experience, the usefulness of the information which is being transmitted during training sessions.

Vendor selection

One of the major considerations in making or breaking the quality success of a product is the selection of vendors and subcontractors whose product will inherently become a part of our own. The selection of vendors for price and delivery is of course important but, in the long run, the selection of vendors who will deliver material of an acceptable quality level may be even more desirable. The selection process frequently involves a survey in which a quality member participates. Such surveys evaluate not only the vendor's capabilities to make the part, but his ability to insure that it is made under controlled conditions and will conform to specifications at the time of delivery. Pre-award contractual requirements should be reviewed with the prospective vendor at this time. While Quality Engineering participates in such surveys, it also participates at a later date in the monitoring of the vendor's product. For example, it may be opportune at various times to counsel with the vendor, or when considered necessary, to visit his plant and assist him in manufacturing the product more effectively to reduce the impact on schedule and cost.

Trouble shooting

From the aforementioned it can be seen that the actions of the Quality Engineer make a significant impact (in addition to a marked effect on profits) on one major area, and that is corrective action. Those areas which have not been foreseen and planned for must be corrected as they arrive on the manufacturing floor. It is through this process of measure and feedback that quality contributes most to the corporate profit picture. Corrective action for defects found on the floor frequently extends back to the process or process-control function, and this is as likely to be in the vendor's plant as in the manufacturer's plant.

Concluding remarks

Much has been said of the difference between government and commercial contracts; however, it can readily be seen that a good quality program is essential to each and is not too dissimilar in either of the plants. Admittedly, government contracts use many government specifications while commercial contracts are more likely to use industry and company specifications. However, a good quality program is based on the requirements of the customer. These quality programs are clearly reflected in government jobs by specifications that are expected to be adhered to, and in commercial jobs by public demand for quality as epitomized in recent national recognition of problems in the areas of insurance, automobiles, etc.

Further, the individual consumer's demand for quality can be seen in the increasing number of law suits resulting from poor quality, and in the large number of articles in the quality literature regarding the responsibility of a quality department for establishing those controls which are not only in keeping with the rest of the industry but are adequate to protect the customer against any damage which he may suffer as a result of both reasonable and foreseeable use of the product once it is in his hands. Thus, if the products still on the drawing board and those yet to be developed are going to meet the requirements of the quality minded user, the Quality Engineer, along with a comprehensive quality program are now, and will continue to be, essential elements toward improving products as well as profits.

Pre-validation testing of ATE programs

A. M. Greenspan

One useful application of probability and statistical inference at RCA is in the design review of computer programs for Automatic Test Equipment (ATE), where a review team judges if a program is ready for validation. This paper introduces the reader to the meaning of basic sampling concepts with emphasis on their use in the design review of ATE programs. It shows how sampling plans are selected and applied and offers examples demonstrating their use so that those encountering probability and inferential statistics in ATE programming may better understand and use this discipline. The paper also demonstrates the manner in which sampling can be used to set up criteria through which future computer programs can be judged.

IN THE DESIGN REVIEW of an ATE (Automatic Test Equipment) program, a finished program is examined by a review team, usually consisting of a design engineer, a senior ATE programmer, a Quality Assurance representative, a program management representative, and the program designer. The purpose of this review is to make certain the program is ready for validation. This is necessary to protect against wasted ATE machine time which is generally quite precious. The result of the design review is a decision that either the program hypothetically can or cannot isolate an expected percentage of faults. The method of checking the program is to select certain hypothetical faults, and then demonstrate the ability of the program to find these faults in the unit under test.

Certain criteria must be established before one can sample in order to make inferences about a program. First, it is necessary to decide upon the degree of certainty with which the conclusions resulting from the sampling results can be accepted. No sampling results are absolutely conclusive, but it is possible to establish their level of significance before sampling takes place. To do this, one must be aware of the consequences inherent in selecting a given level of significance as well as the meaning of sampling results in light of the level of significance selected. Second, the size of the sample must be selected; too small a sample will cause erroneous results, and too large a sample would be inefficient. Finally, the nature of the population must be analyzed in order to ascertain the most appropriate sampling technique. That is, one must decide upon the proper equations representing a distribution that will provide inference from the sample population.

A typical subassembly program will be concerned with 200 to 300 faults. Since it is not possible, from a time and economic standpoint, to insert all possible faults at a design review, it is necessary to devise a means of arriving at a conclusion about a program's completeness on the basis of a small sample of randomly selected faults. However, in order to do this, a certain understanding of probability and inferential statistics is necessary.

Probability and inferential statistics

Probability means the likelihood of occurence. Odds are an everyday expression of probability. They are a statement about the likelihood of an event taking place as opposed to the likelihood it will not.

Tossing a die provides an example of how probability is determined. A die has six faces; if it is fair, each face has an equal chance of coming up. Therefore, on any given roll the probability is $1/6$ for a given number on the die coming up. If one wishes to calculate the probabilities of each even numbered face coming up, he can add their individual probabilities or

$$1/6 + 1/6 + 1/6 = 1/2.$$

Thus when the probabilities of all individual events are known the probability of any combination of events can also be found.

In inferential statistics, probabilities are used to arrive at conclusions about a large group of possible occurrences, called a population. The method used is to examine a small portion of the population, called a sample and (based on the results of sample observations) to determine details about the population. The population details that are sought are called parameters. For example, if an investigator desires to estimate the number of Democratic and Republican voters in a population; a sample of the population could be

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taken. The values obtained in the sample taken would be statistics, and from these statistics an inference would be made as to the populations parameters, these parameters being the actual number of Democratic and Republican voters.

The results of estimating a parameter by a statistic is necessarily uncertain. A statistic derived from a limited number of observations cannot be expected to have the same value as the parameter it estimates. Therefore, a risk always exists that a conclusion about a population which is reached through sampling will be in error. The risk can be expressed as an error probability, and this error probability is used as a measure of the confidence with which one can accept certain conclusions about the population.

Probability and inferential statistics are an integral part of the design review of programs written for Automatic Test Equipment (ATE) at RCA Aerospace Systems Division in Burlington, Mass. The design review takes place before a program is actually validated on the equipment. In the design review, the program is checked theoretically to establish a level of confidence that it will do the job expected. In practice, the design review has avoided wasted machine time during program validation.

To achieve a given confidence in a program, the design review employs a statistical approach: hypothetical faults are selected for the unit under test, and the designer then demonstrates that the program is able to isolate these faults.

It is unreasonable to expect that the program to be reviewed will be perfect: i.e. that it will isolate every possible fault. Moreover, it is impossible, from the standpoint of time and cost, to have the reviewers insert every hypothetical fault into the unit under test. Fortunately, this is not necessary. By selecting a small number of faults at random, the reviewers can determine—within a stipulated probability of error—if the program meets its requirements. (Finding at least 90% of all possible faults is a common requirements for such programs).

Some decisions must be made as to the number of hypothetical faults that must be selected, and of these faults, how many must be successfully isolated for the program to be accepted. These are only two of the criteria that are established before the design review begins. This information is part of what is called the sampling plan.

Sampling plan

To develop a sampling plan, certain information must be known regarding the characteristics of the body of items (population) to be measured. For example, a population can be either quantitative or qualitative. If a population is quantitative, consisting of values that can be measured numerically (such as test scores), certain sampling techniques are indicated. When the population is qualitative, or merely descriptive (such as men versus women), then other sampling techniques are used.

The population under consideration when examining an ATE program is characterized by the test plan and by the possible fault modes that may exist in the unit under test. This population is qualitative and dichotomous—having the characteristics of success or failure. A success occurs if the program being tested finds the faults; a failure occurs if the fault is not found.

Another important consideration made in deciding upon a sampling plan is the number of items which make up the population. If one assumes a total of 200 to 300 possible faults (typical for subassembly programs), a decision must be reached as to how large of a sample must be taken from the population in order to draw inferences. It is desirable to keep the sample size small for the purpose of efficiency. However, too small a sample can lead to erroneous conclusions about the population being tested. The central limit theorem[1] guarantees that regardless of the population distribution, a sample, if sufficiently large, will approximate a normal distribution. But in an ATE program, the sample size is necessarily small due to the smallness of the population. In addition, the distribution of the population is not even, but is expected to be shifted such that 86 to 96% of the hypothetical faults will result in a success. Therefore, a normal distribution can not be assumed, and the design review team cannot use a sampling technique that depends upon the shape of the population distribution or sample size. the χ^2 (chi-square) goodness-of-fit test provides such a sampling technique. The χ^2 distribution is a non-parametric distribution: no assumption is necessary regarding the form of the population distribution. Furthermore, the χ^2 test is very well adapted for use with discrete and/or nominally classified data such as the success / failure characteristic of ATE programs.

The χ^2 distribution depends upon the number of degrees of freedom in a sample, rather than sample size. Degrees of freedom is a term used to denote the number of categories minus the number of linear restrictions on the quantities involved. For example, given N

elements in a sample and the sample mean, $N-1$ of these elements are independent variables; i.e. free to vary in value. However, the N^{th} element is predetermined by the values assigned to the preceding $N-1$ elements.

For example, given a mean, $X=2.5$; three parameters $X_1=2$, $X_2=2$, and $X_3=4$; and a population N=4.

$$X=\frac{\sum_{i=1}^{4} X_i}{N}$$

then

$$\frac{2+2+4+X}{4}=2.5$$

and $X=2$.

Therefore, only $N-1$ independent linear comparisons can be made among N categories. In the case of ATE program where there are only two categories—success (finding a fault) or failure (not finding a fault)—there is one degree of freedom.

Level of significance

As has been stated previously, the results of a sampling procedure is never certain. However, it is possible to predetermine the degree of certainty with which one can accept the results. This is called the level of significance to which the population is tested. The level of significance must always be stated before testing takes place as part of the sampling plan.

The sampling plan also requires that a hypothesis be stated for the sampling procedure to test against. The hypothesis for a design review is determined by the requirements set for a particular program. For example, if the design review requirements are that the program must find 96% of all possible faults and the reviewers wish to be 95% certain that this is true, a null hypothesis will be formulated to test against. The null hypothesis is usually formulated as something which is to be disproved. The reason for this is that, as a general rule, it is always easier to discredit a hypothesis than prove it. Also the null hypothesis will be very specific, and thus it will be possible to discredit it with a high degree of significance. The null hypothesis usually designated H_o and could be stated as follows: there is no reason to doubt within a 95% level of significance that 96% of all possible faults are found by the program.

Thus, though the personnel conducting the design review hope to insure against the possibility that less than 96% of the faults are found by the program, the hypothesis tested is there is no reason to doubt this is true. If the null hypothesis is rejected, an alternate hypothesis must be accepted; this is usually designated H_a and could be stated: there is reason to doubt within a 95% level of significance that the program can find 96% of all faults.

This is less specific than the null hypothesis for it makes no statement as to the percentage of faults found, but it is sufficient for rejection of the tested program.

It should be noticed that the null and alternate hypothesis are both stated with a level of significance—in this case 95%. The level of significance must always be stated when testing statistically.

Errors

The possible types of error in a sampling procedure are divided into two classes. Type-1 or α-error is said to exist if the outcome of the sampling experiment causes the null hypothesis to be rejected when it is in fact true. Type-2 or β-error is said to exist if the outcome of the sampling experiment leads one to accept the null hypothesis when the alternate hypothesis is true. It is important to remember that type-1 and type-2 error are interdependent. That is, as the probability of type-1 error is decreased, the probability of type-2 error is increased; therefore care must be taken in choosing a value for type-1 and type-2 error. In a design review, the reviewers wish to be quite certain that the program does not fail to catch 96% of all possible faults, to avoid wasted validation time. The result of type-1 error would be unnecessarily sending the programmer back to do additional work on the program. While this is wasteful and costly, it is not as costly as excessively long validation time on the Automatic Test Equipment for a program that is not ready to be validated. Therefore, the program is tested to a 95% level of significance or a 5% possibility of type-2 error. This means 95 out of 100 times acceptance of the null hypothesis will prove to be the proper decision. However, it is possible to set the level of significance at 99% or 99.95 if the consequence of false acceptance is felt to be serious enough.

Critical ratio

The statistic used for the testing plan is called the critical ratio.

The critical ratio is defined as follows:

$$X^2=\frac{(O_s-E_s)^2}{E_s}+\frac{(O_f-E_f)^2}{E_f^2} \qquad (1)$$

where:

X^2=The critical ratio

O_s=The observed number of faults successfully found

E_s=The hypothetically expected percentage of faults successfully found

O_f=The observed number of faults not successfully found

E_f=The hypothetically expected number of faults not successfully found.

This ratio is used to determine if the difference between sample results and the hypothetical (or expected) result is statistically significant. The determination is made by comparing the value obtained from Eq. 1 against a value that can be easily obtained from a graph or table describing the sampling statistic that is being used. Since a χ^2 test is used to describe the population for ATE programs, a precalculated χ^2 table is necessary (Fig. 1).

The value obtained from the χ^2 table is called the critical or rejection region. This value is known before testing takes place and is part of the data necessary for the sampling plan.

The χ^2 table in Fig. 1 contains sample values of χ^2 in the body of the table. The top stub shows the probability that these values will be exceeded when the sample is drawn from a χ^2 distribution with degrees of freedom as indicated in the column at the left. The probability value at the top of each column is the same as the probability of type-1 error. In order to find the rejection region for the null hypothesis previously stated (H_o: there is no reason to doubt within a 95% level of significance that 96% of all possible faults are found.) one would find the intersecting point for one degree of freedom and type-1 error of 0.05. This is 3.84 in the table.

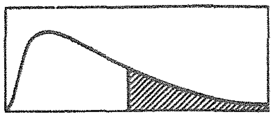

Fig. 1—Table of chi-square values for type-1 errors.

df	Probability that chi-square value will be exceeded							
	.995	.990	.975	.950	.050	.025	.010	.005
1	---	---	---	.004	3.84	5.02	6.63	7.88
2	.01	.02	.05	.10	5.99	7.38	9.21	10.60
3	.07	.11	.22	.35	7.81	9.35	11.34	12.84
4	.21	.30	.48	.71	9.49	11.14	13.28	14.86
5	.41	.55	.83	1.15	11.07	12.83	15.09	16.75
6	.68	.87	1.24	1.64	12.59	14.45	16.81	18.55
7	.99	1.24	1.69	2.17	14.07	16.01	18.48	20.28
8	1.34	1.65	2.18	2.73	15.51	17.53	20.09	21.96
9	1.73	2.09	2.70	3.33	16.92	19.02	21.67	23.59
10	2.16	2.56	3.25	3.94	18.31	20.48	23.21	25.19
11	2.60	3.05	3.82	4.57	19.68	21.92	24.72	26.76
12	3.07	3.57	4.40	5.23	21.03	23.34	26.22	28.30
13	3.57	4.11	5.01	5.89	22.36	24.74	27.69	29.82
14	4.07	4.66	5.63	6.57	23.68	26.12	29.14	31.32
15	4.60	5.23	6.26	7.26	25.00	27.49	30.58	32.80
16	5.14	5.81	6.91	7.96	26.30	28.85	32.00	34.27
17	5.70	6.41	7.56	8.67	27.59	30.19	33.41	35.72
18	6.26	7.01	8.23	9.39	28.87	31.53	34.81	37.16
19	6.84	7.63	8.91	10.12	30.14	32.85	36.19	38.58
20	7.43	8.26	9.59	10.85	31.41	34.17	37.57	40.00
21	8.03	8.90	10.28	11.59	32.67	35.48	38.93	41.40
22	8.64	9.54	10.98	12.34	33.92	36.78	40.29	42.80
23	9.26	10.20	11.69	13.09	35.17	38.08	41.64	44.18
24	9.89	10.86	12.40	13.85	36.42	39.36	42.98	45.56
25	10.52	11.52	13.12	14.61	37.65	40.65	44.31	46.93
26	11.16	12.20	13.84	15.38	38.89	41.92	45.64	48.29
27	11.81	12.88	14.57	16.15	40.11	43.19	46.96	49.64
28	12.46	13.56	15.31	16.93	41.34	44.46	48.28	50.99
29	13.12	14.26	16.05	17.71	42.56	45.72	49.59	52.34
30	13.79	14.95	16.79	18.49	43.77	46.98	50.89	53.67
40	20.71	22.16	24.43	26.51	55.76	59.34	63.69	66.77
50	27.99	29.71	32.36	34.76	67.50	71.42	76.15	79.49
60	35.53	37.48	40.48	43.19	79.08	83.30	88.38	91.95
70	43.28	45.44	48.76	51.74	90.53	95.02	100.43	104.22
80	51.17	53.54	57.15	60.39	101.88	106.63	112.33	116.32
90	59.20	61.75	65.65	69.13	113.14	118.14	124.12	128.30
100	67.33	70.06	74.22	77.93	124.34	129.56	135.81	140.17

Sample size

The final item which must be determined in the sampling plan before sampling begins is the size of the sample. While the χ^2 distribution is relatively insensitive to sample size, too small a sample will tend to inflate the χ^2 value and cause errors. The minimum sample size advisable in using this distribution is taken as at least five items per category in the population being sampled. In dealing with ATE programs where there are only two categories (success and failure) and thus only one degree of freedom, a sample size of 30 has been found to provide good results in respect to accuracy versus efficiency.

Examples

An actual example will be useful to demonstrate the use of the statistic in a design review situation.

We first apply the Null Hypothesis, H_o: There is no reason to doubt within a 95% level of significance that 96% of all legitimate faults are found by the program. This results in a level of significance of 0.05%, which is the probability of type-1 or α-error.

We can then find the rejection region in the table (Fig. 1). With $\alpha=0.05$ and one degree of freedom, the critical ratio from the table is 3.841.

Assuming the results of the design review were that of 30 faults (randomly selected) 27 were found successfuly, we can apply Eq. 1 to find the critical ratio:

We have $O_s=27$; $E_s=N_o=30$ (.96) = 28.8 or 29; $O_f=3$; and $E_f=1$. Then,

$$X^2=\frac{(27-29)^2}{29}+\frac{(3-1)^2}{1}=4.14.$$

Applying the decision criteria accept or reject the null hypothesis,

If $X^2>3.841$, reject H_o
If $X^2<3.841$, accept H_o

Since 4.14>3.841, the program must be sent back for rework because it does not meet the criteria set for it.

Now, assume the results of the design were that of 30 faults (randomly selected) 28 were found successfully.

Then $O_s=28$; $E_s=29$; $O_f=2$; $E_f=1$; and the critical ratio is

$$X^2=\frac{28-29}{29}+\frac{2-1}{1}=\frac{1}{29}=\frac{30}{29}=1.03$$

In this case, 1.03<3.841 and the null hypothesis will be accepted. Therefore, a general rule can be established: in a design review where an ATE program must be checked to see if it can find 96% of all possible faults to a 95% level of significance, the program will be accepted for validation if no more than two faults are missed and will be sent back for rework if more than two faults are missed.

Conclusion

Through the use of inferential statistics, it is possible to set up a simple and convenient criteria for judging Automatic Test Equipment Programs prior to validation, thereby effecting significant savings in an Automatic Test Equipment programming effort.

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The computer in education—a systems approach

W. R. Bush

RCA developed data-processing systems have been used within several educational systems for instruction, administration, and research. This paper identifies the role of computer-aided instruction in the context of modern educational method and describes some of the recent ventures in this field.

In March 1967, President Robert W. Sarnoff announced the inauguration of a major new venture for the Corporation: "It is my privilege to announce RCA's full-scale entry into the computer-based instruction, or CBI—a dynamic new element in the first major effort by industry and education, partnership, to take an integrated systems approach to the problem of individualized teaching in our schools." Mr. Sarnoff went on to state: "RCA's confidence in its capabilities in all the required technologies was a key factor in its decision to enter the field of computer-based instruction. It is a logical extension of our experience in both electronics and education. We are confident that the bold new concepts here at work auger well, not only for our Company, but more importantly, for the future of education."

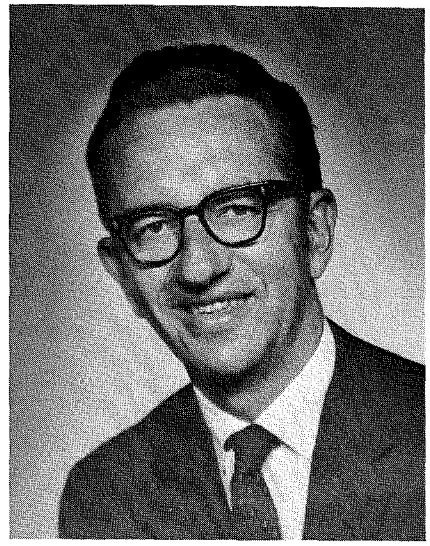
Mr. Sarnoff presented these remarks at the official dedication of the RCA Instructional Systems organization in Palo Alto, California. At that time, Instructional Systems consisted of a small cadre of personnel trained in educational research and computer applications. This group had been organized to conceive and design a data processing system—both hardware and software—which would satisfy the instructional and administrative requirements of the nation's school systems. As Mr. Sarnoff indicated in his statement, the primary philosophy of this group was, and still is, systematic application of modern technology to assist the educational community in solving its problems.

History of education

If one reflects back through the history of education and attempts to pinpoint those occasions on which technology has exerted a truly significant and fundamental influence, one can identify relatively few such events. For example, from the onset of recorded history up to the early Renaissance, education in the Western world was restricted to whatever information could be transmitted by the spoken word. The school system, if we can call it such, consisted of an individual—the tutor or master—who would present information verbally to a relatively small group of students informally gathered around him at a particular time. The students were expected to assimilate knowledge from the master by virtue of informal conversations and/or exposure to his thoughts and philosophies. Their source of knowledge, therefore, was experiential and informal; it was dependent upon the master with whom they were associated at any particular time or upon the student's own personal experiences as they occurred on a daily basis. There were no books, and whatever written information was available to the student consisted principally of the personal notes which each would record of the conversations or discourses with the tutor.

Early education

In the earliest phases of history, we know that the Socratic or dialogue interaction was the prevalent means of communication between tutor and student. It is interesting to note that this method of instruction—prevalent in Classical times—fulfilled the principal goal for which modern education strives: individualized instruction. The drawback to this method, of course, was the fact that there was a very limited number of tutors which severely limited educational opportunities for the youth of that day. In the latter years of this phase, however, the method of imparting knowledge became highly autocratic. This was in large part a result of the formalism associated with the Christian church and the dependence on monastic scholars for disseminating knowledge and teaching the young. During this period, students would listen to their instructor, would take notes, and were then expected to quote back the lesson verbatim on the following day. Throughout this entire period of history, however, the accumulation of knowledge was restricted to the spoken word, and learning was limited to that which could be gained by face-to-face contact.



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received the AB and MA from Brown University and the PhD from the University of Rochester in 1954. On the faculty at the University of Rochester, he taught graduate and undergraduate courses in Physiology and Psychology, and directed a research program in Aerial Reconnaissance for the Air Force. Dr. Bush joined RCA in 1956 and has held a series of positions in Defense Electronic Products from that date until 1967. In January, 1967, Dr. Bush joined RCA Instructional Systems where he has been responsible for studies involving the use of data processing systems in instruction and school administration, for developing functional specifications for instructional systems products which incorporate the requirements and needs of the education community, and for the preparation and implementation of study and research contracts.

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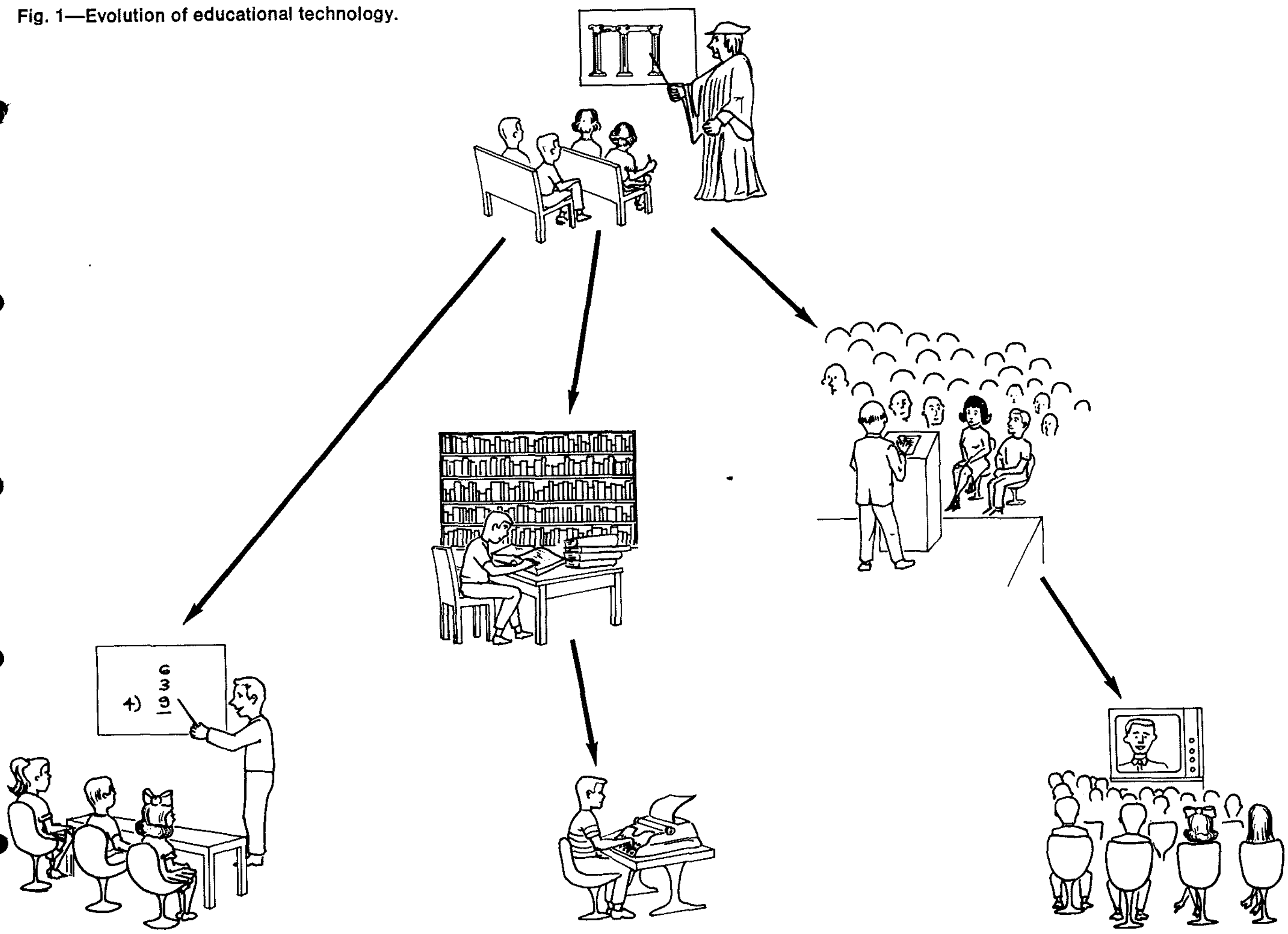
Fig. 1—Evolution of educational technology.



Printing—a revolution

A major revolution in the teaching process can be identified with the invention of the printing press. For the first time, a scholar was no longer limited to face-to-face contact as a means of gaining knowledge. As the number of books increased it was possible for the student to be selective in determining the sources of his knowledge; he could pick and choose among various points of view as presented on the printed page. The number of students increased tremendously because education was no longer restricted to what could transpire within the speaking tongue of a small group of individuals. In fact, it is not too preposterous to hypothesize that the entire advance of civilization which has occurred within the last 500 years can be largely attributed to the expansion of educational opportunities as a result of the utilization of the printing press. As a consequence of this revolution, however, the educational process has become one of mass teaching, with large numbers of students per teacher and few opportunities for individualized learning or personal teacher-student contact.

Today's revolution

A second major revolution in the educational process is the one with which we are involved at the present time. This revolution has been brought about by two major activities in this country: technological and socio-political. On the one hand, we can identify the advent of our electronics technology with its potential applications in the fields of communication, data processing, information retrieval and storage, and multimedia presentations of materials. The application of electronics technology to education is only thirty to forty years old at this time; as yet, its potential effect on the field of education has hardly been scratched and certainly cannot be completely prophesied. Coupled with these technological advances and certainly interdependent with them, has been the changes which are taking place within the various socio-economic-political organizations and groups throughout the Western world.

Increasingly, we see numbers of individuals of all ages and origins, to whom education had previously been an abstract concept, demanding and expecting immediate satisfaction in achieving their educational desires. The total numbers of such people are variously estimated at anywhere from twenty to fifty percent of the educable population in the United States; whatever the actual numbers are, they certainly represent a major problem for educational leaders of our country. What is important to note is that, with the application of modern technology, the opportunities for providing realistic education to these peoples has become possible; in addition, the concept of individualized instruction and a method of fulfilling personal goals in education can at last be foreseen. These efforts are diagramed in Fig. 1.

RCA's system

Within this historical context and with these requirements in mind, RCA Instructional Systems has designed and developed data processing systems which can be utilized by educators for wide and diverse groups of applications, including instruction, administration, and services.[1] In designing an instructional system to accommodate each of these groups, we are able to offer the educational community multipurpose capabilities reflecting significant economic savings to the educational user. For example, if an available computer system is capable only of providing instruction, it is idle during nonschool hours with a resulting increase in the cost of the system to the user. In contrast, by designing a system which can be utilized for administration and services as well as for instructional purposes, it is possible to schedule the use of the computer around the clock with a sizable decrease in the operating costs. Furthermore, such an approach allows an individual user to acquire a computer system which will accomplish a particular group of applications and still be capable of implementing additional or different applications at some future date without major changes in the hardware or software.

Instructional applications

Let us review some of the instructional applications for which data processing systems are being used in various educational communities throughout the country. Although various labels have been given to the instructional applications, they all require a computer in which is stored various teaching strategies and appropriate data and information for the teaching processes, and terminal devices by which the student can communicate with the computer system. They are, therefore, given the general title of computer-assisted instruction (CAI). Depending upon the teaching strategies and purposes to which the system is being used within the educational environment, the level of hardware and software sophistication can vary over extremely wide

PLEASE TYPE YOUR NUMBER. *135*
NOW YOUR FIRST NAME. *TIMMY* HARRIS

THIS IS A MIXED LESSON ON ADDITION AND SUBTRACTION. WATCH THE SIGNS.

```
   53
+  47
  ---
  100

  803
+ 124
  ---
  927

   84
-  46
  ---
    6
```

NO, TRY AGAIN.

```
   84
-  46
  ---
   38

   63
-   3
  ---
   60
```

END OF LESSON 11430101.
4/15/68

11 PROBLEMS CORRECT, 78 PERCENT, IN 180 SECONDS
GOOD-BY TIMMY
COPYRIGHT 1968 THE L. W. SINGER COMPANY, INC.
PLEASE TEAR ON THE DOTTED LINE.
....

Fig. 2—Drill and practice (italics indicate student's response).

ranges. For example, at one end of the spectrum we can identify drill and practice in which the data processing system serves as an adjunct to the classroom environment, and at the other end of the spectrum we can propose a system in which the student and the computer can maintain a sophisticated and instructive dialogue, essentially in realtime, utilizing a natural language. The principal modes of instruction are

Drill and Practice,
Tutorial,
Dialogue,
Simulation,
Problem solving, and
Computer sciences.

→WHEN IT IS CORRECT TO USE THE WORD →I, IT IS CORRECT TO SAY →MIKE AND →I. WHEN IT IS CORRECT TO USE THE WORD ME, IT IS CORRECT TO SAY →MIKE AND ME. TYPE →I OR ME.

→MIKE AND (→I, ME) NEVER FIGHT.
I
YOU FORGOT THE →. TRY AGAIN.
→I
THE LADDER ALMOST FELL ON →ALICE AND (→I, ME).
→I
WOULD YOU SAY "→THE LADDER FELL ON →I"? TRY AGAIN.
ME

Fig. 3—Tutorial (italics indicate student's response).

Drill and practice

The drill and practice mode is designed to afford each student an opportunity to demonstrate his understanding and proficiency of a certain instructional concept (such as vertical addition) and to afford him the opportunity to develop or enhance his capability by drilling on this concept. The student receives immediate knowledge of errors in his drill from the computer and can be afforded additional practice if the errors show a consistent trend (see Fig. 2). The instructional strategy is such that the material presented to a particular student on any one day is tailored to fit his capabilities. He will, therefore, proceed at his individual rate as demonstrated by his own performance to date. The teacher, in turn, is relieved of the responsibility of preparing tests, reviews, homework, and other practice materials for the various concepts that she presents to the class as a whole. In addition, she receives accurate and updated information regarding the progress of her students and their understanding of the material that she presented to them in the classroom situation.

There are several significant advantages for the educational system by introducing and applying drill and practice to the instructional process. In the first place, a drill and practice system can be implemented into an ongoing school system without significantly interrupting that system or forcing the teachers to drastically modify their teaching methods. At the same time, drill and practice allows all members of a school system—administrators, teachers, and pupils—to become familiar with a computer system in their environment and get actual operating experience with it, again without upsetting their normal activities.

In the second place, as suggested above, the drill and practice system represents an important timesaver to the teacher. It will automatically perform all the record keeping and scoring of the student's performance and will make such data available to the teacher upon demand. By storing all arithmetic exercises within its memory system, it represents a timesaving feature in terms of affording thousands of problems to the teacher and her class, none of which she must prepare, grade, or assign to individual students.

But certainly the most important consideration of utilizing drill and practice should be its effect on the child and his ability to learn. For example, drill and practice is definitely an individualized mode of instruction. Each exercise presented to a particular child is a reflection of that child's competency level and what he has accomplished to date. The material, therefore, is responsive to each child's rate of learning and will vary from child to child accordingly. Drill and practice, in addition, becomes highly personalized in terms of child-computer relationship and, consequently, the children are strongly motivated to work at the student stations and "talk with the computer." Elementary children, in particular, tend to personify the computer and afford it humanistic tendencies. All age groups, however, seem to develop an identification with the computer system and react as if the system were an individual concerned about responding to each student's own requirements.

Finally, it should be noted that the drill and practice mode is inherently reinforcing to the child's behavior. The student receives immediate knowledge of results and knows whether or not his performance is right or wrong. No longer is it necessary for an individual child to wait until the teacher has had an opportunity to grade tests or homework—a wait which often extends to several days in length. On the contrary, each child knows the results of his performance before he leaves the student station, both on an item-by-item basis and on an accumulative or summary basis.

Tutorial instruction

Another mode of instruction which requires more sophisticated instructional software is called "tutorial." In contrast to drill and practice, tutorial mode affords new and novel information to the student based upon his performance at the student station. It can, therefore, supplement the information provided by the teacher in the classroom environment. If, for example, the student is unable to give the correct answer to a particular question or problem, the computer system "branches" into a remedial mode by which the student receives information regarding the particular subject matter and then is retested to determine his comprehension (see Fig. 3). Based upon the sophistication of the instructional strategy and the curriculum materials in the data base, a series of such branchings can occur so that the students can actually receive several different exposures of remedial information if he is having continual difficulty with the particular subject.

PLEASE TYPE YOUR NAME AND ID NUMBER
DEBORAH ANDERSON 42
ACCORDING TO MY RECORDS THIS IS HOW YOU DID LAST SEMESTER

CODE	COURSE	GRADE
1	ENGLISH 1	A
2	GENERAL SCIENCE	A
3	EUROPEAN HISTORY	C
4	ALGEBRA	B

IS THIS CORRECT? IF SO, TYPE YES. IF NOT, TYPE NO.
YES
ARE YOU HAVING ANY PROBLEMS WITH ANY OF THESE COURSES? YES/NO
YES
TYPE THE NUMBER OF EACH COURSE THAT IS GIVING YOU TROUBLE. WHEN YOU ARE THROUGH, TYPE /
3 /
WHAT KIND OF PROBLEM DO YOU HAVE WITH EUROPEAN HISTORY? PLEASE TYPE IN THE NATURE OF THE PROBLEM. A FEW WORDS WILL BE O.K. WHEN YOU ARE FINISHED, TYPE /

— — — — — — — — — — — — — —

O.K. . . . .
THE GRADES YOU GET IN HIGH SCHOOL LARGELY DETERMINE THE TYPE OF COLLEGE YOU WILL BE ABLE TO ATTEND. LET'S JUST TAKE A LOOK AT YOUR PROJECTED HIGH SCHOOL GRADES BASED ON YOUR PRESENT PERFORMANCE.
STUDENTS WHO GET GRADES LIKE YOURS IN JUNIOR HIGH, DID AS FOLLOWS AT SAN FERNANDO VALLEY STATE COLLEGE:
70% EARNED A OR B
20% EARNED C+
10% EARNED C
ON THE BASIS OF YOUR PROJECTED GRADES, YOUR PRESENT COLLEGE CHOICE INDICATES THAT YOU ARE THINKING PRETTY REALISTICALLY ABOUT YOUR FUTURE LIFE .

Fig. 4—Dialogue (italics indicate student's response).

Dialogue

A third mode of instruction—still very much in the experimental stage—is that situation in which the student carries on a dialogue with the computer system. The dialogue mode represents a fundamental change in the instructional strategies between the student and the computer. In both the drill and practice and the tutorial modes, the computer system has determined the material which a student will receive based upon his performance to date. In the dialogue mode, however, we find the student determining what information he wants from the computer and commanding such information from the data base. The instructional strategy now is determined by the user of the system (the student) and not by the system itself. A student can, therefore, carry on an interactive "conversation" with the computer by which he can seek solutions to various problems and request information. Such a dialogue will presumably continue until the student has either received satisfactory answers or the computer is forced to confess that the desired information is not available in the system (see Fig. 4). The dialogue mode is frequently employed at the high school level and above in those situations in which a student must demonstrate his ability to select and manage a logical series of steps required to solve a complex problem. He must have available a relatively large and sophisticated data source from which he can select and try various options leading to problem solution.

Simulation

Finally, we can utilize the computer as a means to simulate real life situations. We can, for example, expose the student to an analogy of a real-world experience by employing a computer as a surrogate for those situations in which time, costs, availability, or personnel preclude the actual experience.

RCA's approach to drill and practice

To date, RCA's instructional approach has been to concentrate on the drill and practice mode. Three courses have been prepared for utilization by elementary and secondary school students in the areas of mathematics, English, and remedial reading.

Mathematics drill and practice

The mathematics program, developed under the direction of Professor Patrick Suppes of Stanford University, is published by the L. W. Singer Company and is currently being utilized

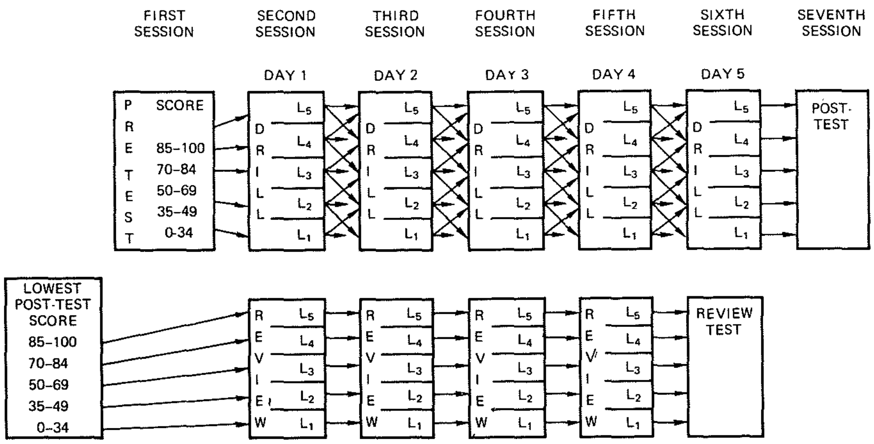


Fig. 5—Concept block for math drill and practice.

on the RCA instructional systems operating in New York City, Waterford, Michigan, and Cincinnati, Ohio.

The content of the year's work for grade levels two through six has been divided into a series of concept blocks. Each block contains lessons for seven days' work. The lessons have been arranged sequentially in blocks to coordinate with the development of mathematical concepts as introduced by popular text series. In the case of either very rapid or slow learners, concept blocks from other grade levels may be inserted in the sequence as needed.

The first day's lesson of each concept block is a pre-test. This serves to identify the level of achievement for the student on each concept block. Based on pre-test performance, a student is automatically assigned one of five lessons, each of a different degree of difficulty, the following day. Following each lesson, the student's performance is automatically computed in terms of percent correct and the student is given a lesson of greater difficulty, the same difficulty, or of less difficulty, the following day. The level of difficulty is a function of the student's performance on the previous lesson. A post-test constitutes the seventh and last day of each concept block.

Following each daily drill, students are given individual review material selected from the block in which the student had the lowest post-test score. Each student may be reviewing a different concept, again at one of five levels of difficulty as determined by the post-test score. Following four days of review, the student is given a review test. The review test score that replaces the previous post-test score will be used to determine the selection of future review lessons. The model for a typical concept block is shown in Fig. 5.

Students spend from four-to-ten minutes on drills each day and may work through material as rapidly as desired. By adjusting the difficulty level, poorer students can have successful experiences just as well as students of high ability.

CAI Elementary English

This program was developed by the Computer Curriculum Corporation and is published by Harcourt, Brace and World.

CAI Elementary English is a program of individualized practice in language arts for students in grades four, five, and six. Because the sequence of major lesson blocks can be easily changed, the program is readily adaptable for use with all popular classroom textbooks.

The curriculum data base consists of approximately one million characters. Each grade level consists of blocks of one to five lessons dealing with the same subject, called topics. There are 85 to 95 topics per grade level. Lessons are either core or supplementary, with 180 core lessons and 270 supplementary lessons for each grade. Some core lessons are overview lessons and are treated as ordinary core lessons, except each overview lesson is a topic in itself. Each lesson consists of 10 to 23 question-answer items. Students who complete the core lesson within the assigned time limit are able to receive additional practice with one or more appropriate supplementary lessons.

Because the area of language arts is often dull and boring to students, a "Gaming Technique" is employed in the presentation of this material. The average lesson has 20 items with a criterion of ten consecutive correct answers. If the student does not meet the criterion, the 20 items are presented again in a scrambled order; in fact, it is possible to replicate the presentation four times if necessary. When the criterion is met, a bell at the student station rings signaling that the "Game" is over and the student then proceeds to a more difficult lesson. An example of a typical lesson is shown in Fig. 6.

CAI Remedial reading

This program has been developed for problem readers in junior high school and is currently available from Harcourt, Brace and World. The program can also be helpful to upper grade elementary school pupils and to older students, including adults.

The remedial reading program offers individualized daily practice in selected reading skills. It is designed to diagnose reading skills first, then offer practice in the skill area in which the student appears weak, and finally, to test again for improvement.

The four major parts of the program are decoding (letter and work recognition), vocabulary (work attack skills), syntax (sentence study), and comprehension (paragraph meaning). All students begin the program with a pre-test on decoding. The program analyzes each student's command of the skills and selects a proper beginning point for practice. The student then takes a series of lessons designed to overcome his deficiency until he reaches a criterion.

A drill lessons consists of approximately 20 items, either short answer or multiple choice. Each item requires a student response of a letter, a number, or a word. If the student has not completed the criteria of the lesson when he has attempted all the items, the items are then presented again at random. Thus, the program allows a

```
PLEASE TYPE YOUR NUMBER 345
NOW YOUR FIRST NAME JOAN JOHNSON
→SUBJECTS      →LESSON 1      CRIT: 10
  (THE → SYMBOL INDICATES A CAPITAL
LETTER)
  →A NOUN IS A NAMING WORD. →A SUB-
JECT IS A NAMING WORD THAT TELLS
WHO OR WHAT THE SENTENCE IS ABOUT.
→TYPE THE NOUN THAT IS THE SUBJECT.

→THE MOUSE RAN ROUND AND ROUND.
MOUSE
MOUSE
SCORE 1
→THE CAT'S RED EYES WERE SHINING.
CAT'S
EYES
SCORE 0
→CHICO CAN STAND ON HIS HANDS.
CHICc        ←the student corrected an answer
               without penalty
→CHICO
→CHICO
SCORE 1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
→MY UNCLE BUILT US A FORT.
UNCLE
UNCLE
SCORE 9
THE LIGHTS IN THE CITY SHINE ALL
NIGHT.
LIGHTS
LIGHTS
SCORE 10

→CONGRATULATIONS, YOU WON THE
  GAME IN 16 TRIALS.
→YOUR TIME: 4 MINUTES AND 26 SEC-
  ONDS.
JANUARY 6, 1969
COPYRIGHT 1968 HARCOURT, BRACE AND
WORLD, INC.
PLEASE TEAR OFF ON DOTTED LINE.
.........................................
```

Fig. 6—Example of elementary English drill and practice (italics indicate student's response).

```
CONTRACTIONS: SUPPLYING CONTRAC-
TIONS     CRIT: 10
TYPE THE CONTRACTION THAT CAN BE
USED FOR THE WORDS IN PARENTHESES.

(WHERE IS) THE NEAREST GROCERY
STORE?
WHERE'S
SCORE 1
MOST CATS (DO NOT) LIKE WATER.
DON'T
SCORE 2
HE MUST KNOW THAT (I AM) GRATEFUL
TO HIM.
I'M
SCORE 3
THIS IS THE BEST SHOW (WE HAVE) SEEN.
WEVc
WE'VE
               ←the student corrected an answer
                 without penalty
SCORE 4
I WANT THE BOOK (THAT IS) ON THE
TOP SHELF.
THATS
ANS: THAT'S
SCORE 0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
THE SAD TIGER (DID NOT) EAT THE
MEAT.
DIDN'T
SCORE 10
GOOD WORK. YOU LEARNED AS YOU
WENT ALONG.
NOW GO ON TO THE NEXT LESSON.
```

Fig. 7—Examples of remedial reading curriculum (italics indicate student's response).

student to concentrate in the areas of his weaknesses without forcing him to repeat items for which he had demonstrated an understanding. Examples of the remedial reading curricula are shown in Fig. 7.

User development curriculum

A major innovative objective of CAI is the ability to accept teacher-written curriculum materials.

Instructional System Language I (ISL-I) is a computer language developed by RCA Instructional Systems for use by teacher curriculum authors. The curriculum author prepares courses in two distinct, but functionally dependent, parts. One of these parts is a set of instructions to the CAI system, directing it in the display of messages to student stations, acceptance of student responses, etc. This set of instructions is called a procedure program.

The other curriculum component is the curriculum data base, consisting of the questions, expected answers, and tutorial messages to be used by the procedure program. Consequently, the classroom teacher is given the opportunity to develop curriculum materials as varied as the author's imagination.

CAI reports

One of the most useful features of CAI is the ability to keep performance records. The curriculum author can specify that the computer maintain a detailed record of each session spent at a student station. The progress of each student in the course is recorded automatically during the lesson, and individual and class averages are computed during non-CAI hours.

Because bookkeeping functions are performed automatically, the teacher can rechannel time ordinarily used for correcting papers into more creative tasks. Data from performance records is used to compile statistics and generate printed reports. For example, upon completion of a drill, review, or test, the author may specify that the number (and percent) of questions correct, wrong, and timed out be displayed, along with the date, for the student and recorded on magnetic tape. This information becomes part of history and performance records used by computer programs to prepare various reports.

Administrative data processing

One of the major problems facing the educational administrator is the effective processing of the burgeoning information flow within the school systems. A major application of computer technology—administrative data processing—is designed to alleviate this problem. The three basic objectives of administrative data processing are that the data must be accurate, relevant, and timely. When these criteria are met, the administration of the school district becomes highly efficient, thus enabling the administrators, principals, and teachers to perform the creative responsibilities entrusted to them by the community.

Administrative data processing can be divided into two major divisions: 1) pupil personnel accounting and 2) financial accounting.

Pupil personnel accounting

Census

The census application system receives data from school district enumerators on a periodic basis as determined by state and Federal statutes. The collected data establishes a file which becomes the master file of the students' permanent records. This master file is used as the base for all other educational applications (attendance, grade reporting, scheduling, etc.) and, in fact, becomes the base line for a school management information system.

Attendance

This application system creates and maintains pupil attendance information through the use of the integrated master file. It is employed to generate attendance reports such as attendance registers (what students are located in what classes and in which school), cumulate year-to-date summary information, and state average daily attendance (ADA) reports.

Grade reporting

Grade reporting utilizes the master file as its base file in maintaining and updating information on pupils regarding courses taken, grades received, credits earned, and grade-point averages. It processes the data for preparation of reports such as report cards, honor rolls, failure lists, permanent record labels and other special type reporting.

Student scheduling

The major feature of student scheduling is the mechanical assignment of students to classrooms provided by the school instruction program and the preparation of a class schedule for each student. The system is organized to allow for the greatest possible latitude in section assignment philosophy so that schools with varying scheduling rules may still create student schedules and class lists by computer.

Student scheduling has traditionally been one of the most difficult and time consuming activities for a school system. Prior to the advent of an automated capability, scheduling has only been possible on an annual basis, and even then has involved the administrative team for up to six months of the year. In a typical case, students would prepare an initial registration form—indicating courses desired—in the spring of each year. These would be hand-sorted and collated by the administration, and tentative schedules prepared and distributed prior to the beginning of summer vacation. The entire summer would oft times be spent in assigning class times, instructors, class courses, and students to the various courses. In addition, a second scheduling is prepared in early summer to accommodate new registrants, departing students, and faculty changes. Finally, a third schedule is generated in late August which, on the average, would accommodate up to 90% of the schedule requirements for the next year. Under this approach, the remaining conflicts in courses, instructors, classrooms, and time would be force-fitted—generally to nobody's satisfaction.

The use of automated scheduling has drastically reduced the problem of conflicts as well as personnel involvement. The schedule program can be run frequently and with a high level of efficiency. Conflicts generally do not exceed 2%. Furthermore, variable or flexible scheduling can be instituted which allows frequent variations in class meetings, class size, periods, and student assignments. In fact, some schools are experimenting with scheduling the school on a daily basis—certainly a far cry from the yearly system in use until now.

Other benefits to the administrator through utilization of an automated system include the following: student directory information, conflict matrix, master section list, error list, class loading report; homeroom, grade and school rosters; schedule cards, list of sections taught each period of the day, list of students requesting each course, preliminary schedules, class lists, homeroom lists, class rosters, study hall lists, pupil schedules, and I.D. cards.

Test scoring and analysis

This system is a unique one by industry standards in that it utilizes a series of generalized programs that will convert raw test scores into meaningful results such as grade equivalences, percentiles, stanines, national and local norms, etc. The system presently scores, converts and performs various analyses on thirteen major standardized tests simultaneously as follows: Cooperative English Test, Iowa Test of Basic Skill, Iowa Test of Educational Development, Metropolitan Achievement Test, Sequential Test of Educational Progress, Stanford Achievement Test, California Test of Mental Maturity, Differential Aptitude Test, Kuhlman-Anderson Test, Lorge-Thorndike Test, Otis-Lennon Mental Ability Test, Otis Quick-Scoring Mental Ability Test, and School and College Ability Test. These tests were chosen as representing the most frequent requirements of the nation's schools; however, with minimal modification the program will be able to score any thirteen tests a school system desires to administer.

Financial accounting

Payroll and personnel

The payroll and personnel program has important benefits to the local school district in that it provides for the reduction of clerical effort required to prepare the payrolls and related reports, distributes payroll costs, and maintains personnel records. The centralization and consolidation of all earning and leave records in the computer helps reduce clerical costs and improve accuracy.

Combining the payroll records with other employee data records in the staff master file enables the data center to prepare reports utilizing information from both payroll and personnel records. The major features of the payroll accounting system are related to the integration of payroll data with other master file information. For example,

1) Hourly payroll time reports are computer prepared for use in reporting distribution of hours to budget codes.
2) Contracts or salary statements are prepared each spring, and salaries are increased by the yearly increment each September.
3) Sick leave and vacation leave are accrued by either a programmed rate each period or by a one-a-year increment along with salaries.
4) Contracts may be paid over any number of pay periods during the year.
5) Gross pay distributions to budget accounts are summarized for the financial accountnig systems.
6) A projection of salaries to be paid in the remaining school year is prepared each month for the financial accounting system.

Financial accounting system

This system provides for the processing of basic transactions and the preparation of required governmental accounting ledgers and reports. This includes the preparation of encumbrance, revenue, appropriations and expenditure, general ledgers and various summary reports. For example,

1) Accounting transactions are entered only once. The coding structure of the system provides the information necessary to channel the transaction to each separate ledger and report in which it must be entered.
2) Full accrual accounting procedures are provided.
3) Budgeting and reporting of appropriations and expenditures by school and district office departmental locations are provided.
4) A separate report of salary budget and expenditures is prepared. Salary contracts may be reported as encumbrances.
5) The basic account coding block and chart of accounts designed for the system are adaptable to the requirements of small, medium, and large school districts.

Educational services

Finally, we should consider how to use the computer to perform other services for the school population. Such services include at least guidance and counseling, information storage and retrieval, curriculum research and development, and learning research.

Guidance and counseling

For approximately two years, RCA Instructional Systems has been working with the Harvard Graduate School of Education in developing an automated vocational decision making system. This system, developed under United States Office of Education funds, will enable high school students to interrogate the computer regarding either vocational or academic opportunities. The student can conduct a dialogue with the computer and can discuss his academic achievements, his aptitudes, avocations, and future goals. He can either ask the computer to recommend what his future academic training or vocational choices should be, or he can state a particular choice to the computer and receive information regarding requisite additional education as well as the various social economic, ethnic, and other considerations which will affect his accomplishing these goals.

This program has been developed and tested in several New England high schools utilizing a Spectra 70/45 computer. We can anticipate that it will be expanded to afford vocational and academic information to college populations and, ultimately, to the general adult population who might be seeking information about new vocational opportunities.

Information storage and retrieval

As more and more schools acquire computers for instructional and administrative uses, we can expect that they will recognize the potential capability of applying a data processing system for information storage and retrieval. At some point in the future, we can anticipate that a system will be developed which can improve upon, if not replace, our present library system. The ultimate goal is to develop a comprehensive information system which is standardized for all school systems in the United States.

The magnitude of this task is staggering when one considers the volumes of information currently available and constantly being generated, and the incredible problem of cataloguing such information into a useful format. The Office of Education has expended considerable funds in recent years on the problem of information retrieval. Some significant results have developed for specialized library systems, such as in the fields of medicine and law, but a working solution applicable to general education is still not in sight. On the other hand, the ultimate usefulness of such a capability demands that this effort be continued.

Curriculum research and development

The lack of a wide spectrum of curriculum appropriate to a computer-assisted instructional system is the most serious limitation to an extensive implementation of such a system. The next few years must see a massive development and evaluation of curriculum which will be applicable to all grade levels from preschool through adult education.

It is not enough to take an existing textbooks and "rewrite" it in a CAI format, if the material is to be useful as a means for individualizing instruction and for taking advantage of the presentation modes unique to a computer. Instead, the curriculum author must be made completely aware of the characteristics of CAI, the modes of presentation and the instructional strategies available from the hardware and software characteristics. RCA Instructional Systems has approached this problem by working jointly with curriculum authors and publishing organizations. We have relied upon these groups to produce the subject matter of the curriculum; it has been our responsibility to instruct them in the various formats which are possible and the instructional strategies which can be employed. As computer-assisted instruction becomes more widespread and its advantages are better understood, we can anticipate more and more publishing organizations and subject authors becoming involved in curriculum development and evaluation.

Learning research

One very significant advantage of the computer as an instructional tool is the fact that it can be used as the principal medium for continuing and longitudinal educational research. The computer can store and maintain performance data for each and every use of the CAI system. It can log individual scores in each item or problem comprising the total curriculum data base. It can also be readily programmed to perform various statistical analyses. It is, therefore, possible for the learning researcher to gather his data in a rapid fashion from a large number of student-subjects and analyze these data whenever he so desires. By taking advantage of the computer's memory capacity and speeds, one can, in fact, determine the results of an experimental variable on a day-by-day basis and vary the parameters of that variable as often as is desired. With such a capability available to a research organization, we can anticipate a significant increase in the amount of learning studies being performed and the development of new learning concepts or strategies over the next several years.

Conclusion

The potential benefits of computers for education are only beginning to be explored. The approach has been, and will probably continue to be in the near future, one of trial and error in which various applications are tested and the effects on the learning process evaluated. Despite this relatively inefficient approach, we cannot help but feel optimistic regarding the potential effects of computer technology on the educational process. Results to date strongly suggest that the effects of utilizing a computer system are highly positive for students, teachers, and administrators alike, and the growing awareness of these possibilities by the educational community indicate that computer technology will continue to play an ever-increasing role in the process of education.

Reference

1. A description of the initial data processing system designed by RCA Instructional Systems for providing elementary school students drill and practice in arithmetic can be found in the article, "Engineering Aspects of Computer-Assisted Instructional Systems," by R. W. Avery, RCA reprint RE-15-1-5.

Phase-locked parametric frequency dividers

W. J. Goldwasser

Binary dividers are used extensively in frequency generation and measurement equipment. The most basic form of the divider is the flip-flop which may be in monolythic form for input frequencies below approximately 300 MHz, or in discrete form for frequencies up to approximately 500 MHz. Above 500 MHz, however, the delay times associated with transistors make them unsuited for divider operation. This article describes the operation of, and gives detailed design information for, parametric dividers—devices which will divide frequencies into the GHz range while keeping the divided signals phase locked to the input. The ability to keep the output locked to the input phase makes these devices very attractive for use in Digital Frequency Synthesizers, but the design information given here will work equally well for any divider application.

IN 1959, three articles[1,2,3] appeared which described a parametric subharmonic oscillator for use in digital computers. These subharmonic oscillators were capable of dividing frequencies up to several GHz by a factor of two. They were originally intended to be used as phase storage elements for digital computer memory circuits, but they can also serve as frequency and phase dividers.

Parametric dividers

Parametric dividers are ideally suited for almost any frequency-dividing job, for several reasons:

1) *Broad operating range*—parametric dividers can divide in octave steps from 100 to several thousand MHz;
2) *Low cost*—they can be manufactured very inexpensively; and
3) *Small size*—they can be built on less than one square inch of printed-circuit-board area.

The parametric subharmonic oscillator, or parametric divider, consists basically of a varactor diode. When a varactor diode is driven by a source of RF energy at a radian frequency of $2\omega_0$, a negative conductance appears across the diode terminals. This negative conductance starts and sustains an oscillation at the subharmonic radian frequency of ω_0[6]. These subharmonic oscillations are phase stable and phase locked to the driving signal. Although division by numbers other than two is possible with the use of idler circuits, the reduced efficiency and, especially, the phase instability at the output makes them less attractive than the divide-by-two circuits, and therefore only the divide by two circuit will be discussed here.

To effectively use the subharmonic energy generated by the diode oscillations at ω_0, a means must be provided to isolate the ω_0 signal from the $2\omega_0$ source while passing it to the load, and at the same time assuring that maximum $2\omega_0$ energy is passed from the source to the diode. The tuned circuits of Figs. 1 and 2 provide the required isolation.

If ω_p, in Fig. 1, is set equal to $2\omega_0$, the tank circuit will provide a short circuit at ω_0 and an infinite impedance at $2\omega_0$. It would therefore be suited as an input tuning circuit to our divider. Likewise, setting ω_p equal to ω_0 in Fig. 2 would provide a circuit with an infinite impedance at ω_0 and a short circuit at $2\omega_0$. Combining the two tanks with our diode and a simple self bias circuit results in the circuits of Figs. 3 and 4.

Inductor L_2 in Figs. 3 and 4 is picked to resonate with the total diode capacitance, C_T, which is the sum of the diode package capacitance, C_p, and the diode capacitance, C_i, which exists at the fixed bias voltage, V_i, at the median frequency of interest, or at

$$\omega_{med} = \frac{2\omega_0 + \omega_0}{2} = \frac{3\omega_0}{2}$$

The instantaneous junction capacitance of a varactor diode, C_i, varies with the instantaneous voltage, V_i, applied across the diode:

$$C_i = \frac{C_0}{\left(1 - \frac{V_i}{\phi}\right)^n} \qquad (1)$$

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received the BSEE from the Georgia Institute of Technology in 1967. Mr. Goldwasser is currently attending Northeastern University where he will complete the requirements for the MSEE. After his graduation in 1967, Mr. Goldwasser joined the engineering staff of Collins Radio in Dallas, Texas. He worked as a research and development and design engineer on various military and commercial products. He was jointly responsible for the design of a lightweight, low-power digital frequency synthesizer for avionics use in distance measuring equipment. He was jointly responsible for redesign work on a Troposhere Scattering Communications set used in southern Asia. Before leaving Collins, Mr. Goldwasser was engaged in the design of VHF and UHF digital frequency synthesizers. Since joining RCA in 1968, Mr. Goldwasser has been engaged in the design of DIMATE III and IV, the Depot Installed Maintenance Automatic Test Equipment. Mr. Goldwasser is currently working on a new frequency synthesizer and fixed frequency multipliers for the VHF, UHF, and microwave bands.

Here, ϕ is the diode contact potential approximately 0.7 volts for silicon); C_0 is the zero-bias capacitance; C_i is the capacitance at a reverse-bias voltage of V_i; and n is approximately ½ for abrupt-junction diodes and approximately ⅓ for graded-junction diodes[4].

Capacitor C_1 (Figs. 3 and 4) is picked to offer a minimum AC impedance at $2\omega_0$, and C_5, is picked to offer a minimum AC impedance at ω_0.

C_1 and R_1 form the self-bias circuit. On the first positive swing of the RF drive signal, C_1 appears as a short circuit. Therefore, CR_1 is forward biased, drawing current through C_1, and charging it to the peak value of the drive signal. However, C_1 can not discharge through CR_1 during the rest of the drive cycle because the diode is back biased. Therefore, C_1 acts as a bias source for the diode back biasing it at 1.414 volts (E_{gen}). R_1 is chosen to make the product R_1C_1 equal to approximately $100/\omega_0$. It provides a high impedance discharge path for C_1. R_2 is a large resistor, approximately 10kohm, and is used to prevent parasitic oscillation of the diode.

The AC steady-state equivalent circuits of Figs. 3 and 4, shown in Figs. 6 and 7, respectively, for both $2\omega_0$ and ω_0, show how maximum power is transferred to the diode at $2\omega_0$, and to the load at ω_0.

The only circuit component remaining to be chosen is the diode itself. The choice of the varactor diode used in the divider is based on three parameters: the breakdown voltage, the junction capacitance, and the quality factor.

The breakdown voltage of the diode selected must be greater than the peak-to-peak RF voltage that will exist across the diode.

The junction capacitance of the diode chosen should be as low as possible. Either C_0, the zero bias capacitance, or C_X, the diode capacitance at a reverse voltage of X volts, normally 6V, will be specified by the diode manufacturer. If C_X is specified, C_0 must first be calculated using Eq. 2.

$$C_0 = C_X\left(1 - \frac{V_X}{\phi}\right)^n \qquad (2)$$

Then, substituting either the given or the calculated C_0 into Eq. 1, the capacitance at the desired bias point, C_i, can be calculated. The value of capacitance used for the calculation of the series inductor, L_2, is the value of C_i plus the diode package capacitance, C_p.

$$C_T = C_i + C_p \qquad (3)$$

Glass-bead and pill-type diodes have a package capacitance of approximately 0.2 pf. Low values of C_T permit L_2 to exist in a physically realizable form.

The diode quality factor, Q_D, is a function of the desired operating frequency, 2ω, and the maximum operating frequency of the diode:

$$Q_D = \frac{\omega_{max}}{2\omega} = \frac{f_{max}}{2f} \qquad (4)$$

The maximum operating frequency

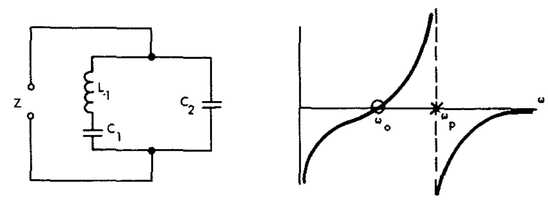
$$f_{max} \simeq 1/t_t \qquad (5)$$

where t_t is the diode transition time. For the divider to function, $Q_D > 6$ for abrupt-junction diodes and $Q_D > 4$ for graded-junction diodes[5].

Other versions

Parametric design is not limited to the PI and T-coupled versions only. Other types may also be built. A transistor with a high F_T may be used in a parametric divider by using its collector-to-base capacitance as the nonlinear subharmonic oscillator element. Inserting the tank circuit of Fig. 1 between the base and ground (or the tank circuit of Fig. 2 between the output and ground) and tuning C_{CB} to ω_{med} with an inductor in the base lead, a divider with a limited bandwidth and low loss can be built.

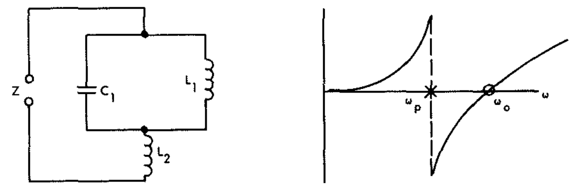
For operation above approximately 600 MHz, the discrete elements used in the input and output tank circuits become extremely small, and distributed elements should be used. The input tank can be replaced with an open-circuited length of transmission line that is $\lambda/2$ at the input frequency, $2\omega_0$. The output tank is the same length as the input line, but it is short circuited. The input tank, therefore, appears as an open circuit to $2\omega_0$ and a short circuit to ω_0 and the output tank appears as an open circuit to ω_0 and a short circuit to $2\omega_0$. When calculating the



$$Z = \frac{\left(\frac{1}{\omega C_2}\right)\left(\omega L_1 - \frac{1}{\omega C_1}\right)}{j\left(\omega L_1 - \frac{1}{\omega C_1} - \frac{1}{\omega C_2}\right)} = -j\left(\frac{1}{\omega C_2}\right)\left(\frac{\omega^2 - \omega_o^2}{\omega^2 - \omega_p^2}\right)$$

where $\omega_o^2 = \frac{1}{L_1C_1}$, $\omega_p^2 = \frac{1}{L_1C_T}$, and $C_T = \frac{C_1C_2}{C_1 + C_2}$

Fig. 1—Tuned circuit.



$$Z = j\omega L_2 + \frac{j\omega L_1}{1 - \omega^2 L_1C_1} = j\omega L_2\left(\frac{\omega^2 - \omega_o^2}{\omega^2 - \omega_p^2}\right)$$

where $\omega_o^2 = \frac{1}{L_TC_1}$, $\omega_p^2 = \frac{1}{L_1C_1}$, and $L_T = \frac{L_1L_2}{L_1 + L_2}$

Fig. 2—Tuned circuit.

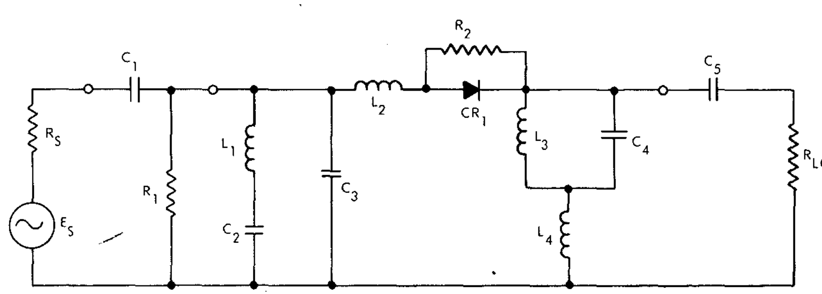


Fig. 3—PI-coupled parametric divider.

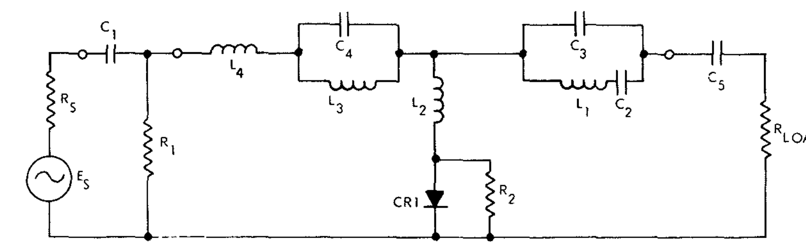


Fig. 4—T-coupled parametric divider.

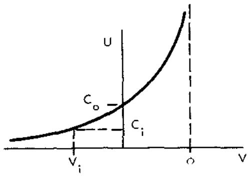


Fig. 5—Typical voltage-capacitance characteristic.

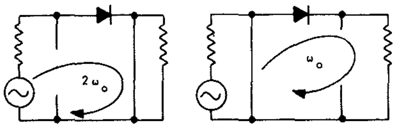


Fig. 6—PI-model—AC steady state equivalent circuits.

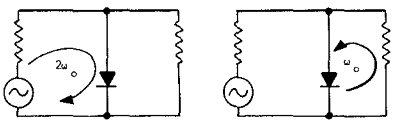


Fig. 7—T-model—AC study state equivalent circuits.

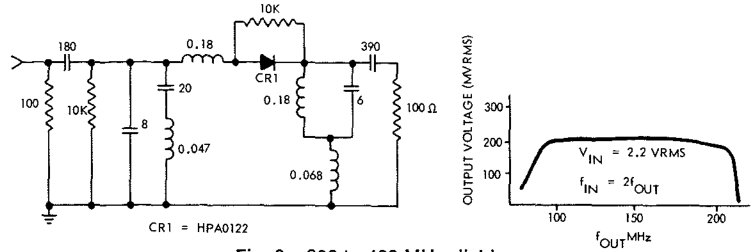


Fig. 8—200 to 400 MHz divider.

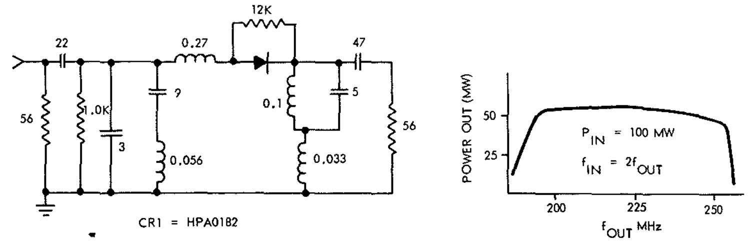


Fig. 9—1 to 1.2 GHz divider.

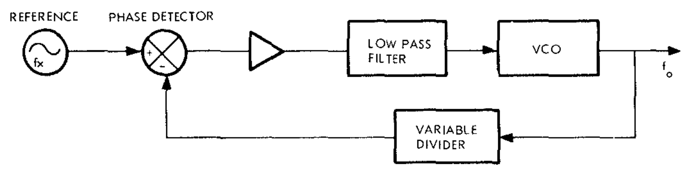


Fig. 10—Phased-locked loop of digital frequency synthesizer.

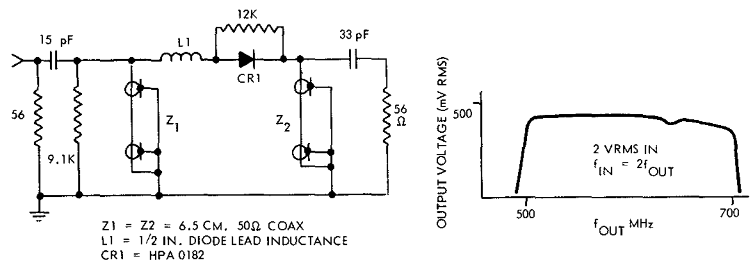


Fig. 11—400 to 500 MHz divider.

actual length of the two stubs, the velocity coefficient of the conductor must be considered.

Parametric dividers may also be tuned to divide by numbers such as 3, 4, 3/2, 7/2, etc., but the idler circuits and power required do not make them desirable at this time.

Several dividers operating from 100 MHz to 2 GHz have been built using the summarized design procedure given in Tables I and II. The circuits for two of these dividers, along with the output waveform for each, are given in Figs. 8 and 9. Note in Fig. 9 that the input tank (consisting of L_1, C_2, and C_3) and the output tank (consisting of L_3, L_4, and C_3 of the PI-configured divider have been replaced with a transmission line. Z_1 is an open-circuited transmission line which is approximately a half wavelength long at the median input frequency (1200 MHz) and, therefore, a quarter wavelength long at median output frequency. It therefore acts as an open circuit at $2\omega_0$ and a short circuit at ω_0. Z_2 is a short-circuited transmission line which is the same length as Z_1. It therefore appears to be an open circuit at ω_0 and a short circuit at $2\omega_0$. Naturally, Z_1 and Z_2 can also be made using microstrip-transmission-line techniques.

Design example

This example will illustrate the design a divider for the phase-locked loop of a 400 to 500 MHz digital frequency synthesizer having an output of 100 mW. It is desired to have fifty channels spaced two MHz apart. In the phase locked loop of a digital frequency synthesizer (Fig. 10) a portion of the final output signal, f_0, from a voltage controlled oscillator (VCO) is fed back to its input through a variable frequency divider which is programmed to divide by a given number, N. The output of the divider, f_0/N, is then compared, in a phase detector, with the f_x, the output of a stable source—normally a crystal oscillator. The phase detector output is a function of the phase or frequency difference between the two inputs. This signal is then converted to a DC ramp by a low-pass filter, and this ramp voltage then is used to bias a variable capacitance diode in the VCO tank circuit. The change in diode capacitance causes a frequency output change which is now passed through the divider back to the phase detector. When f_0/N is equal to f_x, a constant output voltage, rather than a ramp, is produced by the phase detector and low pass filter which keeps the VCO on the desired frequency.

To supply the 50 channels required by our example requires a variable divider with 50 steps. There are no commercial dividers available which operate to 500 MHz, but if we first use a parametric divider to divide the output by 2, we can then use integrated circuits to divide the 200 to 250 MHz resultant signals by 200 to 250. Using a 1-MHz crystal oscillator, we require that the final divider output, f_0/N, be 1-MHz to keep our loop "locked."

In other words, if the variable divider is set to 200, the total divide ratio will be 400, and the VCO output must therefore be 400 MHz for a locked condition to exist. At N = 225, f_0 must be 450 MHz, and for N = 250, f_0 must be 500

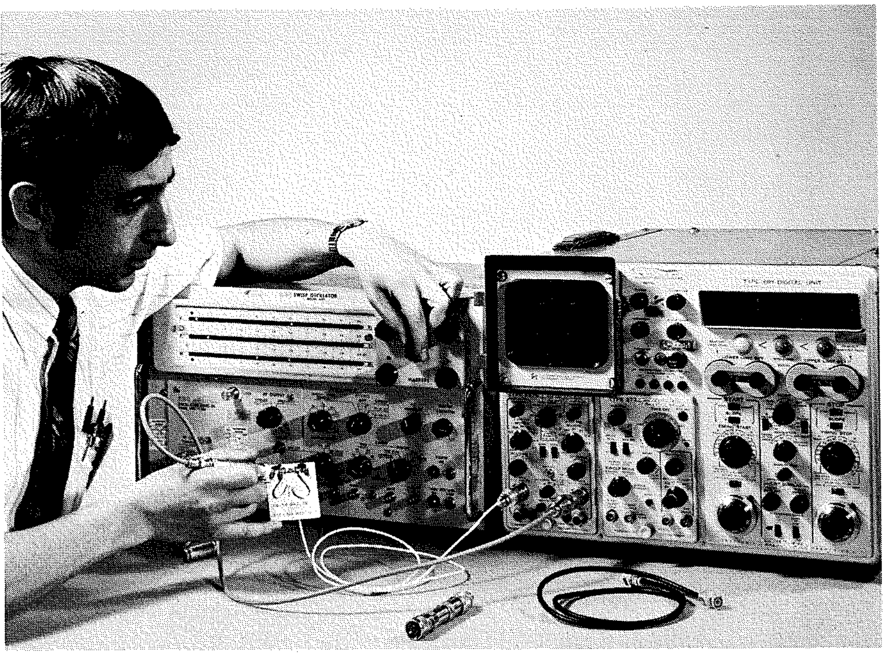


Fig. 12—Author demonstrating performance of frequency divider.

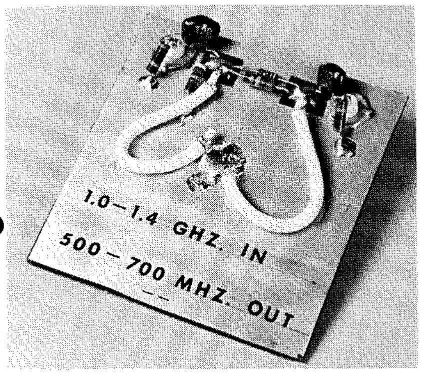


Fig. 13—Frequency divider.

MHz. This system gives us the required 50 channels spaced 2-MHz apart.

The parametric divider required to divide from 400 to 500 MHz will now be designed using the procedure of Table I.

1) The median input frequency is 450 MHz. With an available signal level of 100 mW, there will be 6.2 Vpp across the 50-ohm circuit.
2) A Hewlett-Packard 0182 step recovery diode with a specified C_o of 2.0 pf, a breakdown voltage of 35 volts, and a transition time of 200 ps is chosen.

$$f_{max} \simeq \frac{1}{t_t} = \frac{1}{200\text{x}10^{-12}} = 5\text{x}10^9$$

Therefore,

$$Q_D = \frac{2f}{f_{max}} = \frac{500 \text{ MHz}}{5 \text{ GHz}} = 10 > 6$$

3) With a 6.2 Vpp input level, the diode capacitance, C_i, will be

$$C_i = \frac{C_o}{\left(1 - \frac{V_B}{\phi}\right)^n} = \frac{2.0}{\left(1 + \frac{-6.2}{0.7}\right)^{1/2}} = 0.64 \text{ pf}$$

$$C_T = C_p + C_i = 0.2 + 0.64 = 0.84 \text{ pf}$$

$$f_{med} = \frac{2f_O + f_O}{2} = \frac{450 + 225}{2} = \frac{675}{2} = 337.5 \text{ MHz}$$

Therefore,

$$f_{med} = \frac{1}{2\pi\sqrt{L_2 C_T}} \text{ or } L_2 = \frac{1}{4\pi^2 f^2_{med} C_T}$$

$$L_2 = \frac{1}{4\pi^2 (337.5\text{x}10^6)^2 0.84\text{x}10^{-12}} = 0.265\ \mu\text{H}$$

4) Choose $L_1 = 0.056\ \mu$H. To resonate at the median output frequency of 225 MHz, $C_2 = 9$ pf.
5) Therefore, the required total capacitance to resonate with 0.056 μH at 450 MHz is $C = 2$ pf. Therefore, 2 pf$= C_2C_3/(C_2 + C_3)$ or $C_2 = 3$ pf.
6) Choose $L_3 = 0.1\ \mu$H. This required C_4 to be 5 pf to resonate at 225 MHz.
7) To resonate with 5 pf at 450 MHz required an $L = 0.023\ \mu$H. Therefore, $0.023 = 0.1L_4/(0.1 + L_4)$ or $L_4 = 0.030\ \mu$H.
8) At 450 MHz, a 22-pf capacitor with 0.25-inch leads is approximately a short circuit, and at 225 MHz, a 47-pf capacitor is approximately a short circuit. $C_1 = 22$ pf, $C_5 = 47$ pf.

9) $$R_1 = \frac{100}{\omega C_1} = \frac{100}{2\pi (450\text{x}10^6)(22\text{x}10^{-12})} \simeq 2k\Omega$$

The final circuit with its operating curve is shown in Fig. 11.

Table I—Design procedure for discrete-coupled parametric divider.

1) Determine the required operating frequency range and the maximum peak-to-peak voltage available to drive the circuit.

2) Choose a varactor diode considering its breakdown voltage, zero bias capacitance, and quality factor.

3) Compute C_T and choose an L_2 which will resonate at ω_{med}.

4) Choose an L_1 and a C_2 which will resonate at ω_0—the center of the output frequency range.

5) Compute C_3 necessary to resonate with L_1 and C_2 at 2 ω_0—the center of the input frequency range.

6) Choose L_3 and C_4 to resonate at ω_0.

7) Compute the L_4 required to resonate with L_3 and C_4 at $2\omega_0$.

8) Choose a C_1 which will appear series resonate at $2\omega_0$, and choose a C_5 which will be seried resonate at ω_0.

9) Find $R_1 = \frac{100}{\omega_0 C_1}$

10) An R_2 of approximately 10k should stop any parametric oscillator.

Table II—Design procedure for distributed-element parametric divider.

1) Determine the required operating frequency range and the maximum peak-to-peak voltage available to drive the circuit.

2) Choose a varactor diode considering its breakdown voltage, zero bias capacitance, and quality factor.

3) Compute C_T and choose L_2 which will resonate with it at ω_{med}.

4) Calculate the length of Z_1, a half-wave length of open circuited transmission line or microstrip, at $2\omega_0$, taking into effect the velocity constant of the line.

5) Make Z_2 the same length as Z_1, only short-circuited.

6) Choose a C_1 which will appear series resonance at $2\omega_0$ and choose a C_5 which will be series resonant at ω_0.

7) An R_2 of approximately 10k should stop parametric oscillations.

8) Find $R_1 = \frac{100}{\omega C_1}$

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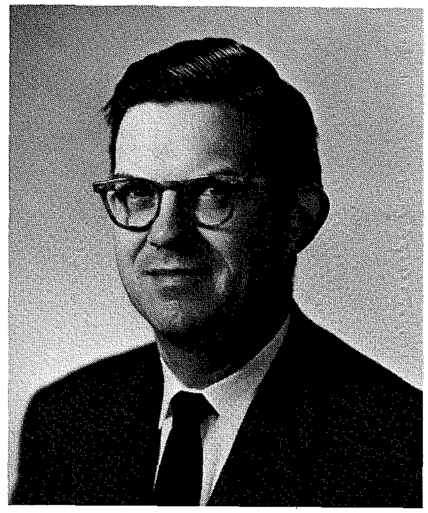
A simple stable temperature controller for resistance-bulb or thermistor sensors

H. O. Hook

A temperature controller has been designed and constructed which provides ±1°C temperature control with either thermistor or resistance-bulb temperature sensing. It can be built in our shop for less cost than comparable purchased units and has been built in large enough quantity to evaluate the reliability. Experience to date indicates that of ten units one might expect 2 failures per year. With a stable pre-amplifier, it is possible to control to ±0.001°C, using a resistance bulb, or even better by using a thermistor.



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received the BA with chemistry major from Elon College in 1947, and the BEE from North Carolina State College in 1949. In 1950, he received the MSEE from the same College. Since 1950, Mr. Hook has been with the RCA Laboratories where he is Manager of the Photochemical and Chemical Processing Group. He holds several patents relating to display-storage tubes and solid-state display devices. As a member of the Technical Staff, he worked on opto-electronic computer components, vacuum technology, color picture tubes, and the optics of displays. Mr. Hook is a Senior Member of IEEE and a member of the Instrument Society of America, the American Vacuum Society, and the Society of Photographic Scientists and Engineers.

The regulation and control of temperature is a common laboratory problem. This paper describes a simple temperature controller capable of holding most ovens and furnaces to a temperature variation of less than 1°C. With platinum resistance bulb sensors, high accuracy is maintained to 750°C. Reduced accuracy and gradual change in the platinum resistance thermometer may result when it is operated at temperatures up to 1000°C or higher. Thermistor sensors provide even closer control over restricted temperature ranges up to 350°C (650°C with diamond thermistors). The controller is complete and self-contained including the bridge necessary to operate the resistance thermometer, the control amplifier, and the control circuitry for operation on 120 or 208 volts with loads up to 32 amperes depending upon the selection of the SCR's used in series with the load. More than 100 of these units have been constructed and are in use in RCA Laboratories.

Choice of temperature-sensing element

Many types of transducers may be used to produce an electrical signal corresponding to the temperature which one desires to control. Thermocouples seem to be the sensors most frequently used in the past. Thermistors and resistance thermometers using pure metal wire such as platinum or nickel have been used less although, in their usable temperature ranges, they offer substantial advantages compared to the thermocouple. Thermistors have high sensitivity but are usually limited to upper temperatures of the order of 350°C. Between room temperature and 350°C they change by a factor of 10^3 in resistance. This large change in resistance makes their application somewhat unwieldy except for narrow temperature ranges. Platinum resistance thermometers are particularly good because the resistivity of platinum is well tabulated and changes nearly linearly as a function of temperature. They may be used at temperatures as high as 1000°C with good reliability and accuracy. The signal power from a platinum resistance thermometer bridge is 10,000 times larger than that from a thermocouple which makes the amplifier design much easier. In addition, the stability and repeatability of platinum resistance thermometers is superior to thermocouples. (The Bureau of Standards uses platinum resistance thermometers as standard interpolation thermometers between −100°C and approximately 700°C.) Thermistors may be used with these units by changing the value of the standard resistor in the bridge circuit; however, they must be selected to have a resistance at the required operating temperature somewhere between 1000 and 5000 ohms. Above 5000 ohms, the resistance of the thermistor is greater than the amplifier input resistance which reduces the sensitivity; below 1000 ohms, the power input to the thermistor may result in thermal runaway. The range may be extended to lower resistances if the thermistor is in good thermal contact with a large thermal mass so that thermal runaway is prevented.

Another advantage of the resistance thermometer as a temperature sensor is its freedom from room-temperature and lead-wire limitations. With thermocouples, the potential output is always a function of the cold-junction temperature. Often the cold junction is at room temperature so that the sensed temperature varies directly with the room temperature. In other instances, the cold junctions are at unknown temperatures resulting in large errors. For a platinum resistance thermometer, long lengths of small copper wire can be used and allowed to cycle over large temperature excursions with only minor errors in the sensed temperature.

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For example, if the leads have one-half ohm resistance and are of copper (40 foot extension with #18 wire), the error in the temperature measurement is only 1% of the temperature fluctuation of the leads when used with a 50-ohm resistance thermometer. These effects are at least a factor of 10 smaller with thermistors which operate at higher resistances.

Application

Fig. 1 is a photograph of a typical portable temperature control unit; Fig. 2 is a photograph of the rack-mounted version. The meter indicates approximately the difference in actual sensor temperature and the temperature corresponding to the dial setting on the Helipot. The three binding post terminals on the front are used for external programming or range extension. The two binding post terminals on the rear, which are not visible in the photograph, are the terminals to which the resistance thermometer or thermistor is attached. The back of the unit is marked with the resistance of the Helipot (either 100 ohms for units intended for platinum resistance thermometer or 10 K for units intended for use with thermistor). The dial may be read directly in ohms using proper location of the decimal based on full-scale resistance. The temperature for which the controller is set is determined by the resistance reading of the Helipot dial plus whatever series resistor may be connected between terminals A and B on the front. By referring to a table or curve of resistance versus temperature for the resistance thermometer, the operating temperature is determined. Fig. 3 is a calibration curve for a 50-ohm platinum sensor. To operate, the resistance thermometer is attached, the controller is plugged in, and the load to be controlled is plugged into the receptacle at the rear.

Sensor location

Generally, the sensor should be located between the heater and the heated volume. Overshoot may result if the sensor is located at the load, because a lot of heat may be stored between the heater and load by the time the heater is turned off. In this type of operation, the temperature will fluctuate and proportional control is probably no better than that which can be obtained with an on-off type of controller. However, if the temperature sensor is put sufficiently close to the heater to anticipate the heat arriving at the load, very smooth control with very little overshoot can be obtained. Some commercial controllers incorporate an anticipatory circuit to compensate for the stored heat. This circuit is sometimes tedious to adjust and has to be adjusted for each oven. Even so, it is not always possible to get correct compensation. By placing the control sensor closer to the heater and, if necessary, using another sensor for measuring the actual temperature at the load, many problems can be avoided.

Circuit description

Fig. 4 is a schematic diagram of the controllers. The controllers incorporate square-wave drive for the thyristors so that the inductive and transformer coupled loads can be operated.

A double-pole switch and two fuses are used so that the load may be fused independently of the amplifier circuitry. The load fuse, which is shown as a 20-ampere fuse in the circuit diagram, may be chosen to protect either the the SCR's or the load. The 3-ampere fuse protects the circuitry itself. The power supply is conventional using two bridge rectifiers and a half-wave rectifier to derive the several voltages needed for the controller.

Temperature sensing

The bridge rectifier connected to terminal 6 and 8 on the P6375 transformer supplies the Zener-regulated voltage for the bridge circuit in which the temperature sensor is located (Fig. 4). There are two reference arms to the bridge. One of these arms is used to derive the signal for the transistor amplifier, the other is a fixed arm which is used for the indicating meter on the front panel of the instrument. For 50-ohm platinum resistance sensors, the meter indication of ΔT in approximate degrees centigrade is quite correct for readings within $\pm 10°C$ of set point and at $\pm$ 20°C is off by about 2°. At equilibrium, the indicator is usually within $\pm 5°C$ of the set point so that ΔT can be read with confidence. The other adjustable arm goes to the transistor amplifier and allows the offset of the amplifier to be

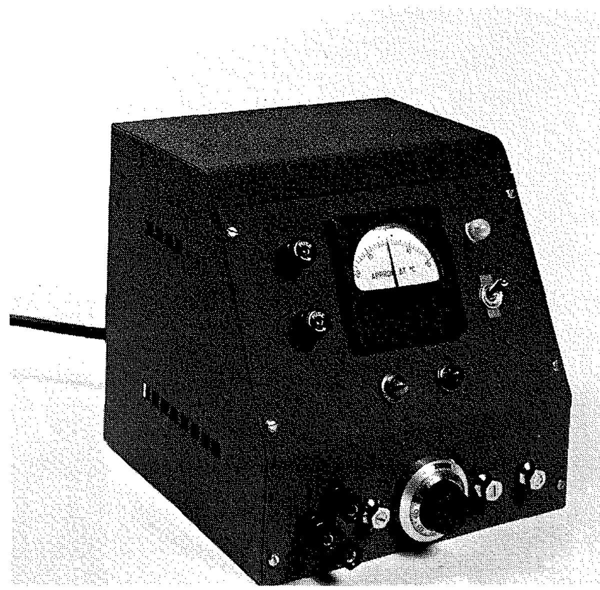

Fig. 1—Portable temperature controller.

compensated at the power level required to hold temperature. Thus, the indicator may be made to read zero. This adjustment is not required for the correct operation of the controller, but it does tend to give the operator a little more feeling of security. The adjustment is made at operating temperature by changing the setting of the potentiometer until, with the furnace at equilibrium, ΔT reads zero. Since the bridge ratio arm for the meter is fixed, when the meter is at zero the resistance of the temperature sensor may be read directly from the Helipot dial on the front of the instrument. The sensed temperature can be determined by reference to appropriate tables. The dial reading plus the ΔT reading from the front of the meter is another means of determining the actual temperature of the sensor. However, with the sensor closer to the heater than the load, this indicated temperature may be higher than the actual load temperature.

Circuit description

Transistors Q_1, Q_2 form a balanced differential amplifier with a constant-current common-emitter load which is transistor Q_3. The IN3254 diode in series with the 470-ohm resistor provides some temperature compensation. The collector of either Q_1 or Q_2 may be connected to the base of Q_4 which is a constant-current charger for the capacitor connected to the emitter of unijunction transistor (UJT) Q_5. The UJT relaxation oscillator provides the timing pulses for firing the SCR's.

Whether Q_4 is driven by Q_1 or Q_2 depends on whether the requirement is for heating or cooling. The selection is made by moving a wire link on the printed-circuit board. The B_2 voltage of Q_5 is supplied from a full-wave rectified and clipped 120-volt supply giving the 22-volt waveform shown at the top of the circuit diagram. The relaxation oscillator fires at the end of each half cycle when the B_2 voltage drops regardless of the state of charge of the capacitor at the emitter, thereby providing that the relaxation oscillator always starts fresh at the beginning of each half cycle.[1]

Power limit control

The downward excursion of the collectors of Q_1 and Q_2 is limited by the load resistors and the constant-current-emitter load Q_3. The adjustable emitter resistor for transistor Q_4 limits the maximum charging current applied to the UJT oscillator, thus controlling the maximum advance of the firing of the relaxation oscillator. For normal wide-range control the 25,000 ohm potentiometer in the emitter of Q_4 should be set to zero leaving 1600 ohms to limit the maximum current. This limitation permits the UJT to turn off reliably and provides more than 95% of maximum power.

The IN3254 diode across terminals 2 and 1 of the pulse transformer allows the capacitor charging current to flow without creating a pulse in the transformer secondary. When the UJT, Q_5, fires, the capacitor discharges through the pulse transformer firing Q_6 and Q_7 which are low-power SCR's. These, in turn, produce the pulse which lasts for the rest of the cycle and fires the high power SCR's Q_8 and Q_9. The diodes and resistors in this part of the circuit serve to limit the maximum current in the gates of Q_8 and Q_9 limiting gate dissipation while, at the same time, applying a sharp leading edge to insure fast turn-on and minimum dissipation in the load-carrying SCR's.[2] The two coils marked LF provide suppression of the high frequency components by delaying the build-up of the current through Q_8 and Q_9 by a fraction of a microsecond thereby limiting the radio frequencies produced. In addition, the 0.01 capacitor connected from the line to the load absorbs some of the surge voltage and prevents the transmission of radio frequency pulses to the power line. The two pilot lights marked OFF and ON are on the front panel—the OFF light is frosted and the ON light is red. These indicate the approximate proportion of power that is being applied to the load.

The switch in the power supply for the bridge is used to reverse the polarity of the bridge to accommodate either positive-temperature-coefficient or negative-temperature-coefficient sensors. This switch is used only with thermistor sensors since all resistance thermometers have a positive temperature coefficient. It is included on all units so that interchange from resistance thermometer to thermistor operation may be effected simply by changing the value of the Helipot or, alternatively, disconnecting the internal control and connecting a standard variable resistor to the front terminals, B and C. For a 50-ohm resistance thermometer, the 100-ohm Helipot allows temperature control up to approximately 270°C. If the jumper is removed from terminal posts A and B on the front panel and a 100-ohm precision resistor is substituted, the temperature range is then from 270°C to over 750°C. Only for the very highest temperatures need a resistor larger than 100 ohms be placed in series with the Helipot. The built-in 100-ohm Helipot, of course, allows control down to temperatures as low as those for which the resistance thermometer is calibrated, which is at least −220°C. If control of temperatures below room temperature is not required, a 50-ohm resistor could be put between terminals A and B and the dial on the 100-ohm Helipot offset so as to read 50 ohms when the Helipot is against its lower stop. The 15-turn dial now reads total resistance directly up to 150 ohms which corresponds to approximately 560°C. Fig. 3 is a graph of resistance vs. temperature for a 50-ohm platinum resistance thermometer.

External programming

The provision of the terminals A, B and C on the front panel allows several types of external programs. By disconnecting the link or resistor between A and B and using these two terminals for an external programmer, the internal Helipot can be used as a series resistor to limit the lowest temperature to which the program will go (using a resistance thermometer.) If terminals B and C are used, the internal Helipot is completely disconnected and the program is entirely under the control of the external programming resistor. Any type of programmer which provides the necessary resistance changes can be used.

Troubleshooting and initial calibration

For initial calibration and troubleshooting, a 50-ohm resistor is connected

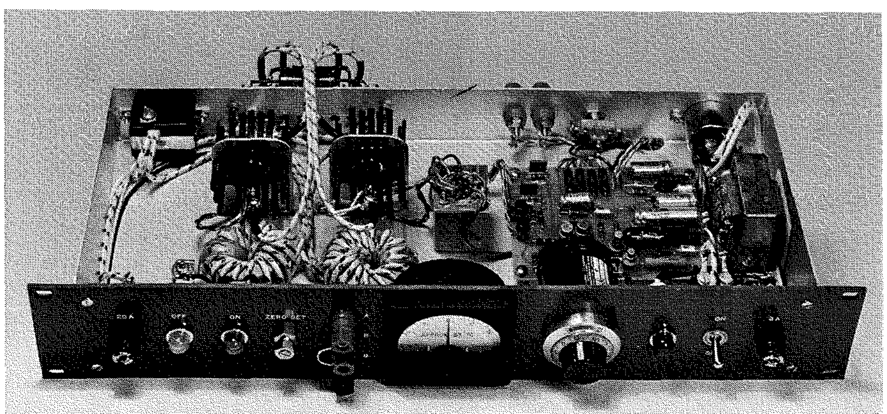

Fig. 2—Rack-mounted temperature controller.

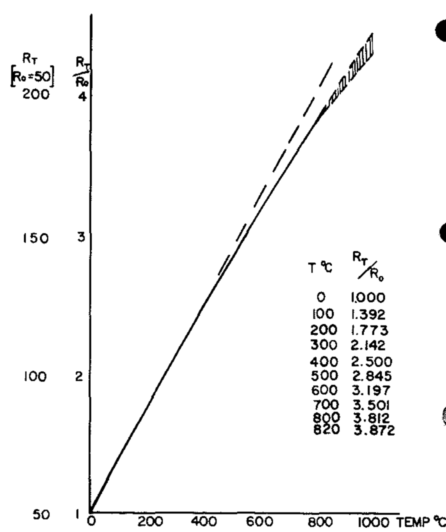

Fig. 3—Typical calibration curve for a platinum resistance sensor.

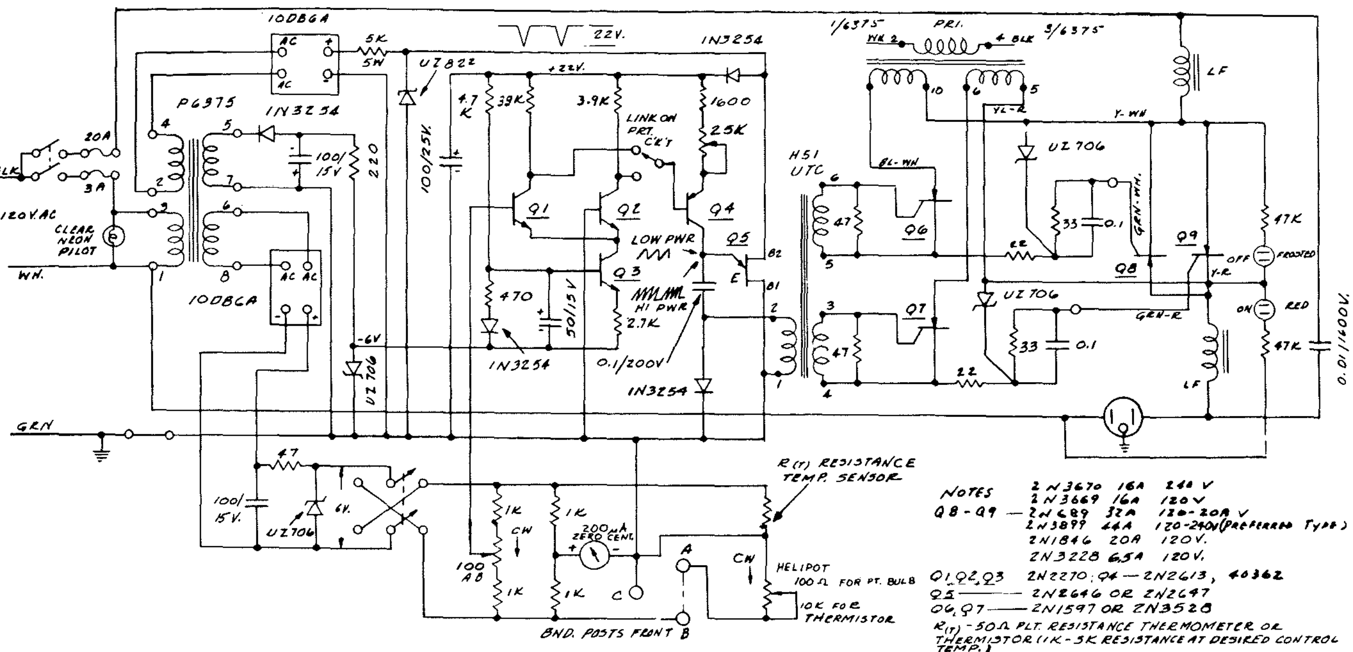

Fig. 4—SCR control unit.

on the rear terminals (R_T) and an incandescent lamp load plugged into the power-out receptacle. Setting the Helipot to 50 ohms should cause the meter to come to zero indicating bridge balance. At this point, the screwdriver-adjust pot on the front panel can be set to give about 50% of full-power output. Control effected by moving the Helipot back and forth from full-on to full-off should occur for about a swing of 10 to 15°C as indicated by the meter on the front panel. If the unit passes this test, it is operating normally and any difficulty is somewhere else in the circuit. If the unit fails this test, it will usually do so in one of a very few ways described below.

If the power remains full on (or half on) look for a short in both (or one) of the power thyristors, Q_8 and Q_9. If power is off all the time, the power thyristors may be open or the signals may not be getting through from earlier in the amplifier. To check for opened thyristors, the gates may be connected to the anodes through resistors (10 Kohm is typical) which should apply full power to the load. No power applied to the load indicates that both thyristors are defective, half power indicates one is defective. Checking beyond this point is best done by using an oscilloscope. The waveshapes at several critical points are indicated on the circuit diagram. A differential input oscilloscope allows one to look at the gate pulses on Q_8 and Q_9 without having to see it as a tiny pip on a large line voltage. As the control is advanced from no power to full power, the gate voltage should go from a short pulse at the end of the half cycle to a square wave (perhaps with a rounded top), the leading edge of which moves forward in the cycle as the power called for is increased. These wave shapes are triggered by the first relaxation oscillation of unijunction transistor Q_5 in each half cycle. Therefore as power demanded increases, the oscillation frequency of Q_5 should increase.

The selection of higher beta transistors for Q_1 and Q_2 will allow the current drain on the bridge to be reduced and consequently a higher resistance level to be used with thermistor operation. If silicon transistors for Q_1 and Q_2 can be chosen with betas of the order of 200, thermistor resistances as high as 10,000 ohms at operating temperature, can be used.

Other applications

Addition of a high-gain operational amplifier as a preamplifier along with some care in eliminating of thermal potentials and providing a high precision bridge allows a temperature controller to be built which controls to the order of ± 0.001°C using a platinum resistance bulb sensor. Even tighter control can be obtained using thermistors. However, the stability of the thermistor is probably no better than 0.0002°C. Admittedly most processes do not need such accurate temperature control, but some processes *e.g.*, crystal growth may require monotonic temperature changes at a very slow rate so that such precise control would be necessary in order to provide the desired program. With a sufficiently stable preamplifier, thermocouple input may be used where the maximum permissible temperature of the platinum resistance sensor is not high enough. The type S thermocouple and the type R thermocouple using platinum and platinum-rhodium alloys are useful to 1500°C, which is 500° above the temperature at which the platinum resistance bulb may be used. An optical sensing arrangement probably can be made for the temperature range above which any thermocouple or resistance sensor can be used.

Acknowledgment

E. Watson planned the printed circuit boards and chassis layout. P. Herkart originally suggested the use of platinum resistance thermometers. Many users have made helpful suggestions for improvements.

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Today's design problems require computer-aided thinking

W. P. McDonald

This paper discusses a new approach to engineering design based on system simulation, which can provide the engineer with 1) the dynamic engineering models he needs to find creative solutions to today's complex design problems; 2) a computer configuration with the necessary excellent engineer-model communication; and 3) an engineering design cycle which is compatible with our design automation goals. The final section of this paper discusses the ASD plans to develop new design techniques by increasing our system simulation capability.

THE TREND IN ENGINEERING DESIGN is toward systems that are more complex and more nonlinear. The increased complexity is due to the impact of integrated circuit techniques which are literally making yesterday's systems today's subsystems, and yesterday's subsystems today's components, by removing the restriction on the number of discrete components that can be economically used. The increased nonlinearity is introduced by integrated circuits and by the increasing use of nonlinear designs to achieve optimum performance. The increased complexity requires the use of more sophisticated techniques, such as computer-aided design. However, the increased nonlinearity raises questions concerning the assumptions on which the present building block approach to system design is based.

Linear and nonlinear systems

Definitions

The field of control system design provides definitions of linear and nonlinear which are sufficiently general to apply to circuits and components as well as systems and subsystems. A *linear system* is one that may be described by linear equations, and to which the principle of superposition applies. In a linear system, the output does not contain frequencies not present in the input, and the stability may be uniquely defined. A *nonlinear system* is one that requires nonlinear equations for its description, and to which the principle of superposition does not apply. A nonlinear system cannot be described in terms of a few parameters (frequency, amplitude, phase, etc.), its output may contain frequencies not present in the input, and its stability cannot be uniquely defined.[1]

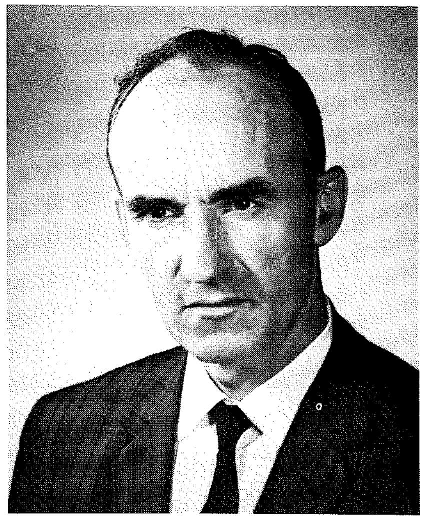
These definitions indicate the source of many of the systems integration problems our present system design approach is encountering. The term *linear system* refers to a hypothetical system whose behavior can be described by linear analysis theory, while *nonlinear* refers to systems which are not linear. A more precise definition of nonlinear is not possible because there is no general theory for the analysis of nonlinear systems. This distinction between linear and nonlinear systems did not arise from the nature of physical systems, but from the availability of analysis techniques for linear systems. The real world of physical systems (hardware in its operational environment) with which the engineer must ultimately deal is not linear.

For example, a "linear" servo loop can be completely designed on paper, and if the design is conservative and high quality components are used, the hardware will probably meet the design specifications with only a few minor adjustments. However, if the same servo loop must be built with limitations on the available space and power, then the nonlinearities in the components (friction, backlash, saturation, etc.) become significant and are very likely to make the ideal linear design completely unrealstic. It is at this point that we need to examine our approach to system design.

System Design

Present system design is based on a building block approach. That is, the system to be designed is divided into discrete subsystems which are analyzed and designed, and the resulting hardware is assembled to form the system. This is a reasonable approach for a system, since linear theory allows the system performance to be predicted based on the performance of discrete subsystems. There are some systems integration problems encountered with this approach due to the inherent nonlinearities in the hardware; however, the experienced design engineer can usually cope with these problems by using his knowledge of hardware characteristics.

When there are significant nonlinearities designed into the subsystems as well as the inherent nonlinearities in



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received the BS in Physics from Massachusetts Institute of Technology in 1950. At the MIT Flight Control Laboratory from 1952 to 1955, Mr. McDonald was responsible for the design of airborne electronic systems for the pre-flight and inflight checkout of fire control and missile systems. He joined RCA in 1955, and has been active in the areas of research flight simulation, simulation studies of the SAGE system, analysis of guidance and control problems, the application of system simulation to engineering design, and the engineer application of computer time-sharing. For the past nine years, Mr. McDonald has been head of the RCA Burlington Analog Computer Facility, for three years he was responsible for the operation of the Air Force Cambridge Research Laboratory, Analog Computer Facility, under an Air Force Contract to RCA, and for the past two years has been responsible for the engineering time-sharing computer facilities.

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the hardware, or when space and power limitations preclude conservative design, the actual system performance can be quite different than the performance predicted by linear or linearized analysis. In this case, even the experienced design engineer may find it difficult to explain the behavior of the hardware or to suggest design changes because it is quite likely that each of the subsystems is performing according to its specifications. At this point in the design cycle we usually ask "what is wrong with the hardware?" and we make design changes in the hardware to improve its performance. This reaction reflects the fact that most engineers have been trained to design linear systems and to work with linear or linearized math models. As a result, component nonlinearities are considered to be faults which should be corrected so that the components will be more ideal.

The advantage of this design approach —the tremendous simplification analysis—is now being outweighed by its disadvantages: the unnecessarily high quality required of components, the severe restrictions in the realizable system properties, and the serious integration problems caused by the widening gap between the ideal linear model and the actual nonlinear hardware.

System simulation

System simulation was developed to deal with complex nonlinear systems, such as aircraft, missiles, and space vehicles. The initial purpose of this simulation was to reduce the amount of direct testing of vehicles required by allowing designs to be tested before fabrication. As systems became more complex, the role of simulation expanded to include the design of the electronic systems as well as the vehicle.

System simulation allows the system engineer to construct a realistic system model which is easy to manipulate and which includes all the subsystems and the system environment. The model can then be used as a design tool.

The compelling advantage of system simulation is that it provides the system engineer with a means of studying the system performance in a realistic environment without being restricted

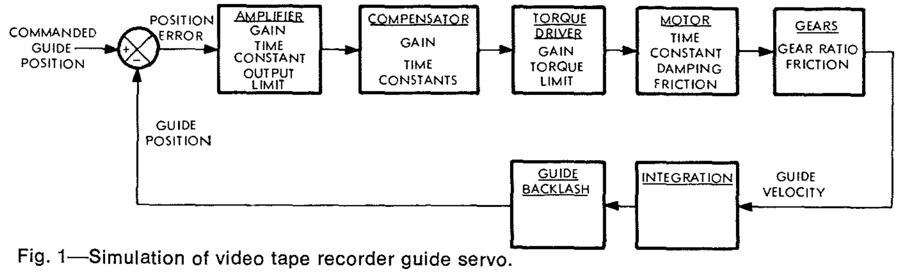


Fig. 1—Simulation of video tape recorder guide servo.

to linear or linearized models, and without the limitations of the building block approach.

The application of system simulation techniques to actual engineering problems can be illustrated by two studies performed on the ASD analog computer. These were studies of systems integration problems made after the design was completed. Many of these systems integration problems could have been been avoided by making use of system simulation techniques during, rather than after, the design phase.

Video tape recorder guide servo

ASD was requested to redesign a tape guide servo to improve its performance. As we can see from the block diagram (Fig. 1) the servo loop is quite conventional if the friction and backlash can be ignored. However, in this case, it was necessary to control the tape position so closely that both the friction and the backlash were important factors in determining the response, speed stability, and positioning accuracy.

The first phase of the simulation was to program the loop on the Analog Computer, check that the loop response without nonlinearities agreed with linear analysis, and that the response with nonlinearities agreed with the observed response of the tape recorder. In the second phase, the dynamic response of the computer model (displayed on a plotting board) was used to indicate type of changes required to improve the performance of the servo loop. In the third phase, the design changes were incorporated into the computer model and tests were made of the loop performance as a function of variations in the friction, backlash, motor damping, amplifier limits, and compensator parameters.

As a result of this simulation, the redesign goal was met by reducing the servo response time by a factor of two, with improved damping. The redesign cycle was completed in a two-week period.

LM rendezvous radar antenna control loops

The purpose of this simulation was to investigate the performance of the gyro voting system in the presence of gyro failures. For this reason, the radar segment containing the gyro voting system was used in its prototype hardware form in the simulation. The remainder of the antenna control loops were simulated on the analog computer (Fig. 2). The simulation made use of the solid state multipliers purchased as part of the analog computer updating plan for the 400-Hz modulators. In the first phase of the simulation, the shaft and trunnion axis response was compared with the response obtained from previous single-axis studies of the shaft and trunnion axis, in which the complete simulation was performed on the analog computer. While making these checks it was found that one of the DC amplifiers and one of the gyro torque amplifiers in the segment had failed. To avoid having to repair the segment, these amplifiers were simulated on the analog computer.

In the second phase of the simulation the performance of the gyro voting system was investigated as a function of various types of gyro failures in the presence of saturation rate commands. As a result of these investigations, a decision was made to install a switch in the LM module to allow manual override of the gyro voting system in those modes in which accuracy and speed of failure detection were not needed.

While the gyro voting system was being studied on the simulator, a limit cycle oscillation was observed following large disturbances in some of the LM radar models being tested. This oscillation was reproduced in the simulator, and after a study of the parameters to which the oscillation was sensitive, the source of the phase shift producing the oscillation was traced to saturation in one of the gyro summing amplifiers. When zener diodes were added to the gyro summing amplifier to prevent saturation, the oscillation no longer occurred. This change is being incorporated into the radar.

This simulation is now (February 1969) being used to investigate the feasibility of using gyros which are outside the present specifications.

These examples demonstrate the application of system simulation to systems integration problems. However, many of our systems integration problems could be avoided by using system simulation techniques to provide more realistic engineering models in all phases of engineering design. As the first example shows, a system does not have to be large scale or complex to be difficult or to represent realistically by available math models. As the second example shows, a system whose properties can in theory be completely defined can exhibit widely different properties when the ideal engineering model is converted to actual hardware.

System simulation approach to engineering design

A new approach to engineering design is necessary because:

1) As systems become more complex and more nonlinear our present building block approach to engineering design is becoming less efficient because there is no general theory of nonlinear systems to allow us to predict how a combination of discrete nonlinear subsystems will interact, even when the properties of the subsystems can be well defined.

2) The implied assumption that our engineering models adequately simulate the properties of actual hardware is not always valid.

3) Computer-aided design has not yet proven to be a practical design tool for problems which cannot be precisely defined, because of the requirement for precisely defining the problem and its solution, the lack of engineering languages, and the lack of an economical means of continuous interaction between the engineer and the computer model.[2,3,4] This practical limitation is the reason engineers are reluctant to make use of computers, rather than the "emotional gap"[5] between the engineer and the computer, or the difficulty in learning a new language.[6]

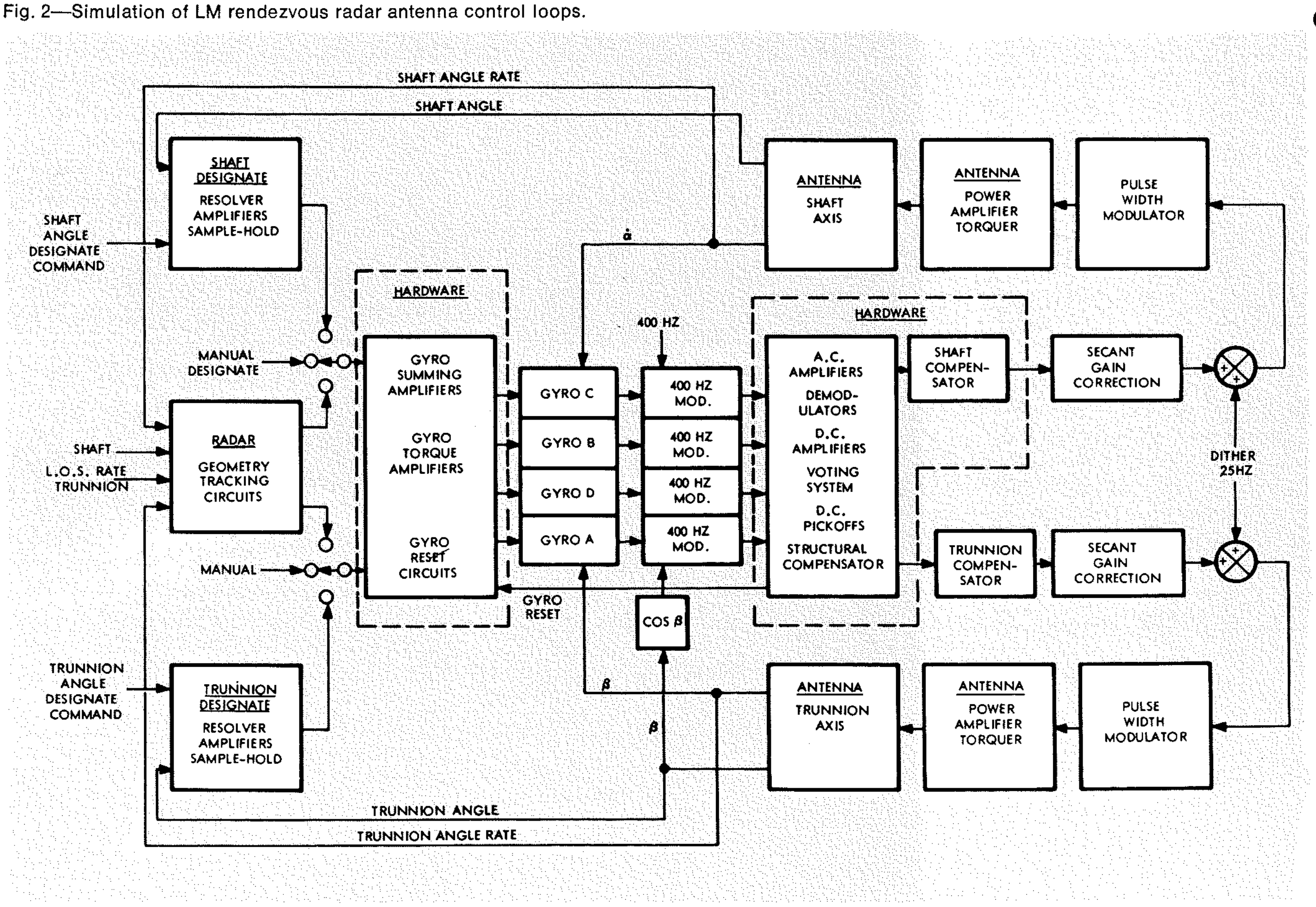
4) The progress of design automation at the systems level has been slow because of our restricted view of design automation (as the automation of our present design cycle rather than as a completely new approach in which mass production is replaced by flexible production). This restricted view not only retains the disadvantages of our present design cycle, but also gives us the mistaken impression that design automation is not economical unless it involves a high level of production of identical units.

The feasibility of a system simulation approach to engineering design is indicated by:

1) The success of the aircraft companies in applying system simulation techniques to the design of complex man-machine systems. This success demonstrates that computer models of a system and its environment can be developed which accurately represent the actual hardware and its environment.

2) The development of the hybrid computer which combines the speed, hardware simulation capability, and excellent engineer-model communica-

Fig. 2—Simulation of LM rendezvous radar antenna control loops.



tion of the analog computer with the accuracy and versatibility of the digital computer, to economically provide the simulation power necessary for engineering design at the systems level.[8]

Computer-aided thinking

Computer-aided design and computer-aided analysis have reduced the amount of time engineers must spend doing routine calculations and routine analysis. The simulation power available in a hybrid computer now makes it possible to develop computer models the engineer can use to solve problems which cannot be well defined, to synthesize as well as to analyze, or to consider the whole problem instead of isolated fragments of it—in other words, to make use of a dynamic computer model to think about and define the design problem before he thinks about the solution.

Computer-aided thinking is based on the assumption that the greatest potential of computers lies not in their ability to solve our problems for us, but in their ability to provide models which will allow engineers to think about the real world of nonlinear processes the way they now think about the theoretical world of linear processes. To achieve this potential requires a computer configuration that allows the engineer to set up and interact with his model in an engineering language rather than with a computer in a computer language (Fig. 3). With such a computer model, the engineer would be free to do what he does best; that is, define the problem, set goals, formulate hypotheses, determine criteria, perform evaluations, and design experiments.[3] The computer would be used to structure the model, generate the model environment, perform data reduction, and generate displays. The engineer-computer interface would provide continuous engineer model communication by allowing displays to be programmed in an engineering format, and model changes to be made while the model is operating.

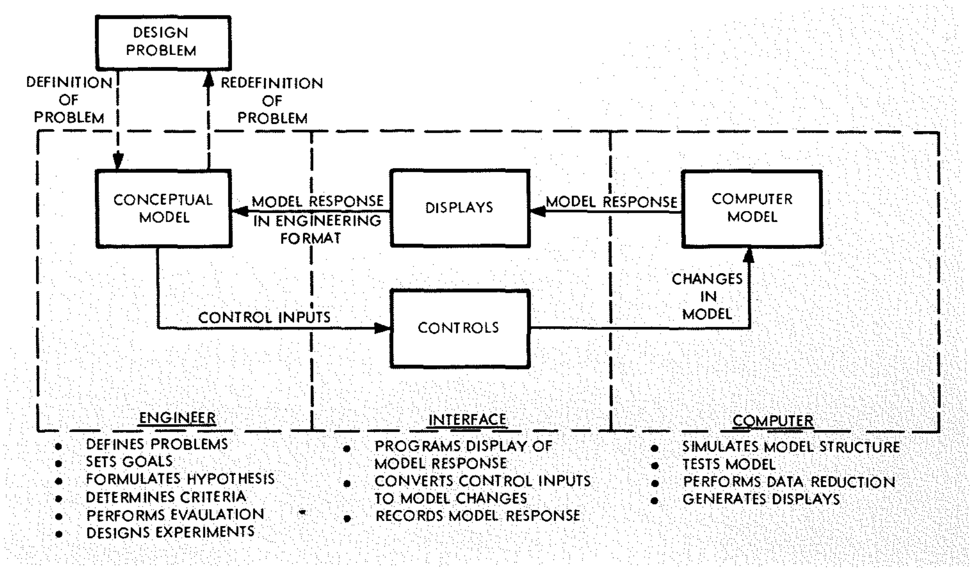


Fig. 3—Computer-aided thinking concept.

Engineering design based on system simulation

As we automate those design functions that can be precisely defined, it becomes vitally important that the information received by these design functions be not only precise but also accurate. To achieve this accuracy in the information on which design automation is based, the design must be subjected to intensive testing in all phases of engineering—to insure that the design specifications actually define a system that, when converted to hardware, will perform as required. These requirements cannot be met by basing the design on breadboard models which are subjected to a few isolated tests, or systems analysis of an idealized theoretical system, or by assuming that systems integration problems are mere engineering details which can be worked out after the system is assembled. These requirements can only be met by basing every phase of the design on the system requirements, and by providing a means of testing the design at a systems level in a realistic system environment (Fig. 4).

The design cycle shown in Fig. 4 provides a capability for continuous analysis, testing, and modification of the design from its conceptual phase through the production phase. The primary purpose of this design cycle is to generate a flow of realistic design information to the design automation functions. In this design cycle,

1) The system specifications would be studied by system design engineers using a computer model of the system and its environment (computer-aided thinking), as well as the normal system analysis techniques.
2) The subsystem specifications would be based on these system studies.
3) The design engineers would use computer-aided design for well-defined design problems and system integration problems, in addition to the usual breadboard models.
4) The breadboard models (including prototype hardware) would be tied into the simulated system and tested as part of the system before firm design specifications were released.
5) The initial production units would be tied into the simulated system to replace the equivalent simulated hardware until the simulator function was reduced to that of providing the system environment.

At this point the design cycle would, in theory, be complete. However in the real world the only thing permanent is change, and the simulated system (with or without the hardware) could be used to answer "what if" questions such as: What if the system specifications were changed? What if the system environment were changed?; What if a major system component did not quite meet its individual specifications?; What if a substitution had to be made for a particular component in the system?; What if the mass-produced circuits did not have the same tolerances as the prototype circuits? In addition, the simulated system could be used to design and test automatic test equipment for the system while the system was being designed or after the design was completed.

Plans to develop a system simulation capability

ASD plans to develop a system simulation capability in three phases:

In *phase I* the ASD analog computer is being updated by replacing the

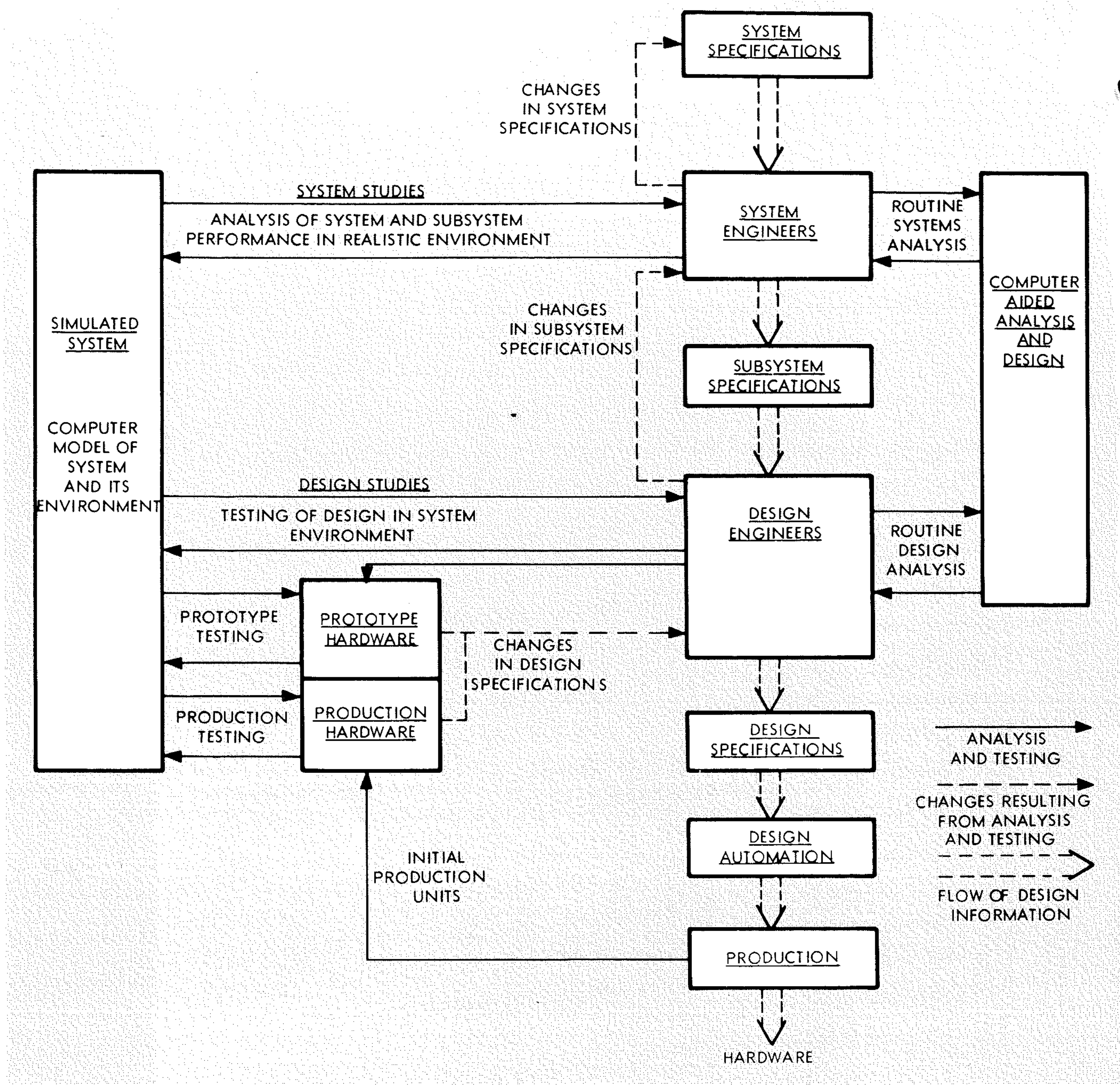


Fig. 4—Engineering design based on system simulation.

electro-mechanical multipliers and resolvers with solid state units; a digital plotting system is being added to allow digital data on paper tape to be plotted on the existing analog plotting boards, and an electro/optical (multisensor) simulation laboratory is being constructed in the analog computer room which will be tied into the updated analog computer. This phase will increase the performance of the analog computer sufficiently to make it usable as part of a hybrid computer facility, and will make available a limited electro-optical system simulation capability.

In *phase II*, a medium-sized analog/hybrid computer will be added. This computer combines high speed with digital control to provide the excellent engineer-model communication necessary for System Simulation design, and real-time simulation of electro/optical systems.

In *phase III*, high-speed conversion and control equipment will be added to interface the analog/hybrid computer with a digital computer. This phase will add the accuracy and versatility of a digital computer to make available the simulation power of a hybrid computer.

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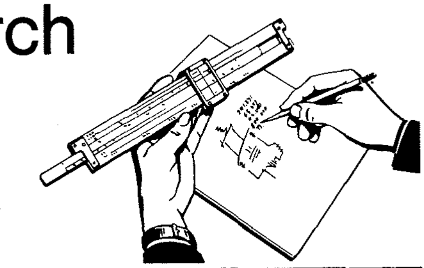
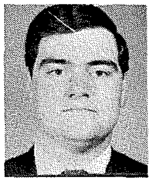


Brief Technical Papers of Current Interest

COS/MOS Arithmetic unit array



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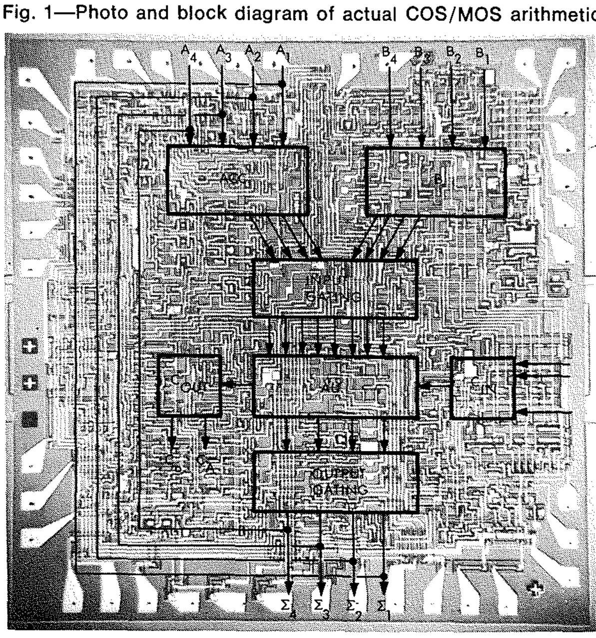
An LSI, four-bit arithmetic-unit array has been developed using the COS/MOS (complementary symmetry MOS) technology; the array has a flexible multi-function capability. The array logic is equivalent to 186 two-input gates which would normally require 744 devices. Due to the random complexity of the composite layout, functional logic gates were utilized to substantially reduce the number of devices to 563.

The array block diagram, as depicted in Fig. 1, is a result of a judicious tradeoff study between the functional flexibility of the array and the physical constraints of size and pin count. In general, the array performs parallel operations on four pairs of bits. There are two operand registers, (ACC and B), which can accept external parallel inputs. In addition, the ACC register can accumulate the array output. The INPUT GATING transfers the content of the operand registers to the arithmetic unit (AU) in either true or barred form. It can also change the accumulator operand into excess-six to permit decimal arithmetic. The AU is essentially a four-bit adder which, besides performing the sum at the output, can also generate the exclusive-OR or the OR logic functions. A fast carry is incorporated both internal and external to the array. The OUTPUT GATING transfers either the true or the barred output of the AU to the output terminals of the array (and back into the accumulator register inputs). It also performs a decimal correction dependent on the carry output during decimal operations. Hence, the array functional repertoire includes the following:

1) Four-bit binary addition or subtraction in 1's or 2's complement;
2) Decimal addition or subtraction in excess-six;
3) Increment or decrement function;
4) AND, OR, NOR, INVERT logic function;
5) Fast carry;
6) Tests for equality, greater than, or less than;
7) Tests for all 1's or all 0's; and
8) Operand storage in two separate registers (including accumulator).

Fig. 1—Photo and block diagram of actual COS/MOS arithmetic-unit.



The logic is structured with functional logic gates, where feasible, instead of typical NAND/NOR gates. Functional gating realizes logic expressions directly in a single-stage operation. An advantage of the COS/MOS technology is that it readily lends itself to relay switching logic as is necessary for successful implementation of functional gates; for example, implementation of the logic to generator C_0 with the NAND/NOR realization requires 26 devices, while the functional realization requires 12 devices. Hence, the functional realization requires fewer devices than the NAND/NOR realization and permits more complex logic to be implemented on a single substrate. If the array had been implemented using only NAND/NOR gates, one-third more devices would have been required.

The COS/MOS arithmetic-unit array (Fig. 1) represents a low power, high speed MOS logic element which is a repeatable, basic building block of a central processor. The data transfer rate for a sixteen-bit word is 500 nanoseconds. At this rate, an array has an operating power of 50 milliwatts. The standby power dissipation of an array is 10 microwatts.

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Preparing pre-cavitated rotogravure plates for printing

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A pre-cavitated rotogravure plate is formed from a relatively hard material (e.g., stainless steel) with many regularly spaced cavities on one of its major surfaces. The cavities are filled with a relatively soft material (e.g., plastic) that is vaporizable by heat.

The plate is prepared for printing purposes by exposing its cavitated surface to an image whose radiant energy is sufficiently intense to vaporize some of the material in the cavities. The effect of this exposure is to remove the material from the cavities, both by vaporization and expulsion, in quantities proportional to the intensity of the energy striking the material. The cavities of the exposed plate can now be inked and the plate can be used in the usual manner for making prints.

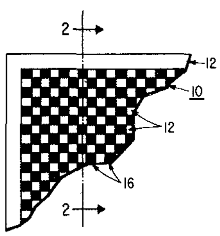

Fig. 1—Plan view.

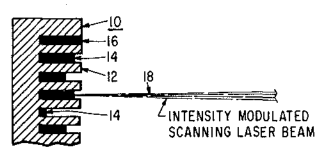

Fig. 2—Cross-section of plate.

Figures 1 and 2 show plan and cross-sectional views of a portion of the novel pre-cavitated rotogravure plate. The plate (10) is made from a hard metal, such as stainless steel, and has one major surface (12) formed with a plurality of regularly-spaced cavities (14). The cavities may be formed in a checker-board arrangement, and are filled with a heat-vaporizable, relatively soft material (16), such as nylon, bakelite, or any other suitable plastic, vaporizable material.

The plate (10) may be exposed to a radiation pattern by directing an intensity-modulated, scanning laser beam (18) onto the surface (12) of the plate so as to vaporize the soft material (16) in the cavities (14) in quantities proportional to the instantaneous intensity of the modulated laser beam (18), as shown in Fig. 2. The exposed plate (1) provides an engraved plate from which intaglio printing can now be done.

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Synchronization System for Television Signals with Auxiliary Information Transmitted During the Vertical Blanking Interval—R. F. Sanford (Labs., Pr) U.S. Pat. 3,472,962; Oct. 14, 1969.

Consumer Electronics

Phase Shifting Circuits for Color Television Receivers—E. W. Curtis, T. C. Jobe (CE, Indpls) U.S. Pat. 3,454,708; July 8, 1969

Keyed Burst Separator—J. N. Pratt (CE, Indpls) U.S. Pat. 3,454,709; July 8, 1969

Service Aid for Color Television Receiver—P. E. Crookshanks, R. D. Altmanshofer (CE, Indpls) U.S. Pat. 3,461,225; August 12, 1969

Continuous Video Peaking Control Circuit—J. F. Slusarski, J. A. Konkel (CE, Indpls) U.S. Pat. 3,461,234; August 12, 1969

Electron Beam Convergence Apparatus—P. G. McCabe (CE, Indpls) U.S. Pat. 3,459,989; August 5, 1969

Single Ended and Differential Stabilized Amplifier—E. J. Wittman (CE, Som) U.S. Pat. 3,460,049; August 5, 1969

Combination Chrominance Amplifier, Burst Amplifier, and Burst Gate Circuit for a color Television Receiver—W. P. Iannuzzi (CE, Cherry Hill) U.S. Pat. 3,469,022; Sept. 23, 1969.

Automatic Frequency Control System—W. W. Evans (CE, Indpls) U.S. Pat. 3,469,025; Sept. 23, 1969.

Detector and AGC Circuit Stabilization Responsive to Power Supply Changes—L. A. Harwood (CE, Som) U.S. Pat. 3,469,195; Sept. 23, 1969.

Frequency Modulation Detector Circuit Providing Balanced Detection over a Wide Range of Signal Levels—J. Avins (CE, Indpls) U.S. Pat. 3,462,694; Aug. 19, 1969.

Integrated Amplifier Circuit Especially Suited for High Frequency Operation—J. Avins, J. Craft (CE, Som) U.S. Pat. 3,467,909; Sept. 16, 1969.

Electrical Switching System Which Defeats Automatic Fine Tuning Control through One Switch Contact, Actuated During Manual Channel Change or Manual Fine Tuning—J. A. Milnes (CE, Indpls) U.S. Pat. 3,466,549; Sept. 9, 1969.

Automatic Frequency Control—J. Stark, Jr. (CE, Indpls) U.S. Pat. RE26686; Oct. 7, 1969.

Video Amplifier Transient Response Control Circuit—D. H. Willis (CE, Indpls) U.S. Pat. 3,472,954; Oct. 14, 1969.

Defense Microelectronics

Electrical Neuron Circuit That Includes an Operational Amplifier—L. P. Wennik, P. B. Scott (DME, Som) U.S. Pat. 3,476,954; Nov. 4, 1969.

Integrated Arrangement for Integrated Circuit Structures—L. Dillon, Jr. (DME, Som) U.S. Pat. 3,473,094; Oct. 14, 1969.

Aerospace Systems Division

Logic Circuit—W. Henn (ASD, Burl) U.S. Pat. 3,457,434; July 22, 1969

Halftone Image Generator System—C. R. Corson (ASD, Van Nuys) U.S. Pat. 3,463,880; Aug. 26, 1969.

Gas Sampler—F. U. Everhard, R. E. Hartwell (ASD, Burl) U.S. Pat. 3,461,727; Aug. 19, 1969.

Electrically Operated Throttle Device—F. U. Everhard (ASD, Burl) U.S. Pat. 3,465,790; Sept. 9, 1969.

Current Pulse Driver with Means to Steepen and Stabilize Trailing Edge—C. E. Granger (ASD, Burl) U.S. Pat. 3,470,391; Sept. 30, 1969.

Mechanical Configuration of Laser Pump with Integral Cooling—B. R. Clay, T. A. Haddad (ASD, Burl) U.S. Pat. 3,454,900; May 6, 1969; Assigned to U.S. Government.

Information Systems Division

Magnetic Tape Transport Head Assembly with Azimuth Adjustment—J. B. Kelly (ISD, Cam) U.S. Pat. 3,457,556; July 22, 1969

Priority Circuits—P. K. C. Hsieh (ISD, Cam) U.S. Pat. 3,460,043; August 5, 1969

Amplifier Control System—D. J. Poitras (EDP, Cam) U.S. Pat. 3,469,203; Sept. 23, 1969.

Reliability Check Circuit for Optical Reader—J. R. Beltz, D. E. Phelps (EDP, Cam) U.S. Pat. 3,465,130; Sept. 2, 1969.

Character Reader—B. P. Silverman, H. B. Currie (ISD, Cam) U.S. Pat. 3,465,288; Sept. 2, 1969.

Systems Engineering, Evaluation & Research

Check-out Counter or Similar Article—W. E. Kinslow (SEER, Mrstn) U.S. Pat. D215,380; Sept. 23, 1969.

Commercial Electronic Systems Division

Remote Control for Deflection System of a Television Camera—L. J. Bazin (CESD, Cam) U.S. Pat. 3,463,962; Aug. 26, 1969.

Slide Projector Including Two Light Paths and One Slide Magazine—B. F. Floden (CESD, Cam) U.S. Pat. 3,462,215; Aug. 19, 1969.

Automatic Lamp Changing Apparatus—C. B. Meyer (CESD, Cam) U.S. Pat. 3,471,745; Oct. 7, 1969.

Astro-Electronics Division

Scanner Having Rotating Double-Sided Reflector—D. Kelsall (AED, Pr) U.S. Pat. 3,443,110; May 6, 1969; Assigned to U.S. Government.

Advanced Technology Laboratories

Integrated Memory System—R. L. Pryor (AT, Cam) U.S. Pat. 3,460,094; August 5, 1969

Laser Recorder with Optical Filter—K. C. Hudson (ATL, Cam) U.S. Pat. 3,465,347; Sept. 2, 1969.

Color Image Display System Utilizing a Light Valve—F. E. Shashoua (ATL, Cam) U.S. Pat. 3,470,310; Sept. 30, 1969.

Graphic Systems Division

Electronic Halftone Image Generator—E. D. Simshauser (GSD, Dayton) U.S. Pat. 3,465,199; Sept. 2, 1969.

Industrial & Automation Products

Automobile Control Manipulating Apparatus—D. A. Donovan (IAP, Plymouth) U.S. Pat. 3,465,577; Sept. 9, 1969.

Defense Communications Applied Research Laboratory

Synchronizing System for Television Receivers—D. P. Dorsey, R. W. Bruce (AEARL, Pr) U.S. Pat. 3,469,032; Sept. 23, 1969.

Television Camera Including an Image Isocon Tube—A. D. Cope, E. Luedicke, O. J. Ziemelis (AEARL, Pr) U.S. Pat. 3,471,741; Oct. 7, 1969.

Electromagnetic and Aviation Systems Division

Random Access Card Memory System—A. Lichowsky (EASD, Van Nuys) U.S. Pat. 3,460,120; August 5, 1969

Cubic Crystal Light Modulator—F. Sterzer (EC, Pr) U.S. Pat. 3,454,771; July 8, 1969

Preset UHF Tuning Mechanism—E. J. Sperber (Indpls) U.S. Pat, 3,459,055; August 5, 1969

Vehicle Detector—G. W. Gray (Pr) U.S. Pat. 3,457,547; July 22, 1969

Professional Meetings

Dates and Deadlines

Be sure deadlines are met—consult your Technical Publications Administrator or your Editorial Representative for the lead time necessary to obtain RCA approvals (and government approvals, if applicable). Remember, abstracts and manuscripts must be so approved BEFORE sending them to the meeting committee.

Calls For Papers

MARCH 24-26, 1970: **Eleventh Symposium on Engineering Aspects of Magnetohydrodynamics,** California Institute of Technology, Jet Propulsion Laboratory. **Deadline info (abst) 12/15/69 (reproducible copy) 2/17/70 to:** Dr. David G. Elliott, Program Chairman, EAM Symposium, Bldg. 122-123, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91103.

APRIL 21-24, 1970: **International Magnetics Conference (INTERMAG),** Statler Hilton Hotel, Washington, D. C. **Deadline info: (abst) 12/12/69 to:** D. S. Shull, Bell Telephone Labs., 3300 Lexington Ave., Winston-Salem, N.C. 27102.

MAY 2-7, 1970: **72nd Annual Meeting & Exposition of the American Ceramic Society,** Philadelphia Sheraton Hotel—Civic Center, Philadelphia, Pennsylvania, The American Ceramic Society, Inc. **Deadline info (titles) 12/1/69 (abst) 12/15/69 to:** (Nuclear Science Section) Eugene D. Lynch, Program Chairman, Babcock & Wilcox Co., P. O. Box 1260, Lynchburg, Va. 24505; or (Electronics Section) J. C. Williams, Program Chairman, Bell Telephone Labs., Inc., Room 1B-321, Murray Hill, N.J. 07974.

MAY 7-8, 1970: **1970 Midwest Symposium on Circuit Theory,** Pick-Nicollet Hotel, Minneapolis, Minnesota, IEEE. **Deadline info (sum) 2/5/70 (paper) 3/15/70 to:** Professor B. A. Shenoi, Department of Electrical Engineering, University of Minnesota, Minneapolis, Minnesota 55455.

MAY 11-14, 1970: **1970 IEEE G-MTT International Microwave Symposium,** Newporter Inn, Newport Beach, California, IEEE. **Deadline info (abst & sum) 1/30/70 to:** Dr. Raymond H. DuHamel, Chairman, Technical Program Committee, Granger Associates, 1601 California Avenue, Palo Alto, California 94304.

MAY 19-21, 1970: **Conference on Signal Processing Methods for Radio Telephony,** London, England. **Deadline info: (ms) 12/29/69 to:** IEE Office, 345 East 47th Street, New York, N.Y. 10017.

JUNE 2-5, 1970: **Conference on Precision Electromagnetic Measurements,** Nat'l Bureau of Standards, Boulder, Colorado, G-IM, NBS, URSI. **Deadline info (abst & sum) 2/6/70 to:** G. M. R. Winkler, U. S. Naval Observatory, Washington, D.C. 20390.

JUNE 15-19, 1970: **1970 IEEE International Symposium on Information Theory,** Noordwijk, The Netherlands, IEEE. **Deadline info (ms & abst) 1/1/70 to:** Dr. P. E. Green, Jr., IBM Research Center, P. O. Box 218, Yorktown Heights, New York 10598.

JUNE 15-19, 1970: **6th U. S. National Congress of Applied Mechanics,** Harvard University, AIAA. **Deadline info (papers) 1/1/70 to:** Prof. Howard W. Emmons, 6th U. S. National Congress of Applied Mechanics, Pierce Hall, Cambridge, Mass. 02138.

JUNE 21-25, 1970: **Design Automation Workshop,** Sherton Palace Hotel, San Francisco, Calif. **Deadline info: (abst) 1/5/70 to:** H. Freitag, IBM Watson Rec. Ctr., POB 218, Yorktown Hgts., N.Y. 10598.

JUNE 29-JULY 1, 1970: **AIAA 5th Thermophysics Conference,** International Hotel, Los Angeles, Calif., AIAA. **Deadline info (abst or ms) 1/2/70 to:** Richard P. Bobco, Building 366, Mail Station C681, Hughes Aircraft Co., Space Systems Div., P. O. Box 90919, Los Angeles, Calif. 90009.

JUNE 29-JULY 1, 1970: **AIAA 3rd Fluid and Plasma Dynamics Conference,** International Hotel, Los Angeles, Calif., AIAA. **Deadline info (detailed abst) 12/19/69 to:** W. R. Warren, Jr., Director, Aerodynamics and Propulsion Research Lab. (130/601) The Aerospace Corp., P.O. Box 95085, Los Angeles, Calif. 90045.

JULY 9-10, 1970: **CASI/AIAA Meeting on the Prospects for Improvement in the Efficiency of Flight,** Toronto, Ontario, Canada, AIAA. **Deadline info (abst) 1/5/70 to:** J. D. Nicholaides, Chairman and Professor, Aero-Space Engineering Dept., University of Notre Dame, Box 537, Notre Dame, Ind. 46556 and D. C. Whittley, Chief Research Engineer, The de Havilland Aircraft of Canada Ltd., Downsview, Ontario, Canada.

JULY 12-17, 1970: **Summer Power Meeting & EHV Conference,** Biltmore Hotel, Los Angeles, Calif. G-P. **Deadline info (papers) 2/15/70 to:** Tech. Conf. Svcs., 345 E. 47th St., New York, N.Y. 10017.

AUGUST 17-19, 1970: **AIAA Guidance, Control, and Flight Mechanics Conference,** University of California, Santa Barbara, AIAA. **Deadline info (abst) 1/5/70 (first drafts) 3/16/70 (final ms) 7/6/70 to:** John R. Scull, Jet Propulsion Lab., 4800 Oak Grove Drive, Room 198-226, Pasadena, Calif. 91103.

Meetings

DEC. 26-31, 1969: **AAAS/AIAA Meeting on Space Astronomy** (Sessions at AAAS National Meeting), Boston, Mass., AIAA. **Prog info:** American Institute of Aeronautics and Astronautics, 1290 Sixth Ave., New York, N.Y. 10019.

JAN. 6-8, 1970: **Sensor Aided Combat Systems Symposium,** DOD/NSIA, National Bureau of Standards, Gaithersburg, Md. **Prog info:** NSIA Dept. SACS, 1030 15th Street, N.W., Suite 800, Washington, D.C. 20005.

JAN. 14-16, 1970: **Hawaii Int'l Conference on System Sciences,** Univ. of Hawaii, Honolulu, Hawaii. **Prog info:** Rahul Chattopadhyay, Univ. of Hawaii, 2565 The Mall, Honolulu, Hawaii 96822.

JAN. 17, 1970: **Worcester Symp. on Industrial Drive Systems and Controls,** Wachusett Country Club, W. Boylston, Mass.

JAN. 19-21, 1970: **AIAA 8th Aerospace Sciences Meeting,** New York, N.Y., AIAA. **Prog info:** American Institute of Aeronautics and Astronautics, 1290 Sixth Ave., New York, N.Y. 10019.

JAN. 24-26, 1970: **Fifty-third Annual Meeting of The Mathematical Association of America,** Miami, Florida. **Prog info:** The Mathematical Association of America, Inc., 1225 Connecticut Avenue, N. W., Washington, D.C. 20036.

JAN. 25-30, 1970: **Winter Power Meeting,** Statler Hilton Hotel, New York, N.Y. **Prog info:** Tech. Conf. Services, 345 E. 47th St., New York, N.Y. 10017.

FEB. 2-4, 1970: **AIAA Launch Operations Conference,** Cocoa Beach, Fla., AIAA. **Prog info:** American Institute of Aeronautics and Astronautics, 1290 Sixth Ave., New York, N.Y. 10019.

FEB. 3-5, 1970: **Reliability Symposium,** Biltmore Hotel, Los Angeles, Calif. **Prog info:** W. R. Abbott, D60-01/B104, Lockheed Mls. & Space Co., POB 504, Sunnyvale, Cal. 94022.

FEB. 4-6, 1970: **AIAA Advanced Space Transportation Meeting,** Cocoa Beach, Fla., AIAA. **Prog info:** American Institute of Aeronautics and Astronautics, 1290 Sixth Ave., New York, N.Y. 10019.

Engineering News and Highlights

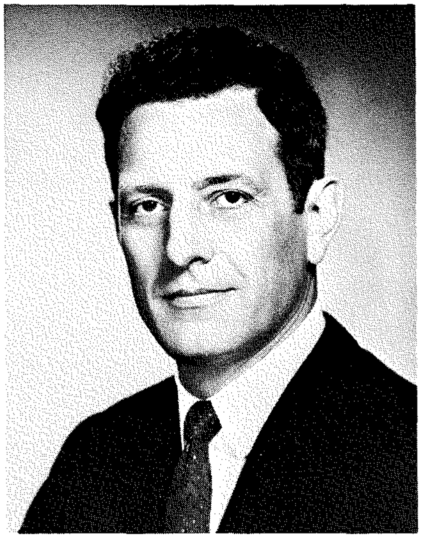
Morrison is Staff VP, Product Safety

Wendell C. Morrison has been appointed Staff Vice President, Product Safety. Mr. Morrison, who had been Staff Vice President, Corporate Engineering Services, will report to **Mr. Chase Morsey, Jr.**, Executive Vice President, Operations Staff.

The Product Safety organization includes **George A. Kiessling,** Director, Product Safety Plans and Programs who will report to Mr. Morrison, and **George T. Petchel,** Administrator, Product Safety Programs who will report to Mr. Kiessling.

In his new position, Mr. Morrison will be responsible for administering existing policies and programs concerning product safety and insuring prompt application of new product safety procedures as they develop. He will also have the responsibility for the continuing safety of all RCA products and equipment.

Mr. Morrison joined RCA in 1940 after receiving the BSEE and MSEE from the State University of Iowa. He was a member of the Technical Staff of RCA Laboratories for 15 years, engaged in development work for such fields at UHF-TV transmitters, antenna pattern calculators, and color TV terminal and test equipment. In 1957, he became a Staff Engineer for the former RCA Industrial Electronic Products organization, and, in 1959, was promoted to Manager, Engineering Plans and Services. Two years later, Mr. Morrison was designated Assistant to the Chief Defense Engineer of RCA Defense Electronic Products. In 1963, he was appointed Chief Engineer of the Broadcast and Communications Products Division. In July 1966, Mr. Morrison was appointed Director, Product Engineering, reporting to D. F. Schmit, Staff Vice President, Product Engineering. In September 1967, Mr. Morrison was promoted to the position of Staff Vice President, Corporate Engineering Services.



Trudel named Director, Corporate Engineering Services

A. Robert Trudel has been appointed Director, Corporate Engineering Services. He will report to **Dr. James Hillier,** Executive Vice President, RCA Research and Engineering.

Mr. Trudel received the BS in Engineering from Swarthmore College in 1943 and a Diploma in Aerological Engineering from the U.S. Naval Academy Post Graduate School in 1946. Mr. Trudel joined RCA earlier this year as Staff Engineer, Product Engineering; previously, he was with the Scott Paper Co. for four years as Assistant to the Vice President, Research and Engineering, and later as Assistant Director of Corporate Development. With Princeton University from 1956 to 1964, he was involved in the design and construction of the Princeton-Pennsylvania Accelerator (PPA), a multi-million dollar laboratory for nuclear particle research. He was Engineering Coordinator and, later Assistant Director of PPA. During World War II he served as a naval officer on destroyers in the Pacific. After the war, he was employed by the Otis Elevator Co. for ten years, including six years in Brussels, Belgium, where he represented Otis in the Benelux countries.

When he previously lived in Princeton, Mr. Trudel served for seven years on the Township Board of Education, including two terms as Vice President. He was also Chairman of the Community's pre-regionalization Joint Committee on Curriculum involving a number of Mercer County school districts. He continued his interest in education when he left Princeton and moved to Pennsylvania. There he served as President of Action for Community College, Inc., a broad-based group of private and industrial citizens instrumental in the establishment of the Delaware County Community College in 1967.

Frank L. Flemming is VP of engineering for NBC

Frank L. Flemming, who has been associated with color television broadcasting for the past 15 years, has been named Vice President, Engineering, NBC Television Network. Mr. Flemming reports to **William Trevarthen,** Vice President, Operations and Engineering, NBC-TV.

Mr. Flemming received the BS in Electrical Engineering from the University of Buffalo, N.J. For the past two years, he has been Chief Engineer with Visual Electronics Corporation, New York. Prior to that, he served for 13 years with CBS, the last three as Director of Plant Systems Engineering. Mr. Flemming is a member of the IEEE, the SMPTE, and the Audio Engineers Society.

S. Nemeyer Elected a Fellow of SMPTE

Sheldon Nemeyer, Manager, Equipment and Sound Services, NBC Newsfilm Department, was elected a Fellow of the Society of Motion Picture and Television Engineers. Mr. Nemeyer, was one of the first graduates of the University of Southern California's Film Department, is a veteran of a quarter-century in motion picture production. As Manager of Equipment and Sound Services, he supervises and controls all service activities in the major newsfilm areas of equipment, laboratory, and sound for NBC News.

ALERT!

ALERT, a computer-based system for automatically notifying engineers and scientists of technical information sources pertinent to their current work, is now operational. A detailed *ALERT User's Guide* is available in all RCA libraries or from Technical Information Services directly (Bldg. 2-8-1, Camden, N.J. PC-3119).

Photo credit: the cover photograph for the Vol. 15, No. 3 issue of the RCA ENGINEER was taken by Tom Barnett of the Missile and Surface Radar Division.

Promotions

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parentheses.

Instructional Systems

Donald J. Mackson promoted to Ldr., Sys. Integration Group. (G. H. Leichner, Engineering)

RCA Service Company

W. W. Gordy from Engineer to Mgr., Operations Control (R. S. Maloney (acting)—Andros Island)

F. V. Wurth from Ship Instru. Engr. to Mgr., Radar Shipboard (D. E. Price, Cocoa Beach, Florida)

D. Botticello from Engineer to Mgr., Missile Systems (J. M. Leopold, Springfield Virginia)

A. S. Gastoukian from Engineer to Mgr., Gun Systems (J. M. Leopold, Springfield Virginia)

D. H. Heasty from Engineer to Mgr., RFI Program (J. E. Reeder, Springfield, Virginia)

H. F. Ramm from Ldr., Systems Service Engrs., to Mgr., Ship Systems Design (J. E. Reeder, Springfield, Virginia)

L. W. VanAntwerp from Engineer to Mgr., Work Study Program (J. E. Reeder, Springfield, Virginia)

R. B. Page from Ship Instru. Engineer to Mgr., Radar Shipboard (J. B. Steele, Cocoa Beach, Florida)

T. D. Hummer from Associate Engineer to Ldr., Trinidad Operations Shift (J. Brady, Cocoa Beach, Florida)

Consumer Electronics Division

E. E. Janson from Engineering Staff to Leader Engineering Staff (R. J. Lewis, Indianapolis, Indiana)

Television Picture Tube Division

C. J. Billian from Senior Engineer to Engineering Leader, Product Development (R. L. Leigh, Marion, Indiana)

Missile and Surface Radar Division

T. Stecki from Engineer to Ldr., Des & Dev (R. M. Fisher, Moorestown)

W. E. Scull from Ldr. Des & Dev to Mgr., PRESS Alcor (L. Nelson, Moorestown)

Electromagnetic and Aviation Systems Division

R. C. Hedtke from Sr. Member D&D Engrg. Staff to Ldr., D&D Engrg. Staff (P. B. Korda, Van Nuys, California)

L. W. Poppen from Staff Engr. Scientist to Ldr. D&D Engrg. Staff (R. Lewis, Van Nuys, California)

J. K. Mathews from Sr. Member, D&D Engrg. Staff to Ldr., D&D Engrg. Staff (J. Chambers, Van Nuys, California)

Astro-Electronics Division

T. J. Furia from Senior Engineer to Mgr., (Specialty) Engrg. (E. Goldberg, Princeton, N.J.)

J. F. Baumunk from Mgr. (Specialty) Engrg. to Mgr. Communications & Data Processing (W. Manger, Princeton, N.J.)

V. J. Mancino from Senior Engr. to Mgr. Quality Assur. Eng. (H. Howard, Princeton, N.J.)

H. J. Zelen from Senior Engr. to Mgr. (Specialty) Eng. (H. Schwartzberg, Princeton, N.J.)

Defense Communications Systems Division

P. Mahaffey from Engineer to Ldr., Des. & Dev. Engr. (J. B. Howe, Jr., Camden, N.J.)

Information Systems Division

E. D. James from Sr. Mbr. D&D Engrg. Staff to Leader, Tech. Staff (H. N. Morris, West Palm Beach, Florida)

RCA Global Communications, Inc.

F. Woefle from Design Engineer to Group Leader, Satellite and Radio Engineering (J. M. Walsh, New York)

Staff Announcements

Defense Electronic Products

S. Sternberg, Division Vice President and General Manager, Electromagnetic and Aviation Systems Division has appointed **R. B. Moses** as Manager, Operations Control.

H. J. Woll, Chief Defense Engineer, Defense Engineering, has appointed **A. J. Vaughn** as Manager, Technical Planning.

Operations Staff

The Board of Directors has elected **George C. Evanoff** as Vice President of the RCA Corporation.

Consumer Electronics Division

D. L. Mills, Senior Executive Vice President, Consumer Products and Components has appointed **R. A. Schieber** as Division Vice President, Operations, which will include responsibility for Engineering, Manufacturing, Materials, and the Product Quality and Safety activities in the Consumer Electronics Division.

A. B. Pollock, Manager, Manufacturing Department has appointed **T. F. Whitten** as Plant Manager, Indianapolis Components Plant.

Commercial Electronic Systems

Barton Kreuzer, Executive Vice President, Commercial Electronic Systems has appointed **E. J. Hart** as Division Vice President, Commercial Communications Systems Department.

Electronic Components

J. B. Farese, Executive Vice President, Electronic Components has announced the organization of Electronic Components as follows: **C. E. Burnett,** Division Vice President and General Manager, Solid State Division; **J. T. Cimorelli,** Division Vice President and General Manager, Receiving Tube Division; **G. W. Duckworth,** Division Vice President, Equipment Sales and Distribution; **L. Gillon,** Division Vice President and General Manager, Television Picture Tube Division; **A. M. Glover,** Division Vice President, Operations Programs; **J. A. Haimes,** Division Vice President, Distributor Products; **C. H. Lane,** Division Vice President and General Manager, Industrial Tube Division; **W. H. Painter,** Division Vice President, Business and Economic Planning; **H. R. Seelen,** Division Vice President, International Development and Glass Operations.

C. H. Lane, Division Vice President and General Manager, Industrial Tube Division has announced the organization of the Industrial Tube Division as follows: **W. E. Bradley,** Manager, Quality and Reliability Assurance; **D. W. Epstein,** Manager, Technical Planning; **W. G. Hartzell,** Manager, Microwave Devices Operations Department; **V. C. Houck,** Manager, Marketing Department; **C. F. Nesslage,** Manager, Financial Controls and Planning; **M. B. Shrader,** Manager, Power Devices Operations Department; **C. C. Simeral,** Manager Operations Services; **C. P. Smith,** Manager, Conversion Tube Operations Department.

C. E. Burnett, Division Vice President and General Manager, Solid State Division has announced the organization of the Solid State Division as follows: **D. J. Donahue,** Manager, Solid State Department; **N. S. Freedman,** Manager, Liquid Crystal Program; **N. H. Green,** Manager, Planning.

J. T. Cimorelli, Division Vice President and General Manager, Receiving Tube Division has announced the organization of the Receiving Tube Division as follows: **W. B. Brown,** Manager, Manufacturing Planning and International Operations; **K. B. Bryden,** Manager, Marketing; **G. W. Farmer,** Plant Manager, Harrison Plant; **F. J. Lautenschlaeger,** Plant Manager, Woodbridge Plant; **J. W. MacDougall,** Administrator, Financial Planning and Controls; **A. F. Pheasant,** Manager, Purchasing; E. Rudolph, Manager, Equipment Design and Development; **J. P. Sasso,** Manager, Quality and Reliability Assurance; **N. A. Stegens,** Plant Manager, Cincinnati Plant; **W. H. Warren, Manager,** Receiving Tube Engineering.

A. M. Glover, Division Vice President, Operations Programs, has announced the organization of Operations Programs as follows: **G. C. Brewster,** Manager, Facilities Planning; **E. O. Johnson,** Manager, Engineering, **R. L. Kelly,** Administrator, Product Assurance; **J. F. Wilhelm,** Manager, Commercial Engineering.

L. Gillon, Division Vice President and General Manager, Television Picture Tube Division has announced the organization of the Television Picture Tube Division as follows: **E. M. Bien,** Administrator, Financial Planning and Controls; **D. R. Bronson,** Manager, International Operations; **J. H. Colgrove,** Manager, Television Picture Tube Manufacturing Department; **R. E. McNickle,** Manager, Quality and Reliability Assurance; **W. H. Myers,** Manager, Marketing; **D. H. Sparks,** Administrator, Product Programs; **C. W. Thierfelder,** Manager, Engineering Department.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.