RCA Engineer

Vol 21 | No 4 Dec | Jan 1975 | 1976

Product design

Though product design rarely has the glamour of research and development, it is nevertheless one of the most important and crucial phases in the development and maintenance of a profitable business. One can hardly overemphasize its importance to RCA, and I applaud the dedication of an issue of the *RCA Engineer* to the subject.

The term *product design* itself is a deceptively simple phrase that identifies a very complex set of activities positioned between R&D and production. Successful product research demonstrates the feasibility of the underlying technology, including the economic potential of the ultimate product. Development translates the technology into practical form and provides a more precise indication of economic feasibility. Product design, taking the information from R&D and many other sources, creates new information to make it possible to manufacture a cost-effective, economically acceptable product that serves a market need and provides for profitable development of a business or creates a new one.

Within this context, the specific nature of the product design function will vary over a wide range according to the circumstances—an aspect of product design that is often overlooked.

At one extreme, for example, is the large, one-of-a-kind complex electronic system that we often build for the U.S. Government. In the middle are the complex systems that we build by the tens or hundreds for the broadcasters. At the other extreme are the still complex color television receivers that we build by the hundreds of thousands for the consumer. There are radical differences in the product design activities of each of these—in their economics, in their details, and in their philosophies. We must recognize and accommodate to these variables in our management, our planning, and our engineering.

Product design is a most challenging and rewarding undertaking. It is a keystone in the achievement of the ultimate goals of all our technical businesses—the creation, manufacture, and marketing of products that serve a need and earn a profit.

Dr. James Hillier
Executive Vice President
Research and Engineering
Princeton, N.J.

Our cover

...symbolizes product design. Each of the pictures surrounding the TR-600 television tape recorder represents an activity that is described in depth in the first case study of this "product design" issue (pp. 4 through 34). The second case study centers on COS/MOS devices (p. 35 through 62). Other product designs featured in this issue include an automatic film projector (p. 63), consumer products (p. 70), and a family of tape recorders for the government market (p. 72).

Vol. 21 | No. 4
Dec 1975
Jan 1976

RCA Engineer

A technical journal published by
RCA Research and Engineering
Cherry Hill, N.J.
Bldg. 204-2 (PY-4254)

RCA Engineer articles are indexed annually in the April-May issue and in the *Index to RCA Technical Papers.*

• 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.

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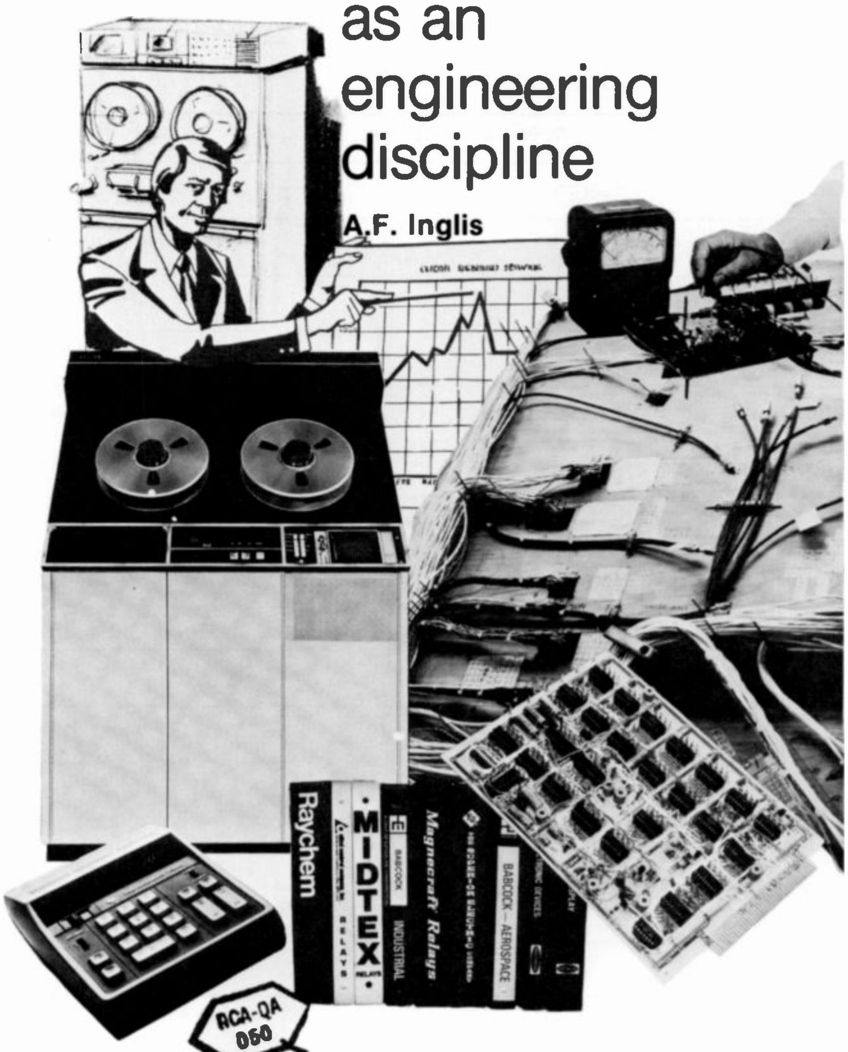
Product design as an engineering discipline

A.F. Inglis



For purposes of this paper, I would define product design as that portion of the engineering process which begins with the completion of a working model embodying all of the product's basic technology and features, and which ends with the start-up of production in a manufacturing environment. This definition would exclude products which are built one at a time or a few at a time under engineering control and management. Also, this paper is primarily concerned with commercial products as distinguished from products developed to specification for the Government.

For many years, I have been concerned that the engineering discipline of product design has not been given sufficient emphasis by either the business or technical communities. Accordingly, I am delighted that this issue of the *RCA Engineer* is devoted to this subject.

RCA has an enviable reputation as a leader in advanced technology. The combination of company-sponsored and Government-funded technology programs in the Laboratories and in the operating divisions gives RCA a technological base of a diversity matched by few other organizations, even in today's highly competitive situation. Our success in developing commercial products which embody this technology, however, can be significantly improved. One of the most important elements which can lead to this improvement is increased management *recognition* of product design as a distinct and specialized engineering discipline. I would identify four areas in which this is needed.

1. Recognition of the *importance* of product design.
2. Recognition of the *difficulty* of product design.
3. Recognition of the *time and money* required for product design.
4. Recognition of *individual achievement* in product design.

Importance

We sometimes fall into the trap of believing that leadership in advanced technology itself will assure technical and commercial leadership. This simply is not true. The development of advanced technology is only the first step for putting a successful product on the marketplace, and if it is not followed by skilled product design there will never be a salable product.

Consider, for example, some outstanding high technology products which have been marketed during recent decades—the Douglas DC-3, the Boeing 707, the General Motors diesel locomotive, and our TK-45 color camera. Although the basic technology employed in each of these products was competitive, in no case did it represent a major breakthrough nor was it competitive by any quantum jump.

The factor that made these products great and which made them dominant in their markets was the excellence of their designs. On the other hand most of us can enumerate products which, while including the most advanced technology, have failed in the marketplace because the excellence of the technology was not matched by the excellence of the design.

In summary then, skill in product design is absolutely critical to the success of a technology-oriented business.

Difficulty

I believe there is a tendency on the part of the highly creative scientists and engineers who are working on the frontiers of technology to underestimate the difficulty of the product-design process. These scientists and engineers have a tendency to regard product design

Reprint RE-21-4-6
Final manuscript received September 20, 1975.

as a routine sort of occupation best carried out by the less bright members of their profession. Nothing could be further from the case. The skilled designer must have simultaneously a detailed knowledge of the technology available to him, the marketplace in which the product will be sold, and the manufacturing process. Product design embodies hundreds, if not thousands, of choices and trade-offs which involve a consideration of all three of these basic factors. For example, the designer must constantly consider features and performance vs. manufacturing cost, and size and weight vs. manufacturability and repairability. All of these decisions require not only a detailed knowledge of technology, of the factory and of the marketplace but also a high degree of judgment in optimizing the design.

An important aspect of this judgment is an intuitive "feel" which defies rational analysis. All really great products have subtleties and intangibles incorporated in their design which cannot be adequately specified even by a most detailed formal document.

In short, product design is at once an art and a science which requires a high degree of professional knowledge and skill, and truly outstanding product designers are as rare as highly creative engineers and scientists.

Time and money

The scenario is familiar. A small team of scientists or development engineers has completed a working model of a new product which they are demonstrating to a group of admiring executives. The demonstration is highly successful, and, superficially, it appears that the product is ready to be put into production and to be offered in the marketplace. The onlooking executives, impatient to capitalize on the new product, press for an early introduction date. The engineers who are responsible for the development are caught up by this enthusiasm and, underestimating the difficulties of product design, encourage this optimism. The result is a premature announcement, a business plan based on a faulty assumption as to product availability, and all of the financial and customer relations problems which follow.

The sad fact is that there is normally a vast gulf between an engineering development model which can be demonstrated in a controlled situation and a product which is manufacturable and salable. Bridging this gulf takes time and money.

In terms of time, two to three years is normally the absolute minimum for products of reasonable complexity, whether industrial or consumer, even assuming that all basic technological problems have been solved. If some of these problems are unsolved, of course, the time will be much longer.

In terms of money, we have found that typically 75% of the engineering expenditures required to bring television station products to the market occur *after* the completion of a working model. This percentage may vary somewhat depending on the product type, but it is very substantial in most electronics products manufactured by RCA.

Individual achievement

Finally, because of all the factors stated above, I believe we need to give a higher degree of individual recognition to those RCA engineers and engineering supervisors who have demonstrated outstanding competence in product design. The creative engineer has numerous vehicles for receiving this recognition: he can publish in professional journals; he can publish in the *RCA Engineer*; he has been nominated for the David Sarnoff Outstanding Technical Achievement Award. These have been available to the practitioner of the equally demanding professional engineering discipline of product design to a much lesser degree.

With this background I am particularly pleased that our Division received two of the David Sarnoff Awards for 1974—Arch Luther, the David Sarnoff Outstanding Technical Achievement Award for a long career of technical leadership of outstanding product design programs; and a team of engineers in RCA Meadow Lands and RCA Somerville received an award for its work on the TACTEC, the new and highly successful hand-held portable radio.

Conclusion

The subject matter of this article has been under discussion with the editors of the *RCA Engineer* for more than three years, and the original draft was prepared in June, 1972. With the perspective gained by the passage of time, the concepts embodied in the initial draft still appear to be correct. The emphasis, however, has changed somewhat because I believe there has been a significant increase in management recognition of product design as an important and difficult discipline. As this trend continues in the future we can look forward to improved planning, improved execution, and, most importantly, improved profitability with our high technology programs and products.

Andrew F. Inglis, Division Vice President and General Manager, Commercial Communications Systems Division, Camden, N.J., received the BS in physics from Haverford College in 1941. Following war-time service, he was associated with Frank H. McIntosh, consulting engineer to the radio-TV industry, and became a partner in the firm in 1949. He joined RCA in 1953 as Manager, Studio Equipment Product Planning and advanced through several executive posts in Commercial Electronic Systems, culminating in his appointment, in 1970, as Division Vice President and General Manager of the Communications Systems Division. His appointment coincided with RCA's establishment of a new Division by merging the Commercial Electronic Systems operations and the Defense Communications Systems operation. In March 1974 Commercial Communications was separated from the Government Communications operation; the company's businesses in broadcast equipment and mobile communications systems constituted the newly-named Commercial Communications Systems Division. Mr. Inglis continued as Division Vice President and General Manager with plant facilities in Camden and Meadow Lands and has since assumed additional responsibilities for Avionics Systems in Van Nuys and the Palm Beach Operations.

Elements of product design

A.C. Luther

Laboratory demonstration of a working breadboard for a new product idea signals the beginning of product design. A vast number of tasks remain to be completed before that product concept can be routinely manufactured and delivered to customers all over the world. This paper describes the various stages of product design and outlines the tasks required at each stage.

PRODUCT DESIGN is necessary to economically produce a quantity of identical products which can be sold to many customers. Quantity production requires so much total labor that it would be impractical and uneconomical to do it with the same skilled personnel who build our laboratory models. Therefore, the design must be developed in such a way that we can use lower-skilled labor and production tools and machinery to produce quantities of our product. Manufacturing organizations exist to provide these skills and the appropriate other facilities for quantity production.

Therefore, product design necessarily entails a transfer of information from an engineering environment into a manufacturing environment. The basic medium for this transfer is engineering drawings—these documents are the real output of a product design department.

Engineering drawings

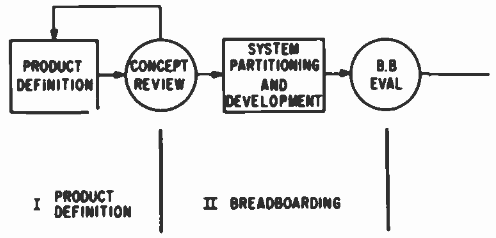
Much of the labor and expense of product design goes into preparation, review, revision, and approval of engineering drawings. Accurate and complete drawings are a vital element in a successful product program. They must describe the product in sufficient detail that it can be manufactured throughout its product life which should be at least five years and sometimes as long as 15 or 20 years. During this period, there will be personnel and organizational changes in Engineering, Manufacturing, and at our suppliers. The drawings are the only permanent link which assures the continuity and uniformity of the product over such a time period.

Another reason for good documentation is to provide proper control of the technical characteristics of the design. Control of the design should be maintained by an organizational element that has the proper knowledge and experience to evaluate design changes. This requires the same expertise as required for the original design of the product, so it is normal for the design engineering group to maintain change control of the drawings after they are released to production. Clearly, this type of control is not possible unless the aspects requiring control appear on the drawings. Anything missing from the drawings cannot be controlled.

A further reason for documentation is to allow for flexibility of purchasing and manufacturing. It would be easier to make drawings for one specific approach to purchasing and assembly of the product than it would be to describe all the characteristics actually required in the product. However, the latter method of specification will allow for parts selection from various vendors, and alternative processes for assembly. It is essential if the most economical production is to be maintained over a long period of time.

Environment of product design

The transfer of information between Engineering and Manufacturing is a two-way street—Engineering needs input from Manufacturing just as much as Manufacturing needs the information from Engineering. This two-way communication occurs throughout a product design program; a product designer gets to know all the segments of the Manufacturing organization. But this is not all—the product designer also must interact with other organizational elements in Engineering, Product Management, and general management. Fig. 1 is a diagram showing the principal activities interacting with a product designer. This diagram uses the organization names as they exist at the Broadcast Systems Camden location; the scope of each of these activities is summarized in Table I.



Steps of product design

As a product concept progresses from initial definition to the final manufactured item, it passes through several readily identifiable phases. Fig. 2 is a flow chart for a tpical product development; it may be divided into six specific phases, each completed by an evaluation or management review action. These phases may occur completely sequentially, as shown in the flow chart—that would be an idealized situation—or they may partially overlap to allow the program duration and costs to be reduced. In any case, it is critical that the evaluational steps be retained and used properly by all persons involved to assess the continuing success of the program.

I. Product definition

During the product definition phase, the principal objective is to develop a paper description (design goal) of the product, and obtain agreement of all parties to this goal. The major participants in this activity are Product Management and Engineering; they are facing the issues of the tradeoffs between the desires of the marketplace and the realities of state-of-

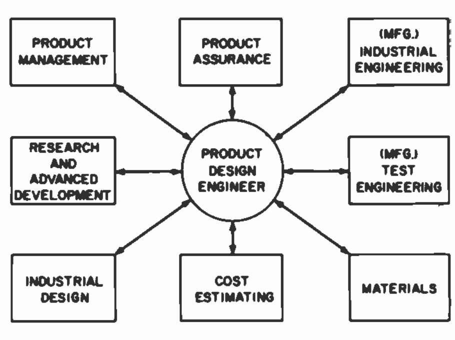


Fig. 1 — Product design interactions.

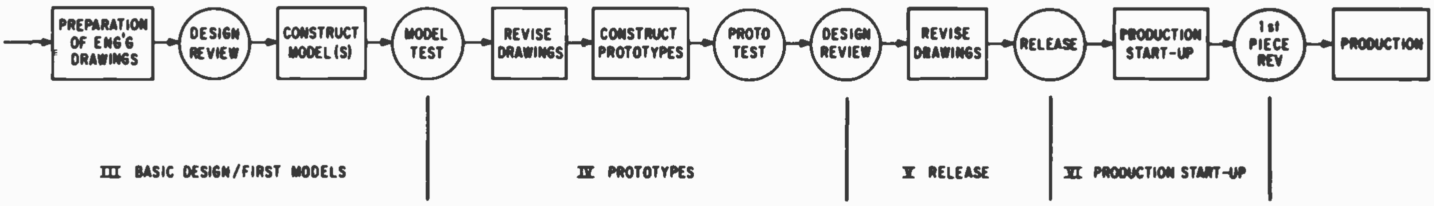


Fig. 2 — Product design flow chart.

the-art technology, design, and manufacturing technique. This is an iterative process which should result in a design goal that will provide us with a highly competitive product when the program is completed (probably three years in the future), but with reasonable chance of being achieved in that time with the resources available. The design goal should *not* be a description of exactly what the engineers are *sure* they can meet—it should be a challenge to the engineers. This will insure that we are striving for something more than the competition might also have in three years.

II. Breadboarding

During this phase, the product concept is broken down into subsystems and detail work is done to develop the design techniques that will be required in the final design. Specific techniques are breadboarded; if the total product is largely new, a complete systems breadboard may be constructed. The key to this phase is that the activity occurs with little documentation, so that changes are easily made, and their cost is minimized. Breadboarding should be done in a way that gives the engineers maximum flexibility to improve their designs, while they gain the vital experience that can only be obtained by building something and making it work. Upon completion of breadboarding, the product description is updated and a new level of detail can be added to it. In many programs, product definition and breadboarding may be heavily overlapped in time.

III. Basic design/first models

Now begins the most expensive single phase of product design. Following the detail design goals and the specific results of breadboarding, the final equipment configuration is designed in detail. Layouts are made for all assemblies, electrical and mechanical, and sufficient detail drawings are made that all parts, circuit boards, and assemblies may be built from the drawings for the first product design models. During this phase of activity, the program will add support help in the form of draftsmen, shop people, ordering clerks, expeditors, etc.

Table I — Product design activities.

Product Management is responsible for the choice of product concept, detailing of its description, and direction of the design, production, and product introduction activities.

Product Assurance oversees the entire organization to assure that the final delivered product fully meets our specifications and the expectations of the customer.

(Mfg) Industrial Engineering develops and implements equipment, processes and procedures for fabrication, handling, and assembly of the product during manufacturing.

(Mfg) Test Engineering develops and implements the procedures and equipment for testing of components, subassemblies, and finished product.

Materials selects and develops vendors; purchases and accepts all material and procured assemblies for the manufactured product.

Cost Estimating coordinates and completes the estimating of cost to purchase material, assemble, test, and pack the finished product, including manufacturing start-up costs.

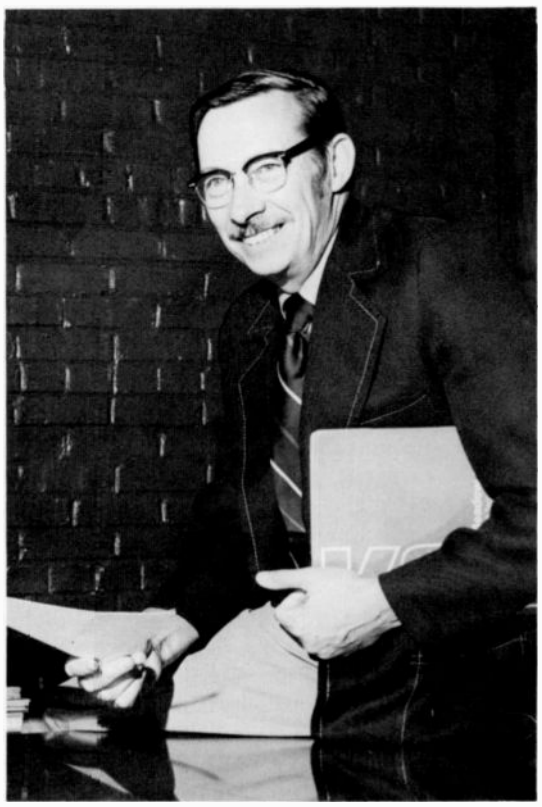
Industrial Design develops styling and appearance concepts for the product, and performs human factors engineering.

Research and Advanced Development performs studies and develops models to prove feasibility of new product concepts.

A.C. Luther, Chief Engineer, Broadcast Systems, Commercial Communications Systems Division, Camden, N.J., received the BSEE in 1950 from Massachusetts Institute of Technology. He joined RCA in July 1950 in the Broadcast Studio Engineering Department. In 1959 he moved to the TV Tape Recording Engineering Department where he had a major part in the development of the first all-transistorized TV Tape Recorder, the TR-22. In 1962 he became Manager of the TV Tape Recording Engineering Department. He directed this department during the development of the TR-70 high-band video tape recorder, the TCR-100* video cartridge recorder and many other supporting accessory items. In 1971 he became Manager, Broadcast Engineering, responsible for technical planning and direction of all engineering and advanced development programs for Broacast Systems. Mr. Luther holds 29 U.S. patents. He is a member of Eta Kappa Nu, a Fellow of the IEEE, and a Fellow of the SMPTE. He received the David Sarnoff Outstanding Technical Achievement Award in 1975, and in 1973 he received the David Sarnoff Gold Medal Award from the SMPTE. He has published and presented numerous technical papers on television subjects.

*In 1975 RCA received an Emmy Award from the National Academy of Television Arts and Sciences for the development of the TCR-100.

Reprint RE-21-4-7
Final manuscript received October 1, 1975.



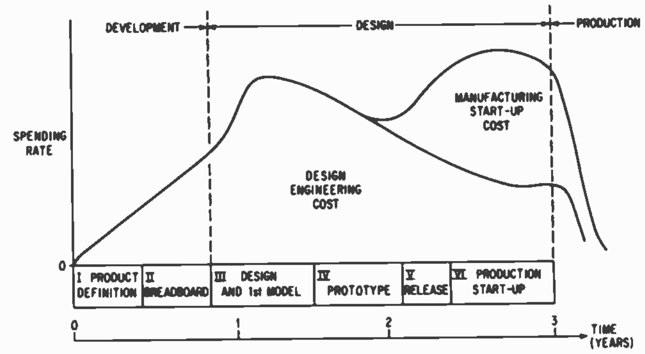


Fig. 3 — New product non-recurring cost.

The support team can easily outnumber the engineering personel by several times, and the program spending rate skyrockets. The result of this will be a working model of the product that hopefully meets our goals and, most importantly, a set of drawings that describes the product. There must now begin a serious discipline—that of assuring total agreement between the product models and the drawings. This is not easy to achieve when we realize that changes will constantly be occurring in both models and drawings as the design is completed.

IV. Prototype

It is extremely likely that so many changes have occurred in the course of perfecting the first model of the product that it is not possible to really bring that model up to what we think the final design should be. We will be making changes to the drawings for the final product which cannot be fully evaluated in the current model. Therefore, most programs require a second model or set of models—made from the "finished" drawings—we call these prototypes. These models again go through test and evaluation, and probably more changes. The need for strict discipline in keeping the drawings up to date is even more serious—since we will not check them again (by building from them) before we release the first production order.

V. Release

"Release" is the process of making the drawings available to Manufacturing for ordering of parts and assembly of first product. It is preceeded by a "sign-off" by engineering which signifies that the drawings become formal documents which must then be under formalized change control. From this time on, drawings can be changed only by completing the highly formalized Engineering Change procedure. This insures that changes are properly approved by management and that all persons are properly notified of any change.

On a new product program, "release" is usually not an instantaneous event. Because of the sheer bulk of the work, and the probability that different parts of the design are at differing degrees of completion, a release is usually phased over several months. It begins with 'long-lead item' releases, then parts ordering releases, and ends with pc board releases. This allows the final prototype work and some of the production start-up work to be telescoped together.

VI. Production start-up

After release, the Manufacturing organization moves actively into all the tasks of obtaining material, tooling and processing, and assembly of the product. However, engineering activity does not stop. There are many tasks of follow-up and support, and there are material acceptances and first-piece approvals. In addition, there are certain engineering tasks that can be left until this time for completion—such as writing instruction manuals. There may also be more product evaluation work, field tests, environmental tests, etc. which may uncover problems and result in changes which must be cut in. The design engineers will not be finished with their work until the product is shipping routinely from production and performing in the field.

Design assurance

You will note that each phase on the flow chart ends with an *evaluaton* step, such as a design review or a test. This is a fundamental tenet of product design—we must continually evaluate our work. Much of the activity in product design is directed toward *proving* that what we have designed meets its performance goals, is accurately documented, and that it is manufacturable at an acceptable cost. All of these activities may be grouped under the heading of *design assurance.* This is a task that must be pursued throughout the program by every person involved—that of evaluating and constructively critiqueing everything done on the project. It is an attitude that a good product designer will develop to the fullest—an indispensible ingredient of successful product design.

Program costs

Good product design is an expensive process. The costs incurred *after* the completion of the first working breadboard will dwarf the cost to make that breadboard. Fig. 3 shows a cost profile for a typical Broadcast Systems major product program. As you can see, the total engineering cost (area under the curve) is also substantially greater than the Manufacturing start-up costs. This pattern would of course depend on the production volume that is projected; in this case, the curve is for production of about 100 systems per year. Also evident in this curve is the spending peak that occurs during the basic design and first model phase.

TR-600

It is difficult in one article to express the complexity of product design and all of the interactions between groups which are necessary for a successful program. This may be more readily done by examining the details of a specific project. A good example is the TR-600 program which has been recently completed in Broadcast Systems and has resulted in a highly competitive product for RCA. Following in this issue of *RCA Engineer* is a group of papers which report on the TR-600 program from the viewpoint of the participating activities shown by Fig. 1. These papers will further emphasize that successful product design is not just a test of engineering ability, it calls also for skill in management, problem solving, and self-evaluation. This is a tremendous challenge to any engineer's ability; the reward is in seeing the finished product performing useful services for cusomers all over the world.

TR-600 product design

Product management

G.S. Moskovitz

Product management at Broadcast Systems has the primary responsibility for guiding the conception, birth, and growth of a new product. Determining market needs, directing the translation of these needs into a viable product concept, and coordinating this concept through the engineering development, manufacturing, and merchandising stages are all parts of a product manager's role.

FOR THE TR-600, product design began in May 1971, with a worldwide market survey of videotape recorder users. Taking the results of this survey product planning established, in September 1972, the initial concept of a medium-priced high-performance recorder. Our survey had clearly shown us three significant market factors:

1) Current quadruplex recorders were too expensive, too large, and difficult to operate and maintain.
2) The performance of current recorders was satisfactory
3) Most customers desired "fully loaded" products rather than "stripped" video tape recorders.

Taking this market input, various programs were then initiated among the engineering, product, manufacturing, cost estimating, purchasing, sales, styling, and planning organizations to establish the feasibility for such a product and then a detailed description of the product.

A preliminary product description was issued in April 1973. The TR-600 (or TR-41 as it was designated then), would have three basic design objectives:

1) *Medium price*—The list price would be below any other comparatively equipped broadcast quality quadruplex recorders. The design philosophy to satisfy this objective would be to include all desirable subsystems in the product rather than segmenting the design leading to a stripped product which could be "loaded" with very desirable, but expensive, "accessory" subsystems.
2) *High performance*—Video and audio performance had to be equivalent to, or better than, any other broadcast quality quadruplex recorder available.
3) *Simplicity*—Both operation and maintenance had to be simplified. Automatic functions should be increased with a corresponding decrease in required operational controls.

During 1973, a great deal of engineering concept and development tasks were completed, leading to the final product description in December 1973.

The product now known as the TR-600, was introduced domestically at the National Association of Broadcasters' Convention in Houston, Texas, in March 1974 and shown internationally at The International Broadcast Convention in London, England, in September 1974.

A major role of product management is played in not only coordinating these market introductions from the product's viewpoint, but also of accumulating all relevant market and competitive reactions to the product and assessing impact and possible product ramifications. In this light, various demonstrations and market discussions were coordinated and product changes implemented until the formal manufacturing release was given in May 1974. At the time of this release, it was the responsibility of product management to coordinate with engineering and manufacturing in issuing a "Program Guidelines" document detailing the significant milestones between manufacturing release and final product deliveries.

During this time period, product management also helps formulate the various customer support projects such as instruction manuals, field service, customer training, sales demonstrations, industry committee presentations, and the like.

The product

Following is a description of the final TR-600 as it evolved from the product design

Reprint RE-21-4-9
Final manuscript received September 3, 1975.

Gary S. Moskovitz, TR-600 Product Manager, Commercial Communications Systems Division, Camden, N.J. received the BSEE in 1969 from Carnegie Institute of Technology, Carnegie-Mellon U., Pittsburgh, Pa. where he majored in semiconductor electronics. In 1970 he graduated with an MBA from the University of Pittsburgh where he majored in Marketing and also International Business. He has been in his present assignment since May of 1971 and has been involved in various product management assignments within the Electronic Recording Department since March 1971. These assignments included the TCR-100 Video Cartridge Recorder, Time Code Editing equipments, and Video Headwheel Panel programs. He is a recipient of a Team Achievement Award for his outstanding contribution to the TR-600 Program.

Table I — Abbreviated specifications.

	Standard tape—15 in./s	
	525/60	625/50
Lockup time	1 sec (max)	2.0 sec (max)
Video (highband)		
Signal/noise	6 dB	43 dB
K factor (2T/20T)	1%	1%
Low freq. linearity	1%	2%
Differential gain	3%	3%
Differential phase	3°	3°
Moire	43 dB	32 dB
Audio		
Signal/noise	55 dB	55 dB
Wow/flutter	0.1%	0.05%

efforts described in a number of articles in this issue of the *RCA Engineer*.

The TR-600 is a quadruplex machine packaged in a horizontal configuration. For versatility, it records and plays back in highband, and is also a lowband playback machine. It can operate at both 15 in./s and 7.5 in./s tape speeds, with fast lock-up and fast rewind—taking only 2½ minutes maximum to rewind a 4800-ft tape reel.

The following automatic functions are built into the machine as subsystems:

Chrominance amplitude corrector (CAC)
Velocity error compensator (VEC)
Color dropout compensator (DOC)
Control track phasing (ACTP)
Guide and reel servo systems

Reflecting the value of integrated design, the standard TR-600 is equipped with these additional built-in subsystems:

Single-frame electronic splicer
Record current optimizer
Electronic tape timer display
Tektronix 528 waveform monitor
Monitor selector switcher
Loudspeaker
Venturi vacuum system
LED diagnostic readouts

The abbreviated specifications chart (Table I) shows the high level of performnace achieved by this new technology tape system.

New technology

An example of the new technology used in the TR-600 design is the increased use of integrated circuits and the substantial reduction in diodes and transistors. More than twice as many IC's are used in the TR-600 as in the TR-61 (its predecessor), but only half as many diodes and transistors. Overall, 1300 fewer discrete active devices provide the same functions—a 40% reduction in individual circuit elements.

The digital logic portion of the TR-600 uses the TTL 7400 Series of integrated circuits, the most common type. These were chosen because of versatility, commonality, and low cost.

Five built-in servo systems

There are five servo systems included in the TR-600:

- The Headwheel servo incorporates TTL logic and includes an automatic-frequency-controlled reference signal generator for improved record reliability. The drive to the headwheel is constant-amplitude and pulse-width modulated to achieve fast synchronization of the motor.
- The Capstan servo is also built with TTL logic, and incorporates an edit pulse detector which senses coincidence with tape frame. Headwheel-Capstan lock-up time specification is 1.0 second maximum (NTSC) and 2.0 second (PAL). The capstan is a dc printed circuit motor with a 5000-line tach which gives more servo stability.
- The Reel servo is unique to the TR-600, utilizing tachometers on the reel motors to determine the diameter of tape on each reel. Tach pulses from the supply motor are compared with tach pulses on the take-up motor. With the tape moving at a constant speed, say 15 in./s, the number of pulses tells the servo the rotational speed which corresponds to the diameter of tape on the reel and to the weight. The motor torque is then adjusted to accommodate the full range of reel sizes from 6-in. plastic reels to large 16-in. metal reels. As a result, tape handling is improved, and the possibility of tape damage minimized. The reel servo also provides controlled boost in start up for faster, more reliable lock-up. It keeps tape tension relatively constant over any length of tape in record and play, resulting in more uniform record and playback quality over the length of the tape. Tension is also more uniform in the shuttle modes resulting in better reliability in counting for tape times. Shuttle speed is 2.5 minutes (max) for a one-hour tape and 4.0 minutes (max) for a 90-minute tape.
- The Guide servo and Control Track Phasing servos are both automatic, and eliminate the need for operator adjustment from tape-to-tape.

Latest production technology

Some of the new manufacturing techniques in production assembly and testing used on the TR-600 include computer-controlled component insertion, wire destination testing of the entire machine, and computer testing of all the individual circuit cards or modules.

Hand wiring on printed wiring boards has been eliminated. Standards for board layout were established to permit automatic computer-controlled insertion of axial-lead components. More than half of the components on TR-600 boards are automatically inserted. Internal test signals for each module are brought out to the connector, permitting automatic testing of every board to rigid quality standards. Testing is performed by three automatic computer testers, resulting in uniform consistent quality.

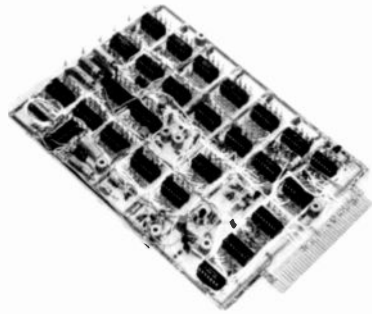
Summary

The TR-600 establishes a whole new set of performance/price/value parameters. It is designed as a unified, integrated system, incorporating numerous automatic subsystems for simpler operation, easier maintenance, and better performance.

The high degree of success of the TR-600 in the marketplace is a testimonial to the success of Product Management working closely with the Product Design team in bringing forth a product that met the market needs at a very competitive price.

TR-600 product design

Engineering



J.R. West

Because the TR-600 is a large complicated television tape recorder, all the procedures associated with a product design project were employed. This included interface with all the support departments within the broadcast organization, as well as outside support. It required the cooperative effort of all the Manufacturing organization, Engineering, Sales, Product Management and Broadcast Management staff. Engineering was responsible for coordination of the various activities in each phase and had Project Management responsibility. This paper describes the problems that occurred and the remedial action taken in the TR-600 project. Thus, it provides some insight into the various phases of product design.

J. Richard West, Ldr., Electronic Recording Engineering, Commercial Communications Systems Division, Camden, N.J., received the BSEE from Drexel University in 1957. For two years, he was a communications staff officer at the U.S. Army Aviation School. In 1959 he joined the Electronic Recording Products Department of RCA. He has worked on the design and development of the Pixlock Servo, Monochrome and Color Timing Correctors, Video Processing Amplifier, Chrominance Amplitude and Velocity Error Corrector. He was project engineer on the TR-5 Video Tape Recorder. In 1967 he was promoted to Group Leader and has since worked on the Tape Editing Programmer, the TR-70 Television Tape Recorder, the TCR-100 Television Cartridge Recorder, the Comsync Pulse Distribution System and the TA/TE-70 Special Effects and Mixing Amplifier. Most recently he was responsible for the TR-600 design and development program. Mr West is a member of the SMPTE and is currently serving as Television Program Chairman of the Philadelphia Section of the SMPTE.

Reprint RE-21-4-8
Final manuscript received September 26, 1975.

THE TR-600 Television Tape Recorder Engineering Program can be discussed by looking at what occurred in five different phases of the project. These phases are typical for any engineering project:

1) Product definition
2) Development
3) Initial design (Engineering Model)
4) Prototype phase
5) Production phase

A significant part of any project is the scheduling of resources, resource limitations, and project cost accounting. Manual pert charting was used as a scheduling tool. Because a project of this size requires three years to complete all phases, assigning and scheduling of manpower were a constant task. Project cost accounting was set up and tracked, utilizing the DEPICT computer program. The information tracked was used to provide Management project status visibility and forecasts for schedule, manpower requirements, and cost.

Product definition

The starting point for the product definition was an extensive field survey, which included interviews with station personnel in over 200 locations. All classes (sizes) of broadcast operations were covered. Included were stations that had no RCA equipment, large network facilities, and production houses. The survey was conducted and the data was compiled by the Product Management and Marketing Research groups.

In very general terms, the product definition was not unlike most product definitions. Relative to the existing products, (RCA and Ampex), the new recorder was planned to be smaller, simpler in appearance, easier to operate. It also had to be automatic where possible, cost less, and have performance equivalent to the best existing video tape recorder in the world. Production release was scheduled to occur in 18 months with product availability in 30 months.

In order to provide a basis for decision-making when we started considering hardware, the following priorities were established in order of importance:

- Cost
- Schedule
- Performance

The cost goal for the TR-600 was established at a level substantially below present RCA or competitive recorders, even though we expected to match or better their performance. Since low cost was top priority, product cost became the overriding challenge to Engineering. The low cost objectives meant that all avenues had to be pursued relative to lowering the cost.

Development

This led to consideration of items such as electrical components, electrical packaging (board format), electrical housing (module nest), mechanical packaging, wiring techniques, assembly techniques, and test methods. Only two areas from previous tape machines were not considered for redesign—the quadruplex tape scanning head and the standard tape format as established by the Society of Motion Picture and Television Engineers.

In developing the machine console package, the tape transport governed the overall size. The tape transport size was determined by SMPTE standardization of the tape path and the desire to handle two hours of program at a tape speed of 15 inches/second. This required supply and take-up reels 15.5 inches in diameter. Wooden models of the TR-600 were designed and fabricated in the plant carpentry shop. The models were conceived from a joint effort between Engineering and the Industrial Design activity modified by numerous reviews with people representing Sales, Product Management, Mobile Applications, and others. Some very important functional features of the new machine evolved from these early conceptual models. The reels were located near the front of the machine at an easily reachable height. Because a two-hour reel of tape weighs nearly 30 pounds, this was an important human engineering factor. With the reels in the front, threading the tape through the various elements in the tape path became more difficult, so a straight line threading concept evolved. Elements in the tape path were made moveable to make the threading easier. Concept of colors, finishes, control panels, cabinet construction, and tape transport castings were all reviewed for styling, functional design, human engineering, and manufacturability. The plywood models were reworked and rebuilt until it was possible to form a clear picture for all the reviewers.

At this same time, it was necessary to decide what to package within the cabinet, in addition to the electronics and the power supply and to be certain it could all be packaged in this smaller cabinet. As a result of these decisions, we mounted the picture monitor external to the machine and required an external high pressure air input. The high pressure air is internally regulated for the air bearing headwheel panel and also passes through a venturi device to create a vacuum for the tape guide in the headwheel panel. Another decision was made to try to use convection cooling which could eliminate the console blower, filtering, and baffling, and a plenum required for forced air cooling. Space to add fans was provided at the top and bottom of the cabinet if convection alone did not adequately cool the electronics. This led to an idea to separate the power supply into two chassis: the heavy heat-producing transformers on one chassis and the regulators on the other. The heat generating components on the regulator chassis and the hot transformers were enclosed in a sheet metal chimney. The chimney, open at the bottom and top, drew the heat of the power supply (over 1000 watts) out of the machine with minimum heat transfer to the electronics. It had the added benefit of making the regulator chassis much more serviceable at a weight of 35 pounds. The transformer chassis weighs 125 pounds. Connectors were used to make the required interconnections. The power supply concept was reviewed internally and with vendors who would bid for the development. A specification was written and two vendors were asked to supply development models.

In an early review of the project with Purchasing, the low cost objective of the TR-600 project was discussed. Purchasing advised that the biggest factor in bringing material cost down would be multiple vendors. Therefore, on all purchased items Engineering tried to develop a minimum of two vendors. This required additional work and cost in the development and production start-up phases. It did, however, provide Purchasing with some real leverage on all the major cost items such as motors, power supply, and delay lines.

Author Dick West standing beside first plywood model.

At the same time that the mechanical concepts were being formulated and reviewed, new ideas were being generated for the electrical packaging. A new module design was required to reduce costs. The objective was to eliminate as much of the hand wiring in the module as possible.

Many reviews were held before we settled on a 9-inch long by 6.4-inch high printed wiring board. This aspect ratio enabled good printed wire access to the front edge of the board and to the edge connector on the back of the board. An 80-pin (40 nearside/40 farside) connector was chosen. The board was to have printed gold-plated connector fingers because they were lower in cost than the discrete board connector. A module shield made of aluminum was also designed as an option for the new standard board. A module puller and module extender were also included. The module extender has folding support arms and is stored in an empty module slot in the electronics nest.

The electronics nest has historically been an expensive assembly made of individual connectors mounted on a plate. This plate was then aligned with rails to guide the modules. The connectors were hand wired. When vendors were consulted, it became apparent that a new technology was developing for electronic nests and it appeared that about 50% savings could result in assembly and wiring labor. Nine different vendors offered variations of a combination printed wiring/wire-wrap glass expoxy backplane with module nest attached. The entire assembly could be purchased with or without the wrapped wires. Models were ordered from two different vendors. The nest consisted of three tiers, with 25 module slots per row. The power supplies (+5 Vdc, ±12 Vdc), and many signal connections are printed on the wire-wrap side of the panel. The module side of the backplane is a ground plane to which all connector pins to ground are connected. Those connections that could not be printed were wire wrapped. Connections to the interface plugs were also made by wire wrap. The entire nest is, therefore, wired by machine. Also, since all connections to the backplane are by connector, it was possible to build an interface to automatically test the backplane and verify that all connections were correct with no opens and no shorts. This testing interface was designed by Production Engineering and has been implemented on the TR-600 program.

The electrical components to be used by the electronics design engineers were also standardized. TTL logic was chosen over others because of device availability and, more importantly, cost. To standardize the electrical design and minimize component types, lists of preferred resistors, capacitors, coils, and potentiometers, etc., were specified. Cost was again a factor in selecting the standard series.

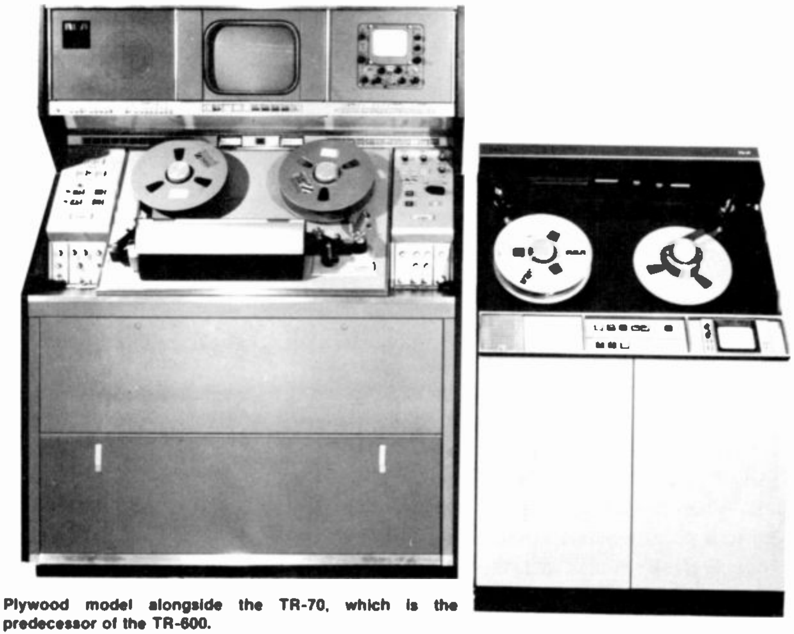
While all the general packaging decisions and reviews were being conducted, the electronic subsystems were also being conceived, partitioned, and reviewed. They are listed here to provide some awareness of the scope of the electronics design project;

TR-600 electronic subsystems

FM
Audio
Video processing amplifier
Time-base corrector
Color time-base corrector
Dropout correction
Velocity error correction
Electronic splice
Control
Electronic tape timing
Headwheel servo
Capstan servo
Reel servo
Guide penetration servo
Automatic tracking servo

Some of the electronics could be repackaged from the newer subsystems in other machines, but most of the electronics had to be developed from concept to product.

At the point where a conceptual picture could be formed of subsystems and the mechanical configuration of the machine, we stopped development effort to make a product cost estimate. This was approximately 16 weeks after the start of the project. The engineers were asked to commit to paper, as best they could at that time, the design of every module and every mechanical part. This rough information was then transformed by the engineers into parts lists, both electrical and mechanical. The parts lists were



Plywood model alongside the TR-70, which is the predecessor of the TR-600.

forwarded to the Cost Estimating group for analysis. Elapsed time for Engineering to furnish complete information was six weeks. Total turn-around time to get the estimate was ten weeks. The purpose of making the estimate was to assure management that what we had conceived could be built at a product cost level near the cost goals. It also gave management the confidence to approve building-in many automatic features previously thought of as accessories.

Since it appeared the cost goal could be met, a formal product description and specification was written. This document, in preliminary form, was circulated to all activities for comment. Comments were received and entered on an action log. Many meetings and some extensive investigation were required to resolve the questions and comments. The TR-600 *Product Description* was then signed as a formal document and the project goals were fixed.

An action log was maintained throughout the project. It was reviewed on a monthly basis and completed items deleted. Each item was reviewed periodically. Items were added as a result of reviews and meetings. The questions were logged by subsystem so that each engineer was aware of items requiring investigation or other action. In the three years of the project, over 900 items were formally logged into, and cleared from, the action log.

Engineering model

The development or breadboard phase was proceeding with hardware throughout the period of product definition. Mechanically, the console or cabinet had been through several wooden-model revisions. A tape transport was fabricated from a plate which was part of another recorder. The electronics subsystems were built as pin-and-jumper breadboards and were then bench tested. A system for building breadboard modules in the standard format that could be plugged into a backplane nest was devised. This system aided the engineers in making partitioning decisions early in the design cycle.

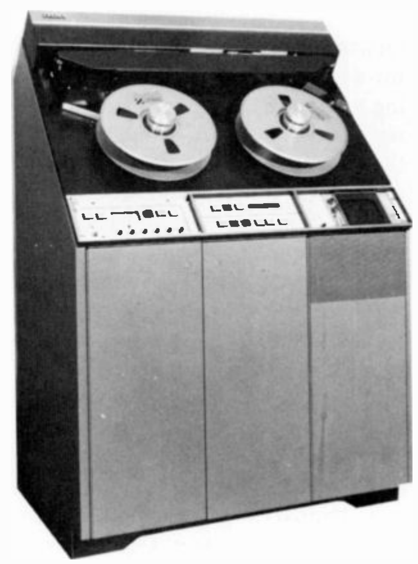
The console and transport reviews were held and the drafting effort started. Mechanical layouts preceded all other drafting. The drafting cycle for the transport and console was 12 weeks. The procurement cycle for the cabinet was short but the transport castings would take another 12 weeks after the drafting was completed. Therefore, it was planned to use the breadboard transport on the metal console until a changeover could be made. The engineering model (all parts built from drawings) was, for a long time, part breadboard and part engineering model. This was true both electrically and mechanically.

Electrical breadboard subsystems were phased into the machine backplane and nest in a logical manner, i.e. control system first, etc. The module backplane was procured with only power supplies and ground as a part of the printed wiring. Most of the wiring was added by wire wrap as each subsystem was integrated into the machine. One year alter inception of the program, power was applied to the engineering model console and we commenced installing breadboard modules. Installation of the breadboard subsystem required three months. As soon as an electrical subsystem breadboard was system tested, a detailed circuit design review was scheduled. These circuit reviews ranged from a prepared presentation to a group of experts down to a "desk-side review" by two or three engineers. The reviews were documented with action items listed and answers required. When the action items had been resolved to a point where confidence was high, engineering model drafting was started on that subsystem.

To help balance the drafting load and shorten the turn-around cycle for the engineering model, only the parts list, board layout and photomasters were drafted. The schematic existed as a symbolized engineering sketch and the assembly and marking drawings were omitted at this time. The drafting cycle per board type to generate photomasters averaged four weeks. A special arrangement with Manufacturing's printed-circuit-board fabrication facility enabled us to get an eight-working-day turnaround on board procurement. Generally, three boards of each type were procured. One was spare, one built for installation in the machine, and one built for continued bench testing. The elapsed time to turn a breadboard subsystem into an engineering model subsystem averaged twelve weeks.

The parts lists from the engineering model drafting effort were continually fed to Cost Estimating so that their information was gradually improved. Mechanical subassemblies and detail part drawings were also forwarded. Over a period of a year, the cost estimating information changed from all engineering sketches to preliminary drawings. Quarterly checks on product cost were made as the project progressed. Decisions affecting the design could be seen almost immediately in the projected product cost. This was a very valuable tool in holding down product cost. In the many design reviews, there were numerous suggestions on how to improve the appearance, the performance, or the functional capability of the machine. None of the suggestions ever tended to reduce the cost. Having up-to-date cost information enabled us to weigh the cost of the suggestions against our position relative to the cost goal.

Completed engineering model modules triggered another series of reviews. These were manufacturability reviews with Industrial Engineering, Broadcast Assurance and Test Engineering. Each of the 56 modules was reviewed and a list of action items made. All mechnical drawings and assemblies were also reviewed by the manufacturing members of the product design team. The action items brought up in these reviews required drawing changes which engineering incorporated before the next build phase which would be the prototype stage.



Engineering model.

When the engineering model was nearly complete (twenty months after inception of the program), it was shown to the public at the National Association of Broadcasters (NAB) Convention in Houston, Texas. Picture performance was marginally acceptable. What was demonstrated—i.e., the servo systems, the new tape transport, the module concept, and the styling at a price of $80,000—was well received. This was again a confidence builder that said we had made the right product decision thus far and that we should proceed as rapidly as possible.

The machine was returned to the Camden laboratory and immediately put in our environmental chamber. A week of testing was carried out to determine the stability of each of the subsystems through the allowable ambient temperature range of 0°C to 45°C. It was also a check on the convection cooling system for the modules and power supply. It was learned that several subsystems did have temperature problems. These were referred to the responsible engineer. Each module had been given an individual temperature test in a small mobile chamber as a part of the bench testing required, but it was not possible to identify all temperature problems in the individual module tests.

A problem that became apparent at NAB was the styling of the machine with respect to the paint colors. The TR-600 was advertised as new and innovative, but there it was in the same old colors. Many

Engineering model electronics.

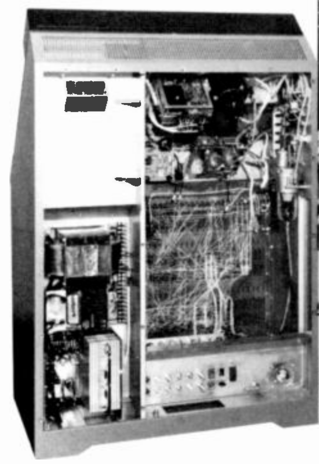
models were built; many meetings were held. The problem took seven months to resolve and it was nine months before we had new paint for our engineering model and prototypes.

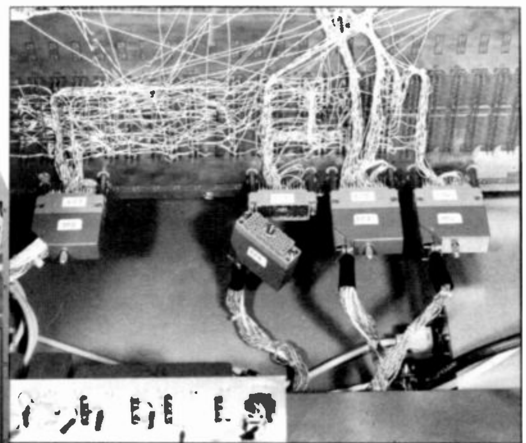
Prototype phase

The engineering model phase of the project for the basic machine was essentially over after the problems at the exhibition were discovered and solutions were in progress. The machine itself, however, continued to be used as an engineering model for further development and as a test bed for system testing prototype modules and other electrical and mechanical subassemblies. The 625-line PAL system was developed in the engineering model machine. It was then shipped to London for the International Broadcaster's Convention. This occurred at the 26-month point of the project. When the machine was returned, more temperature tests were made, and it continued to be used as a test bed for modules. The machine was then converted to the 625-line SECAM television system used by France and Eastern block countries. The engineering model at the 36-month point went to Montreux, Switzerland for the European Broadcasters Convention and was operated in the SECAM system. Today the machine is back in the laboratory being used to finalize the SECAM product design.

The prototype phase of the basic design program began at the 18-month point or before the first public showing at NAB.

Power supply, front view.





Left: machine rear view shows power supply on the left with transformer chassis above it. Wirewrap backplane and underside of tape transport to the right of the power supply. Above: backplane and input/output interface connectors.

The mechanical portions, of course, preceded the electrical subsystems. Parts were ordered to build four models. All prototype parts were to be built from drawings which had been corrected after building the engineering model. To give Manufacturing a pre-production look at assembly problems, it was decided that Engineering would assemble only the first prototype. The Production Engineering section would assemble the second unit, checking that the detail part tolerances could be assembled and providing an overall assembly which could meet system tolerances. It also gave the Equipment Development people the opportunity to develop tooling to aid or check assembly long before production assembly would begin. The third and fourth prototypes were built by Industrial Engineering. They too could develop fixtures, harness boards, and preliminary assembly processes ahead of production. Most importantly, manufacturing was involved in the project at a point where engineering could still react to solve problems. This resulted in fewer initial production start-up problems in the mechanical areas.

Prototype modules were handled in a similar manner. Engineering built one set and Manufacturing assembly process built three sets. All parts, as well as the drawings, were supplied by Engineering for all prototype construction—both electrical and mechanical. As a further check on the drawings, a new stocking system was set up in Engineering. All parts were stored in cabinets by drawing reference number only. As each assembly or module was built, the parts were pulled by drawing number only. Any errors existing on the parts lists were picked up by the individual trying to assemble the unit. This information was fed back to the engineer for resolution.

Four prototypes were needed to satisfy the needs of Engineering and Marketing. One was to be used in a field test,one to support Engineering and Manufacturing problem solving, and the other two to support accessory development projects. As it turned out, the fourth machine was never finished as a complete operational machine. The fourth unit main frame assembly was used instead to develop mechanical accessories, such as an overhead monitoring bridge. The modules were needed for an extensive period of time for test process to develop the automatic test programs for their VATS, LOGIC, and ACET test systems.

Mechanical assembly was complete and power applied to the first prototype 22 months into the program. The transformation of engineering model modules to prototype modules was long and difficult. The engineering design and drafting cycle took six months to complete all 56 module types. The requirement to make engineering design changes in some subsystems and the load on the Drafting Department contributed to the long cycle. The long cycle delayed the complete system performance evaluation and the field test, and it greatly increased the risk of releasing to Production.

Production phase

Production release is a phased procedure. In this case, the mechanical parts were released as soon as they were successfully assembled in the prototypes. This occurred at the twenty month point in the program. Because of long production procurement cycles (approximately eight months) the electrical components were also released at the twenty-month point. The dollar value of the risk in releasing electrical components was low. Because of the standard parts used, the number of "not usable" parts created by design changes was very low. All module printed-circuit boards were held—as

Production model with monitor bridge accessory.

were any mechanical parts or assemblies that had not been completed, checked, and assembled into prototypes.

Prototype machine module integration was phased by prioritizing subsystems as much as possible. Thus, prototype operations tests were conducted on some of the subsystems, such as the servos and the control systems over the entire period. A total system evaluation with all modules in place did not occur until the 28th month. We were then able to evaluate performance of a complete machine against the product description performance specifications. Video parameters for record and play were measured. These included signal-to-noise, 2T and 20T K factor rating, differential phase and differential gain, and frequency response. In the 30th month a team of RCA engineers from outside the group evaluated the prototype. This fresh look by "outsiders" uncovered new problems. Immediate action was taken to correct these problems because production was now proceeding on many modules. The prototype machine was then sent to ABC television network in New York where ABC engineers evaluated its performance. They also made an appraisal of how the machine would operationally fit into their system. This evaluation again resulted in action items but not many of them were performance problems. Since that test the prototype has been used for demonstrations in the United States and in Central and South America. The other two completed prototypes were used for accessory development.

One of the prototypes was used to develop and verify the manufacturing final test procedure that would be used to assemble the pretested modules into the machine. Test Process and Engineering worked together to develop a document that, although preliminary in form, could be used by test personnel for final system testing. This document is over 100 pages long and provides the tester with a logical way to proceed with the test as well as test methods and machine specifications.

The production release proceeded with module boards being released as evaluation problems were solved and drawing corrections made. As the releases grew later, or closer to production shipping, joint decisions were made regarding how the board procurement, module assembly, and test had to be handled. The first units from Production were to be shown at the 1975 National Association of Broadcasters convention. This required the production unit to be completed in the 32nd month and that date could not be changed. Therefore, with late releases a work-around plan was made in order to complete production machines on time. In these cases, the work-around usually was no more than Engineering ordering a small quantity of boards on a special short-cycle order and supplying a small number of some unique parts that could not be procured in quantity in time for the build cycle.

First-piece approval rules were in force. Each time a module or mechanical subassembly was completed, the responsible engineer was contacted. He inspected, tested, and approved each first piece. This was the go-ahead to Production to build additional units.

Module test required some special engineering and manufacturing effort. Prototype modules were used as references to aid Test Engineering in debugging programs for automatic module test. Problems occurred because with 56 module types there was insufficient time to do the program debugging as well as the ongoing testing. Therefore, manual test positions were established with engineering test fixtures and revised test procedures. During the period when this effort was required, some production modules were tested in the Engineering laboratory.

Additional Engineering support was provided to other activities during this project phase. It could be thought of as information dispensing. Everyone had to learn all there was to know about the TR-600. This included instruction book writers, the Broadcast Training activity, Tech Alert personnel, Service Company personnel, Quality Control, and Manufacturing Test personnel.

The basic TR-600 machine required a total of 75 instruction books to cover installation, operation, maintenance, replacement parts, assemblies and schematics. Nearly all of the manuals were ready for the first customer.

A training seminar was given by the Broadcast Training activity to Manufacturing Test and Quality Control personnel before the first completed machine was ready for system test. Service company and Tech Alert personnel worked with Engineering in the laboratory on prototype machines and on the factory floor as the first units underwent initia test.

Summary

At this writing, product is now flowing from Manufacturing. Over one hundred machines have been delivered. Delivery of the second hundred has started and material for the third hundred has been ordered. Schedules were met; product was shipped to NAB on time; and performance goals were met.

The predominant element in the TR-600 program, however, was product cost. Material cost and labor cost were engineered to be low, consistent with meeting performance specifications. As the product matured, some features had to be added and some designs grew in complexity and cost. But, because we started with minimal functions and engineered for low cost, when it became necessary to add functions for whatever reason, the basic cost level remained low. All of the manufacturing team, as well as engineering, was thinking low cost and, therefore, looking for ways to change methods, materials, or operations to lower cost.

TR-600 product design

Materials

J.T. Whisonant

It is surprising to most people that the Materials activity of RCA is active in product design long before the first engineering breadboard material is ordered. This article describes some of the little publicized activities and contributions of Materials in the evolution of a new product designed for the television broadcast market.

After product management had established the need for the TR-600 and defined the preliminary cost and technical objectives, a trio of procurement engineers and value analysts were assigned to work with Engineering in defining the complex technical interface between RCA and its potential major suppliers. These procurement specialists were assigned to cover three principal areas of responsibility:

1) Electrical components and subassemblies
2) Semiconductors, integrated circuits, and hybrids
3) Mechanical components and subassemblies

It is important to learn, early in development, the approximate limits of all critical components. Since these can make or break the entire program, every effort is made to identify the critical components at the earliest possible date. Such items as capstan motors, delay lines, filters, and reel motors were selected as the electrical components requiring the most effort to meet initial development goals for the TR-600.

Long before preliminary specifications were prepared, detail analyses were made jointly by Materials and Engineering on the selected critical components. Initially, this was simply a comparison of the selected item and existing data on the closest similar component. From the analysis, preliminary cost and design objectives were established and areas of cost vs. technical tradeoffs were listed.

Surveys were made to determine those vendors having the greatest technical expertise in the selected state-of-the art components. A series of engineering conferences was arranged with potential suppliers to explore technical approaches, design limits, cost tradeoffs and areas of technical uncertainties. This technical interface between RCA and potential suppliers provided Engineering with valuable information for use in the preparation of the preliminary specification. It also enabled Engineering to generate a design requirement that was within the state of the art and the established systems performance and cost goals.

Semiconductors, integrated circuits, hybrids

The semiconductor market today is extremely fluid. Many vendors are announcing new products while other vendors are dropping existing products almost without notice. On more than one occasion, vendors have discontinued products between the time a developmental model was completed and the prototype or production units were released. This can result in drastic circuit redesign, new printed-circuit board layouts, and major mechanical design changes.

To minimize this type of effort, data were collected from industry and charts prepared by Materials covering semiconductors, integrated circuits, and hybrids of the types most likely to be used in circuit development of the TR-600. These charts showed available types, number and name of currently available sources and cost comparison between devices in plastic vs. ceramic packages. Data were also collected from Government, Industry, and RCA sources on the reliability of plastic vs. ceramic devices in both critical and non-critical applications. These charts and data were made available to development engineers for use in the selection of devices that would be consistent with cost and reliability goals, yet provide maximum availability of the specified product.

The decision to use a combined printed-wiring/wirewrap backplane approach for module interconnection was made very early in the concept and development phases of the TR-600. Meetings were held with Engineering, Manufacturing, Materials, and potential vendors to evaluate feasibility of various concepts. Existing techniques using discrete connectors and hard wiring were examined to determine advantages, disadvantages, limitations, serviceability, adaptability to circuit change, and total cost. Inspection

Reprint RE-21-4-14
Final manuscript received August 14, 1975

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Fig. 1 — Electrowriter used for direct engineering ordering on local distributors.

trips were made to several users of the latest techniques in backplane assembly and wiring to obtain first-hand data on potential design and manufacturing problems. This information was used in making the final selection of the TR-600 backplane and the division of external wiring between the vendor and RCA manufacturing.

Early make or buy

Usually make-or-buy decisions for most components are made during the prototype phase of product design. However, to use available engineering technology most effectively on those phases of the development requiring the highest specialized skills, some decisions must be made during the concept and development phases. Two such decisions were made early in the TR-600 program. Thus, the product design team decided to purchase the video horizontal-line-delay module and the system power supplies. Although technical skills and manufacturing facilities are available within RCA to design and build both of these items, preliminary investigation of available items in the "marketplace" showed that we could not compete in price with outside vendors and that our Engineering and Manufacturing facilities could best be utilized for other portions of the assembly. This early decision provided Purchasing with the opportunity to work closely with Engineering and the vendors during the development and design phases of the TR-600 and to make value engineering tradeoffs resulting in refined specifications for initial procurement. Other advantages of this early decision will be shown later.

A full-size wooden mockup of the TR-600 was constructed, and a series of management reviews was held for design and styling approvals. Engineering was then ready to proceed with the design, fabrication, construction, and test of the developmental model.

Standard parts selection

Selection of common components is made from two volumes of *Broadcast Standards Electrical and Mechanical Components*, available to each design engineer. *Broadcast Standards* are maintained and updated by a Broadcast Standards Committee consisting of representatives of Corporate Standards Engineering, Central Engineering, Design Engineering, Drafting, Materials, Manufacturing Engineering, Test Engineering and Quality. New volumes are published quarterly or semi-annually depending on the extent of the required revisions. Standards bulletins are also issued on a required basis to advise all engineers of significant revisions or new information on standard components.

Commonly used components contained in the *Broadcast Standards* volumes are stocked in either an engineering stockroom or in a production stock account and are available for immediate use by engineering in the construction of breadboard, developmental, or prototype models. These stocks are controlled and maintained by the Materials Operations Activity and all records and transactions are maintained and updated by the latest computerized control techniques.

For those common standard items required which are not stocked by RCA, but which are common electronic parts normally stocked by local distributors, Materials Operations provides a direct telephone line ordering system with a number of local distributors utilizing blanket orders and "electrowriter" equipment (Fig. 1). By use of this service, Engineering Project Clerks may order directly on distributors all items valued at less than $100 by dialing a telephone number and writing an order on the electrowriter. The distributor will then deliver the item to RCA within 24 hours. These transactions do not require the normal purchase requisitions, the normal buyer-vendor negotiations, or placement of purchase orders.

Development

Based on earlier information supplied by the procurement engineer, Engineering was now able to prepare preliminary specifications and initial procurement requirements for special and state-of-the-art components. These are initially released for procurement of components for use in the Developmental Test Model and for extensive individual component test.

Developmental model

During the construction of the developmental model, engineers require the services of model makers, specialized mechanical fabricators, and local machine shops. At this point in the development, many parts are made from either preliminary sketches or verbal instructions and are required quickly, without the restrictions of a normal procurement system. To satisfy this need, blanket model shop services purchase orders are negotiated with local vendors for an estimated number of hours service at an established hourly rate. This enables the design engineers to obtain the required mechanical components and services on a direct vendor contact basis.

Mechanical castings

The mechanical castings for the transport housing, the tape threading assembly cover, and components for the audio and erase heads required major interface between potential casting vendors, Engineering, and Purchasing. Thorough investigation and planning during the development stage enabled design changes, modifications, and improvements to be incorporated during the prototype and production phases with minimum cost and lost time.

Engineering and procurement value analysis tradeoffs were made with regard to type of alloy, type of pattern, machining control points etc. best suited for each application.

The transport casting selected was made of a high-zinc-content alloy for best aging and ultimate stability. This required that the design provide radii rather than sharp corners since zinc tends to tear away from itself in such areas. The pattern was made from hardwood rather than metal so that changes could be made easily and still converted into production at a later date. Planning was such that the final production machining would be accomplished by tape-controlled equipment for minimum cost. With this ultimate objective in mind, the initial drawing was made so as to establish six tooling points in areas where the casting will vary the least. These points are used for locating all fixtures for machining and inspection purposes thereby minimizing manufacturing problems due to casting variations. Foundry expertise in these and related areas was most valuable in the preparation of preliminary drawings.

Rework and modification

After initial components for the developmental model have been accumulated, Procurement Engineers work very closely with Design Engineers in the assembly and test phases to detect and solve material problems and to plan for later procurements. It is important at this point that results of both component and systems test be fed back to vendors and that the effect of any required changes be thoroughly evaluated on both a cost and a technical basis. In some cases, vendors must do extensive rework or modification of components to meet unexpected design or application problems. In other cases, it may be necessary to procure alternate components on an emergency basis because the original component did not perform as expected or could not be modified to perform the intended function.

Prototype planning

After completion of systems evaluation test of the developmental model, the technical and cost objectives are again reviewed and modified as required subject to management approval. The results of these reviews define the final objectives for the prototype models. The goal of the prototype models is to use components, assembly techniques and test methods that are as close to production as possible. This is intended to provide a smooth transition from engineering to later production with a minimum of production start up cost.

Prior to the release of prototype material for ordering, preliminary specifications and drawings are updated to incorporate changes required as the result of engineering component and systems test as well as vendor inputs and experience gained in the manufacture of new and special components.

Lead time—a critical factor

Long lead items are identified and advance releases are made to provide sufficient lead time consistent with the assembly and test schedule. It is important to review lead time with procurement specialists as close to the release time as possible since these vary widely depending on the economic conditions at the time. For example, at the time of prototype releases for the TR-600, the quoted deliveries for computer grade electrolytic capacitors, precision metal-film resistors, and special bearings were ranging from 40 to 60 weeks; whereas in today's market, for the most part, these same items could be obtained within a 14- to 18-week time period. At the time, it was necessary to advance release all system power supplies, capstan motors, reel motors, delay modules, and special discrete capacitors and resistors well in advance of the normal release date. Due to the close relationship between procurement engineers and key suppliers of critical purchased assemblies, early identification of many long-lead items were made and advance ordered by either the vendor or RCA to reduce the ultimate lead time.

Make or buy

During the prototype phase of the TR-600 make or buy decisions were completed in order that production tooling and facilitation could be properly planned and implemented in advance. In all make-or-buy decisions, prime consideration is given to the following items:

- Cost
- Schedule
- Quantity (small vs. large)
- Start-up cost
- Quality
- Inspection cost
- Transportation cost
- Available technology
- Proprietary information
- In-house facility utilization
- Secondary operations
- Tooling cost

Many make-or-buy decisions are automatic due to organization and available facilities. Other items fall into a category which can be either made or bought depending on the above considerations. Some of the major make-or-buy decisions on the TR-600 are listed below:

Make	*Buy*
Audio heads	Cabinet
Erase heads	Power supplies
Video headwheel panel	Capstan motor assembly
Video filter	Back plane
Module nest assembly	Video delay module
Casting machining	Delay lines
Vec 1H delay module	Printed circuit boards

Capstan motor assembly

The capstan motor assembly developed for the TR-600 is worthy of special note in that it contains many features not previously included at the procurement stage. Motors of this type used on previous tape equipments were finished in-house by installing a capstan roller on the shaft and precision grinding the final assembly to the run-out tolerance required. Such motors also required external servo amplifiers and required factory realignment when either brushes or lamps were replaced. The TR-600 capstan motor assembly required no additional operations after procurement in that it comes complete with a precision ground and polished shaft to a 0.0002-in. T.I.R., an internal contained servo amplifier, a high-reliability LED lamp source, and field replaceable brushes. No factory realignment is required when either lamp, brushes, or servo amplifier components are replaced. This approach provided improved reliability and a substantial cost saving in the combined procurement-assembly cost as well as secondary savings in field logistics support.

Special facilities

During the prototype phase, any special tools, fixtures, or special test equipment required by vendors are defined and scheduled for implementation to coincide with the production release schedule.

Of the fourteen special video delay lines used in the TR-600, five required special test modules for engineering, incoming inspection, and vendor test to assure RCA and vendor correlation of test results. Likewise, coils used in the video filter assembly required special test fixtures and standards. Power supplies required special test facilities and loads to be used for incoming inspection. A computer program and mounting fixtures were required for automatic test of the purchased video delay module. Casting patterns required updating and modifications and computer machining tapes had to be provided.

Procurement engineers worked closely with Engineering, Manufacturing, and vendors in defining requirements and special packaging of purchased components for automatic insertion on printed-circuit boards.

Multiple sourcing

A major objective of Materials Operations is to develop at least two approved sources on all major components used in the system. This stimulates both technical and cost competition among suppliers and provides additional insurance against shut down due to strike, financial difficulty, or accident at a particular vendor's plant.

Work on multiple sourcing is started early in the prototype phase and continued through production. Initial sources are usually generated by a joint effort between procurement engineers and design engineers together with test results from the development model. Purchasing then sources the item to all potential qualified suppliers. Based on cost and technical compliance with specification, sample components are ordered from one or more additional sources for engineering approval. When received, components are subjected to inspection, evaluation, and test in accordance with a Broadcast Systems Division "E" form approval procedure. Components may be either approved, conditionally approved, or rejected. If a part is rejected, it is returned to the vendor with a copy of the engineering report for appropriate corrective action and submission of a new sample.

Information on the cost of purchased material on a competitive basis is supplied to cost estimating during the prototype phase. This information is used to predict ultimate production cost and highlight major problem areas in meeting original cost objectives.

Prototype assembly and test

During the assembly and test of the prototype models, the procurement engineer again works very closely with both Engineering and Manufacturing to move in on any potential material problems and to review and analyze data with regard to finding more cost effective means of accomplishing the desired performance. During this period, drawings and specifications are continually reviewed and updated to reflect the latest configuration. Vendor liaison is continued in those areas where changes are required to improve performance, reliability, serviceability or cost.

Fig. 2 — Computer terminal used for tracking location and status of material in-house.

Final procurement

Bill of materials

Prior to the production release of the TR-600, the Breakdown and Ordering Group of Materials Operation was active in keypunching preliminary "bills of materials" in preparation for a complete computer breakdown. This breakdown combines all of the following: functional assemblies, requisitions for the procurement of both purchased and fabricated material, accumulation sheets by each functional assembly, listings of available inventory of any existing material, and the various computerized reports for management and control of material for production. Fig. 2 shows a typical video terminal station used by Materials in tracking status and movement of material.

Contract negotiations

Upon completion of the computer-prepared requisitions for material for the initial production release of the TR-600, the Breakdown and Ordering activity supplied the requisition to Cost Estimating for target pricing consistent with the established cost objectives of the program.

The Purchasing activity received the material requisitions containing target cost information together with the various computer-prepared reports required for the efficient negotiation and purchase of the required materials and services in the most economical quantity and the form best suited for production use. One of these computer reports provided the buyer with total quantities of all like components not only for the TR-600 but combined with all other equipments to be manufactured within a one-year period. This information gives the buyer an opportunity to negotiate for a total yearly procurement with several scheduled releases and deliveries to provide maximum cost advantage combined with minimum inventory cost. A second computer report provided to the buyer with each requisition is previous price history information for the last ten buys of the component. This information enables the buyer to determine pricing trends, effect on cost due to design changes, competition, and other considerations.

Based on the above information, the buyer proceeds to negotiate and commit orders on one of the following bases:

- Corporate contract
- Combined item for price advantage
- Split procurement
- Long-term agreement
- Individual basis
- Development of additional sources

Corporate contracts

Corporate contracts are negotiated by Corporate Staff Materials for standard components used by many divisions of the company, and price is based on total yearly procurement by RCA. Each division orders its own separate requirements at the lower Corporate price. Orders are usually subject to minimum quantity releases.

Combined items

The buyer may combine a group of like components for further price advantage. For example, an agreement may be made with one vendor for combined quantities of fifty different values of ceramic capacitors for the total quantity price.

Split procurements

Split procurements were made on a number of special components such as power supplies, delay modules, glass delay lines, backplanes, and several motors. Such procurements provide insurance on the initial production procurement in case one or more vendors run into technical or delivery problems. It also provides keen cost competition and it provides continued development effort by all suppliers in an effort to gain a competitive advantage.

Long-term agreements

Another technique used by buyers on some complex high-cost items is to make long-term agreements for expected quantities to be released within a twelve- to twenty-four-month period, where the scheduled releases and deliveries are consistent with production schedules. This provides RCA with long-term price protection in a spiraling economy. This is similar to corporate-contracts procurement except that it is handled by a single division. The danger of this type agreement is that RCA is subject to retroactive bill-back for additional cost based on the lower-quantity price in the event we fail to procure the specified quantity of items within the specified time period. Thus, this procurement technique is employed judiciously.

Individual basis

On many standard components that are available from any number of qualified suppliers and are highly competitive within the industry there is usually no price advantage to be gained by any of the above techniques. These are therefore handled on an individual basis.

Multiple sourcing

Dual or multiple sourcing of unique special components was started during the prototype phase of the TR-600, as described earlier. In general this effort is continued and expanded throughout production. As new or improved sources become available, they continue to be evaluated under the "E" form approval system consistent with procurement cost, design features, and total cost to evaluate the source.

Initial production

All of the above procurement techniques are handled within strict accordance with Corporate and Division Operating Instructions and Procedures and are subject to continued Corporate audit.

During the procurement phase of the initial production release, required tools, special fixtures, test modules, coil standards, etc. are provided and supplied to the appropriate vendor or activity as required. Design engineers, and procurement engineers work closely with vendors, production, and purchase materials inspection to establish test methods and acceptance criteria for all special items. Critical areas of inspection and test are defined and components are designated for sample testing or 100% inspection for critical parameters. Vendor warranty and guarantees are negotiated and defined covering both RCA production cycle and customer use after delivery of the end product.

Follow-up

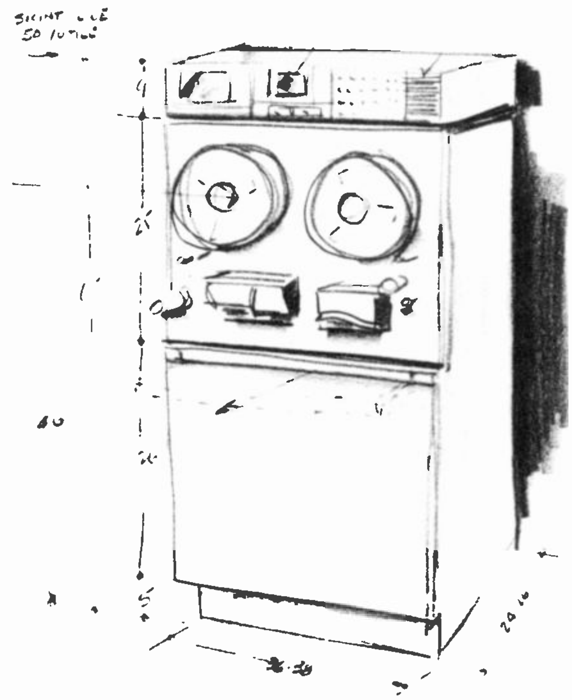
After accumulation and disbursement of all material required for the TR-600 to production for assembly and test, the procurement engineers closely monitored all production material problems for required specification changes, vendor corrective action, or modification of initial make-or-buy decisions. Problems with inspection, material handling, and routing of material within RCA were reviewed for possible value analysis improvements.

The Materials Operations Activity was an important member of the product design team in the evolution of the TR-600 Video Tape Recorder from concept to production. Contributions and services by the various functions as well as inputs from major component suppliers led to the achievement of major cost and technical objectives and the successful customer acceptance of the product.

TR-600 product design

Industrial design

J.J. Bulinkis



The Industrial Designer is concerned with all aspects of a product's use by humans. He is responsible for the product's shape, color, and texture and is deeply concerned with less obvious appearance factors like convenience, comfort, safety, maintenance, and cost.

In THE PROCESS of bringing a new product to market, the involvement of Industrial Design starts with a series of briefings from Product Management and Engineering. In the course of these briefings for the TR-600 reel-to-reel tape recorder, it became evident that this machine would have to meet a demanding set of design requirements.

The TR-600 was to be a link between an older generation of reel-to-reel machines and the emerging new generation. It had to stay within tough cost limits while achieving new standards of compactness and operational ease. The threading was to be simplified, approaching automaticity, but the size and slope of the existing TR-70 tape transport was to be retained. The machine control was to be less obtrusive and less complicated. Added to all these criteria was the stipulation that the TR-600 had to communicate an entirely new look, via finishes as well as dimensions.

Beyond the sheer specifications for a new product, an industrial designer has to consider the market in which the machine is to be sold and used. In the case of the TR-600, the crucial facts were that broadcast stations were discovering the revenue possibilities of local commercials and therefore reel-to-reel tape machines were becoming more important in production, both in and outside the studio. Another controlling element was the impact of inflation on station operating costs and the broadcaster's inclination to search out equipment that might be operated by less skilled people, thereby cutting costs. As a result, the Industrial Design task was to make the TR-600 attractive and harmonious in proportion, materials, and color. It must not assume the character of a technological nightmare—dominating its owner with illogical clutter—and must fit easily into the studio environment.

In thinking of what the designer calls the "cosmetics" of the machine, we had to be cognizant of the TR-600's compatibility with existing machine rooms which are frequently equipped by a variety of makers. The design of the TR-600, as in the case of all new products, had to anticipate design trends so that the product would continue to look contemporary for the reasonable future. Lurking in the background of all this was the realization that rival producers of tape equipment were said to be concurrently working on their own variations of advanced reel-to-reel machines, very likely with similar goals.

The next step in the industrial design process is preparation of visualizations. The intent of these preliminary concepts is to reconcile the thinking of the designer and product engineer. Frequently the designer and the engineer perceive different methods of achieving some of the desired ends. Typically it takes intense discussions to resolve the differences. Once this is accomplished, the preliminary concepts are reviewed with Product Management. Characteristically, the meeting results in a series of modifications to the original concept. When these modifications have been incorporated and approved all around, the visual studies are often submitted on a confidential basis to selected users of equipment for their critical evaluation. Their useful ideas are then incorporated in the equipment.

When the design of the TR-600 had progressed through these steps, full-scale dimensional mock-ups were produced. These were made of foam board, actual hardware, and colored paper to simulate the trim. At this stage, a number of alternative finishes in many combinations are first applied. The industrial designer usually finds that color selections are highly subjective, and every participant considers his view as virtually inviolate. In this situation the designer resorts to experts who can also serve as arbitrators. For the TR-600's "new look" we enlisted the cooperation of the Corporate Design Group. At suitable junctures in this give-and-take process, it is often necessary to recall that the true purpose of the product design exercise is to provide the sales team with a product whose visual characteristics, in addition to its performance features, give him an edge in the marketplace.

The mock-up serves as a guide to Engineering, which has been working concurrently on the circuits, mechanics, and general dimensional outlines of the machine. Now that the dimensions are concrete, Engineering is able to make the

Reprint RE-21-4-15
Final manuscript received August 14, 1975.

necessary modifications in the design and finally produce a set of drawings that will serve to build the prototype.

In this account of the industrial designer's role in the development of a new product, everything *appears* to have happened relatively smoothly. In fact, there are (were) labor pains and many crises and a lot of skirmishes before decisions are made on the housing materials, the hardware, the method of fabrication, the location of controls, the operating techniques, etc.

The final test for any new Broadcast Systems product comes at its "unveiling" at a trade event such as the annual convention of the National Association of Broadcasters. Here product people and designers once again face the conflict between theory and reality. Based on actual experience with similar equipment, users are able to see shortcomings that are often not apparent to the most experienced engineers and designers. These suggestions are scrupulously evaluated. Cost-effective ones are incorporated in the final product.

Joseph J. Bulinkis, Mgr., Industrial Design, Communications Systems Division, Camden, N.J., graduated from the Philadelphia College of Art in 1952. He has held similar positions with such companies as Burroughs Corporation and IBM, Federal Systems Division. Prior to his return to RCA in 1967 he was retained as a consultant to the NASA Mercury and Gemini space programs in the area of Human Factors and developed astronaut anthroprometric measuring devices for which he was awarded five patents. He is a member of the Industrial Designer's Society of America.

Up to this point, the industrial designer has been pictured as coping with problems that are quite substantive in nature. In a subtle way, however, every major decision of the designer is governed by an underlying philosophy that is an indispensable tool of his profession. He is ever mindful of the need for the product design to impart impressions of quality and value. He strives for innovations but often is limited to evolutionary changes. Finally, upon critical review of the product, prospective users must be convinced that the design will permit efficient operation of the product, will be easy to maintain, and will have a long useful life.

TR-600 product design

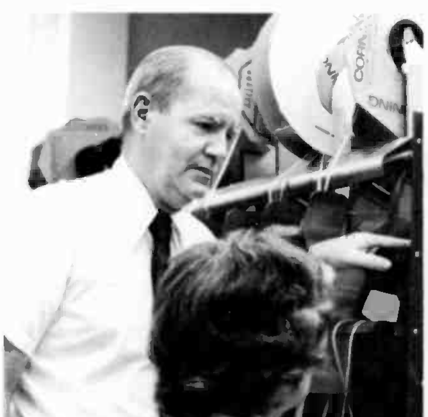
Manufacturing

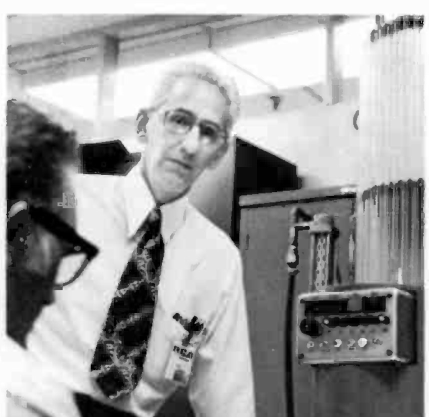
M.J. Gallagher| L.P. Welsch

Manufacturing's role in product design may not be apparent immediately; yet the interface is essential, and in many cases, will influence design decisions. Manufacturing covers many diverse functions; however, the two Manufacturing functions having the greatest impact on product design are Industrial Engineering and Production. It is the relationship of Industrial Engineering to product design that will be examined in this article, for although Production's impact in the design stage may not be entirely dismissed, Industrial Engineering acts as liaison for its inputs.

Maurice J. Gallagher, Mgr., Industrial Engineering, Commercial Communications Systems Divison, Camden, N.J. received the BS from Temple University in 1958. His experience in the field of Industrial Engineering is varied. Dating from 1946, he has been employed in progressive positions while pursuing his formal degree. In 1952, Mr. Gallagher was promoted to Process Engineer and in 1962 assumed responsibilities of Leader, Manufacturing Engineering. In 1969 he assumed like responsibilities in solving divisional multi-layer printed circuit problems. In May 1970, Mr. Gallagher assumed his present responsibilities for all assembly processing, standards and measurement techniques, facilitation, and manpower planning for effective implementation of program goals. Mr. Gallagher is presently a member of the EIA Automated Component Processing and Insertion (ACPI) JC-11 Committee representing RCA.

Leonard P. Welsch, Industrial Engineering, Commercial Communications Systems Division, Camden, N.J., was employed by RCA in 1941. His employment was interrupted in 1943 by the U.S. Army. During his two years in the service, he gained valuable experience in the operation of electronic equipment. Upon rejoining RCA in 1945, he availed himself of formal studies in Methods and Timestudy, Business Economics & Production, Industrial Statistics, Contract Interpretation, etc. In his present administrative position with Industrial Engineering, he is responsible for computer data and tapes for Automatic Insertion, Wire Prep., and Component Prep. These tapes are used to operate the equipment and for scheduling. Len is also responsible for written, formal Procedures for these and other Industrial Engineering Operations.





INDUSTRIAL ENGINEERING is the interface between Design Engineering, Cost Estimating and Production. It is essentially a service activity providing data, facilities, and methods of operation for many other activities. One of the services made available to the design engineer is the analysis of a design from a production standpoint. The expertise gained through many years of experience in the development of assembly methods and in solving attendant problems provides a bank of knowledge to the design engineer to develop his concept.

Cost control

Under the guidance of the design engineer, the Cost Estimating and Industrial Engineering activities, working together, determine the cost of a product early in the conceptual stages of design. Industrial Engineering reviews the design data and converts it into a language that enables the Cost Estimating activity to develop an estimated assembly labor and tooling cost. This estimated cost is used by the design engineer in developing his final design. When the design is "finalized", the Cost Estimating activity then computes its final cost estimate which includes such items as material, tooling, and labor costs. This final estimate is based on data supplied by Industrial Engineering which includes the assembly methods and techniques and the type of tooling required to manufacture the final design concept. The final cost estimate is the one used to monitor the cost of the actual production of the design.

Production process

Another function of the Industrial Engineering activity is to translate the design engineer's drawings into a procedure that can easily be followed by Production's least skilled operators. In this stage, suggestions are frequently made to the design engineer to modify the design to simplify the production process. Industrial Engineering also has the responsibility of providing access to various types of processing equipment and tooling, often designing special tooling in order to accurately produce the design. In this way, Industrial Engineer-

Reprint RE-21-4-12
Final manuscript received August 27, 1975.

ing provides for adherence to the design specifications and insures uniformity of product needed for interchangeability.

Product process

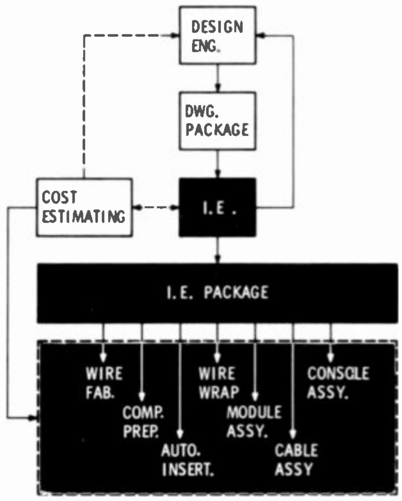
The relationship between Design Engineering and Industrial Engineering is a complex one. The design engineer must base his design on customer desires. Industrial Engineering attemps to guide the design engineer by advising him of current assembly techniques. The Industrial Engineer, however, must accept the challenge of new techniques when required by the design concepts, bearing in mind that implementation can only be done at a cost that has a direct relationship to benefits. The assurance of manufacturing the product within the design concepts is the responsibility of the Industrial Engineering activity.

Production facilities and methods

Part of Industrial Engineering's responsibility is the maintenance and ultimate operation of the various production facilities and the constant endeavor to update them. Industrial Engineering is constantly researching new methods of assembly to allow greater latitude to the design engineer. Often this research takes place independently of the design engineer and sometimes prior to his need. As improvements are made, the new data is made available to the design engineer so that design concepts are made utilizing the latest manufacturing facilities.

Manufacturing standards

Other Industrial Engineering innovations are made available to Design Engineering through the development and issuance of manufacturing standards. Periodically, Standards Design Committee meetings are held and information is provided to the Design Engineering activity outlining the manufacturing capabilities and limitations which may affect the design parameters. These manufacturing capabilities and limitations are often determined by Industrial Engineering through contact with other activities within the Corporation. These activities include Central Engineering, Equipment Development, and Management Information Systems. Another facet in the development of these standards is the



Manufacturing involvement in product design.

Industrial Engineering activity's contact with vendors, both current and prospective, offering new methods and products. This vendor contact may affect component parts or equipment already in use within the organization that may have to be adapted to meet the requirements of the new design concept or it might be research into new component parts and equipment to be utilized on future programs. The research might involve investigating the new component part and equipment under actual production conditions either within our own organization or at the vendor's plant site.

An example of the above is the research currently being undertaken to resolve the problems attendant to no-clinch assembly of components in modules. Elimination of the clinch would allow for greater component density and provide the design engineer with greater latitude in his endeavor to answer Marketing's demands for more compact equipment.

Prototype assembly

In the early stages of the design, Industrial Engineering is called upon to build prototype units. During this phase much information is gathered to assure the manufacturability of the concept and to provide feedback to Design Engineering. This information may include the delineation of assemblies where difficulty is experienced in mating parts, the redesign of some areas to assure ease of operation, correction of drafting errors, or suggestions for better cable routing. This interface with the design engineer during the prototype assembly ultimately proves beneficial to all activities concerned. Manufacturing is provided with a design that is capable of being produced and the Design Engineer is guaranteed that the product assembled will adhere to his final design specifications.

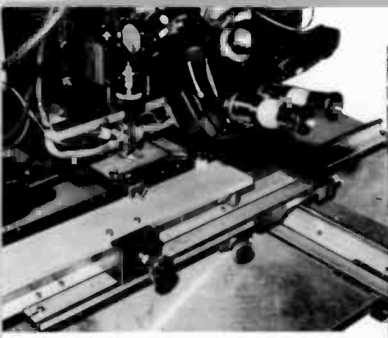
TR-600—down to cases

How this interface between Design Engineering and Manufacturing is working and the advantages to be gained by this interface will be shown by examples on the TR-600 program.

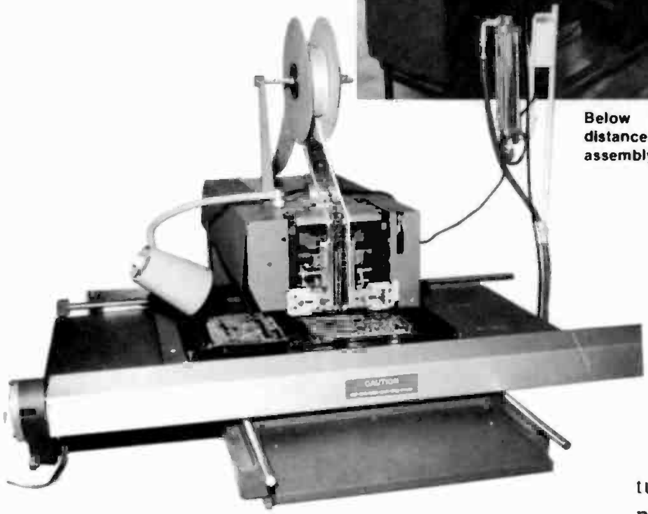
Wiring

As a result of a joint effort between Design Engineering and Industrial Engineering to resolve the long-standing problem of wiring complex units, the decision was made to generate a computer program that would compile all the necessary wiring information. Preliminary meetings were held between Industrial Engineering and members of the computer activity in order to formulate the program. Once the preliminary program had been formulated, the design engineer reviewed it and provided the necessary wiring data. Information was generated from this data that provided wire number, from-and-to information, copper path, loop list, and loaded loop list. The format was designed for quick access to the various circuits allowing for easy application of the Broadcast Standard color coding.

As the wiring information was fed to the computer, a generation of the tab run-off indicated the redundancies and errors in the original data. Generation of this program saved many Design Engineering hours and provided error-proof wiring information. Previously, this wiring information was generated by a number of designers, then collected and kept in volumes of loose-leaf binders by one engineer. This was very time consuming and error prone, due to the massive amount of inputs from many sources. It was not only difficult to find the errors, but often time consuming since a massive amount of paperwork had to be generated and corrected each time an error was found. With the new method, these errors were quickly corrected by utilizing the computer run-off. The action taken was immediate rather than drawn out as the engineers involved were able to



Solder reflow equipment used for surface-mounted devices.



Below left: automatic variable-center-distance insertion machine. Above: typical assembly — magnetic heads.

Left: automatic component cutting and forming machine. Above: automatic component sequencing equipment.

make the changes in the early design stages, rather than at a later time when it was believed that everything had been finalized.

Another benefit of this computer program was the generation of a wire information tape which was used to check out the wiring and cable harnesses using the DITMCO test equipment. In the past, the DITMCO tape was made early, and the errors found while developing the cable required constant changes to be made to the tape. Many times, due to the time involved in issuing Engineering Change Notices, the DITMCO tapes were not to the same revision level as the cable being presented for test. The computer program eliminated this, and as a result, troubleshooting was narrowed down to wiring errors rather than precipitating a massive, time consuming search through Industrial Engineering processes, test processes, engineering data, and Engineering Change Notices.

The use of the computer and its various formats, combined with the design specifications, provided a basis for the designation of one type of white wire. It enabled manufacturing to break down the wire as required and color code it as desired. This, in turn, provided manufacturing with the capability of cutting and preparing the wire for the entire shop order in one continuous flow of operations rather than by individual references with numerous equipment changeovers. It also minimized the wire inventory on the floor and in the stock room, and allowed Purchasing to realize savings by purchasing wire in large economical quantities.

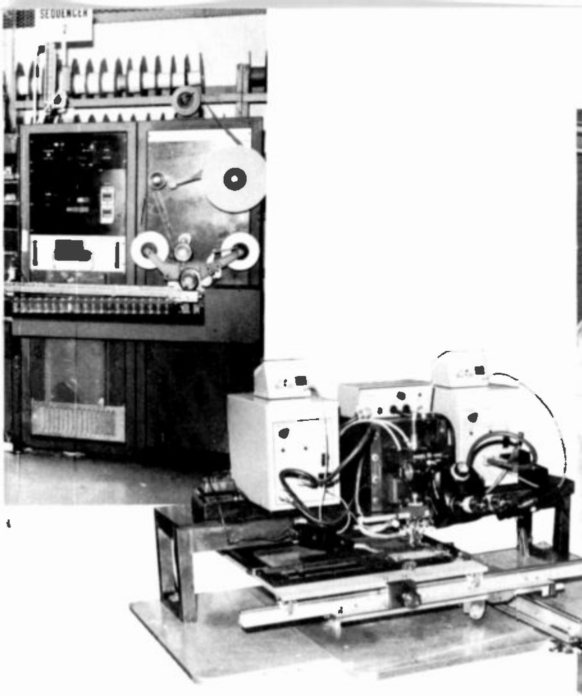
Printed-wiring-board standards

Another example of the participation of Industrial Engineering in the Product Design of the TR-600 was the establishment, with design Engineering, of standards for printed wiring boards (PWB's). Maintaining a standard board size, standard component mounting centers, and standard tooling hole location made these boards highly compatible to the automatic insertion of components. Due to this standardization, over 55% of all components called for on these boards was automatically inserted.

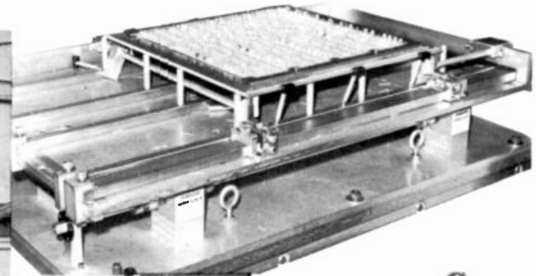
To utilize the automatic insertion process, Industrial Engineering, working with the Cherry Hill Computer Center, developed the module assembly data and specification and provided tapes for the operation of the sequencing and automatic insertion machines. This program greatly reduced the time needed to generate the automatic insertion and sequencing tapes resulting in a much faster "turn-around" from the receipt of the engineering data to delivery of the assembly processes to production. Like the computerized wiring program, this software also provided advantages for Design Engineering in that its redundancy indicated errors of omission and transposition that were highlighted and corrected in the early stages of the product design.

Component preparation

Other enhancements made by the Design and Industrial Engineering team included adding the component mounting centers to the Material List and noting, with an asterisk, any components that had non-standard spacing. This resolved some of the problems encountered in developing the computer input program for automatic insertion and provided information that eased Industrial Engineering efforts in other areas such as developing component preparation data. Because of these innovations, we were able to mechanize the input to the computer program that allows manufacturing to bulk "prep" the components that could not be automatically inserted. These components were prepped at one time for the entire shop order rather than by reference as had been the practice in the past. This resulted in considerable savings as it reduced machine set-up time and operator change-over. With the addition of counters on the machines, the operator was able to divide the components into the amounts needed for the various references while operating the equipment. This in turn eliminated the need to hand



Solder reflow equipment.



Above: vertical milling machine. Above right: horizontal automatic wire-wrap equipment.

Repair of wire-wrap backplane.

count or weight count these components in the stock room, providing for a faster and more accurate count.

PWB and wiring reliability

A committee including Industrial and Design Engineering was organized to review the manufacturing and field problems relative to module failures on prior programs. It was found that open and intermittent circuits occurring during assembly and in the field were often the result of wires on PWBs flexing and breaking during normal handling. The service loops normally provided were quickly used up due to the numerous repairs, both in the assembly area and in the field. An additional design problem was found on those modules containing ground covers. When the wire was fed through the board, the space between the ground cover and the wire was such that the lead often shorted out. As a result of the committee's efforts, a formulation of techniques for attaching wires to mod·iles was approved. It was agreed that attachment to the printed wiring board was to be made by using terminals as the connecting points. The benefits of the committee's decision were quickly realized in manufacturing as it eliminated the need for special holding fixtures to maintain wire dress during the soldering operation, and test rejects caused by wiring problems were substantially lowered.

Automatic wire wrap

The team of Design and Industrial Engineering worked closely to attempt to design a backplane that would allow the automatic wire wrapping machines to be utilized. However, due to the sensitivity of the circuits and the need for a grid layout and wire size not compatible to the automatic equipment, these machines could not be used. Therefore, on the first shop order of the TR-600 the point-to-point connections on the backplane were made on the semi-automatic wire-wrapping machines. These machines also work in conjunction with equipment that automatically twists, measures, strips and cuts to length twisted pairs of wires for installation by the wire-wrapping machines. By utilizing both pieces of equipment, the twisted pairs contained on the TR-600 backplane were connected at the same time and in the same area as the point-to-point connections.

Tapes, generated by a computer program, are used to operate the machines. Utilization of the equipment significantly reduced operator errors in assembling wires to terminals and greatly reduced the testing and troubleshooting time that would have been required with other methods. One of the greatest benefits derived from this method was the general awareness of all parties concerned that a design could be enhanced to utilize a more efficient method of manufacturing. Plans have been formulated by Engineering to develop future designs which will utilize the automatic wire wrapping machines.

Prototype critique

Critique meetings were held with members of Design Engineering and Manufacturing after the prototype was built to evaluate the assembly. From these meetings come many recommendations on how to improve the design and manufacture of the TR-600 to maintain a good uniform appearance and attain a high quality product. Such items as the dress of wire, the redesign and assembly of the control panel with its cable as one item instead of separate assemblies, the provision of studs on the plate where the power supply is mounted, and many other items relative to ease of operation were discussed and implemented, where possible.

Conclusion

The experience on the TR-600 program has shown that there are many benefits to be gained from an early interface between Design Engineering and Manufacturing. The successful product design of the TR-600 program would have been impossible without the full-hearted support and enthusiasm given this program by all parties concerned. Because of this cooperation, the transition from the design concept, through prototype assembly to actual manufacturing assembly was accomplished with fewer problems than past experience had indicated.

TR-600 product design

Cost estimating

J.P. Cellucci | V.S. Koslosky | J.P. Bush

Manufacturing cost is the largest single expense in the Broadcast Systems business. With the emphasis in the broadcast marketplace on lower-priced equipment, and with the general economic trend to higher costs for everything, control of manufacturing costs of new products is vital for continued profitability. To a very large extent, manufacturing cost is controlled by the efforts of the product design engineer, even though the cost is actually incurred at a later time, by different people.

COST ESTIMATING has the primary function for supplying cost visibility during the development of new products. One of the most critical and pressing needs in industry today is forecasting new product costs before completion of the equipment design. Generally, it is at this point in time that business decisions are made, and in many cases, selling prices are established. Fulfilling the forecast is the goal of the entire organization, but depends primarily upon Engineering's performance in designing a product consistent with the technical and cost requirements. This goal also depends upon Purchasing's and Manufacturing's performance in procurement and production of the product within the same design parameters.

This paper describes the role of the Cost Estimating activity in coordinating the cost inputs from the entire organization and thereby assisting in the product design of a new piece of Broadcast equipment. Examples will be shown of the cost estimating efforts on the new TR-600 video tape recorder.

Types of cost estimates

Fig. 1 shows the path of a typical new product concept through the various phases of its development up to production. At any point in time, we must be able to quote the best possible figures about the expected manufacturing cost of the design; and we must therefore have estimating techniques that are applicable to the type of information available at each phase of the program.

Initially, when the product is just a concept, and no hardware exists, we must use what is called the "concept estimating technique." This method can work with very little detail about the product or its manufacture. This type of estimate can be updated through the early breadboarding stages, but by the time complete breadboarding is finished, we have collected more information about the product. At this point, we begin using the detail estimating technique that is used by the Camden Plant Cost Estimating group.

Detail estimating requires a complete item-by-item breakdown of the product.

Joseph P. Cellucci, Mgr., Cost Estimating, Commercial Communications Systems Division, Camden, N.J., attended Rutgers University and Drexel University. In his current assignment he has the responsibility for all phases of the Cost Estimating activity. Mr. Cellucci joined RCA in June, 1940, as a member of the Manufacturing activity. He was transferred to the Industrial Engineering Staff as a Timestudy Engineer in November, 1943. He advanced to the position of Leader in July, 1952, Supervisor in January, 1953, and Manager in March, 1954. In January, 1955, he was promoted to Manager, Timestudy and Cost Estimating. In June, 1958, he was named Manager of Cost Estimating for the Divison. Mr. Cellucci's background of thirty-five years of industrial experience was instrumental in the development of the Concept Cost Estimating Program.

Victor S. Koslosky, Mgr., Meadow Lands Cost Estimating, Commercial Communications Systems Division, Meadow Lands, Pa., received the BS in Industrial Management from St. Vincent College. He has been employed by RCA for the past fifteen years, primarily in cost estimating functions. His present responsibility covers the Mobile and Broadcast Transmitter product lines. His work experience prior to RCA included Timestudy, Methods Engineering and Cost Estimating. He has attended RCA courses in Work Factor Time Standards, Work Simplification, and Value Engineering.

Reprint RE-21-4-10
Final manuscript received August 27, 1975.

James P. Bush, Adm., Manufacturing Standards, Commercial Communications Systems Division, Camden, N.J. received the BS in Accounting from LaSalle College in 1951 and the ME in Business Education from Temple University in 1958. Mr. Bush joined RCA in 1953 as a Time-Study Engineer responsible for time and motion study, establishing incentives, and measured daywork rates. His next assignment was that of a Cost Estimating Analyst, and in 1962 he became a Leader of Cost Estimators. In 1966, Mr. Bush became Administrator of Financial Control and then in 1968 he became Manager of Cost Estimating. Presently, his primary responsibility is for the accuracy, control and issuance of all manufacturing standards concerning the Factory, Marketing, and Financial activities. Mr. Bush has also been on the Evening Division Staff at Camden Community College since 1968 as an instructor in Business Administration.

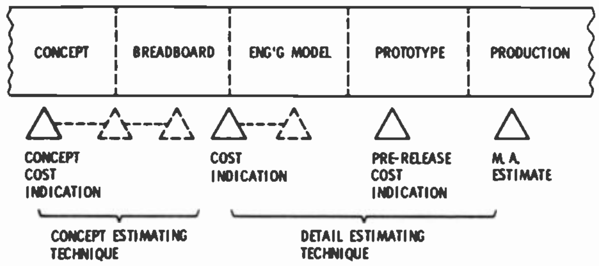


Fig. 1 — Product manufacturing cost estimates. This chart shows the path of a typical new product concept through the various phases of its development up to production.

Costs for each item at each point of its manufacturing cycle are computed and assembled for a total estimate. This kind of estimating requires a good understanding of the manufacturing cycle as well as an understanding of the product.

Concept cost indication

The concept cost indication is a tentative cost based on verbal description, preliminary design studies, and any other available data. It is basically an estimate of a design concept, since no formal parts list or drawings are available at the design feasibility stage. The basic tool of concept estimating is experience. This is the most difficult point in time in which to apply a quantitative approach to cost estimating since the least detailed information is known about the product. In the concept formulation stage it is not always possible to identify all the components required to complete the system. The challenge to Cost Estimators is to project from the known to the unknown, and to use experience gained on existing equipment to predict the cost of new equipment.

Concept estimating, because of its lack of detail, inherently includes an allowance for the probability of design growth during the design cycle that is consistent with the estimator's knowledge.

Cost indication

After the completion of the breadboard model, engineering effort can be applied to produce preliminary parts lists for the Cost Estimating activity to update the original concept cost indication. This is when we begin using detail estimating techniques. At this point in time, the first cost indication of Fig. 1 is produced. Detail cost estimates are considered to be a normal extension, and a more detailed development of, the previous data and information. This normal second step represents a concept of continuity in a program life cycle.

The estimate serves to present the anticipated costs involved in a program. Additionally, since the preparation of the estimate requires in-depth inputs and documentation, it should serve as a basis for future planning and control.

Sometimes after the initial cost indication (using detail estimating techniques) is prepared, an Engineering model is usually available, constructed from parts as similar to production components and structural parts as is practical. At this stage, a second cost indication is usually prepared. The model is built to perform to the electrical specifications and generally conform to mechanical specifications. This serves to provide greater visibility within Engineering, making possible a degree of effectiveness in identifying and removing unnecessary cost. Cost Estimating also has the opportunity of pointing out areas where lower cost items or techniques might be used.

Pre-release cost indication

The pre-release cost indication is an indicated cost based on preliminary Engineering information, models, sketches, etc.

A prototype model is usually available, built from final production drawings utilizing materials, tools and methods of assembly which are as representative of the subsequent production equipment as is possible to achieve.

The pre-release cost indication includes the current standard cost and allowances. During the pre-release cost indication effort, the information is much more detailed and precise and lends itself to specific value engineering work which is carried on in parallel with the costing effort throughout the design period.

The purpose of the pre-release cost indication is to give the best possible measurement of product cost at an appropriate time—a time sufficiently early that management can reconsider its plan for release in the event that product specification and/or target cost will not be met, or business/marketing conditions change, etc.,—a time prior to any extensive dollar commitments for production, parts procurement, processing, tooling, etc. Detail estimating requires a complete item-by-item breakdown of the product.

How cost estimates are derived

Today's system of estimating by industrial engineering procedures can be defined as the examination of separate elements of work at the component part level. Therefore, a knowledge of the cost elements is essential to a basic understanding of the cost estimating task. These elements include manufacturing methods, available plant equipment, current material prices, forecast future prices, and direct labor and overhead rates.

The activities of Design Engineering, Purchasing, and Manufacturing are essentially sequential within the normal product design cycle. However, the associated responsibilities cannot be viewed as being independent of each other. Each of the functions must support the other functions in meeting its obligations. Only with such a cooperative approach can the individual responsibilities be met and the organization's goals achieved. The objective of forecasting new product cost is best accomplished through the utilization of a team approach.

Team approach

Members	*Functions*
Product Management	Provides product plan
Design Engineering	Design concept
Manufacturing & Purchasing	Production plan/ vendor contact
Manufacturing Engineering	Manufacturing methods
Test Engineering	Test methods
Cost Estimating	Cost knowledge

Product Management provides technical and reliability design requirements to Design Engineering through definition and description of the product to be designed. The cost requirements of the product are made visible and are monitored through the establishment of product cost goals.

Product cost goals are considered to be, primarily, design targets which can be used in developing original cost planning for a program. As a program matures through its life cycle, increasing degrees of refinement of the product design estimates, as measured against the goals, provide the product design engineer and management with a guide to the trade-offs that are required between technical features or performance vs. cost.

Design engineering is responsible for developing the product design to meet or better the product cost goals.

In the capacity of team captain, the Design Engineer coordinates the involvement of Cost Estimating, Purchasing, Manufacturing, Test, and Production Engineering during the various phases of the product design. Progress toward meeting product cost goals is continually monitored by the Design Engineer and any potential problems are highlighted for management review as soon as they become visible.

The updating of product cost estimates as the product design program progresses requires an understanding of the manufacturing cycle as well as an understanding of the product. As his part in this team effort, the Cost Estimator develops the complete estimate, interfaces with team members, and presents cost details to Engineering, giving visibility to all major elements of cost.

The estimator must have some engineering ability because he is constantly confronted with problems of estimating on products which have not been previously manufactured. The cost estimator's engineering ability should enable him to determine whether or not further engineering work is necessary before proceeding with the estimate. He also participates in make-or-buy decisions.

Application to TR-600 program

In late 1972, the plan for a new video tape recorder, to be called the TR-600, had progressed to the point where a target cost could be set. This was established by Product Management, primarily through market research analysis. As the product design progressed, the ability to achieve this goal was frequently monitored by the cost estimating group who prepared cost estimates based on Engineering information available at that stage of the design. Fig. 2 shows the cost history on the TR-600 program. The cost to manufacture the equipment has been normalized in this graph, with the initial cost goal shown as 1.00. To have this cost goal be realistic throughout the design phase, a 5% per year inflation factor was added, producing the straight line shown on the graph. The initial concept cost indication was made in January 1973. This was produced with limited information from Engineering: only sketches, rough schematics, and breadboards were available. The cost estimate, while being under the cost goal line, did not allow enough for technical uncertainties at that early phase of the design. At this point in time, Engineering was urged to generate enough information so that the transition from concept to detail cost estimating could be done earlier than heretofore. This would give greater confidence in the accuracy of the estimate so that management could make early decisions about the direction of the program. The estimate done in March of 1973, although labeled in Fig. 2 as a concept cost indication due to its time frame, was done in this manner, and therefore could be called a detail cost indication. In addition to the increased technical information available for that estimate, Design Engineering, using the first concept cost indication as a guide, was able to rework some of the design concepts, so that the new cost indication (March 1973) showed an acceptable margin for technical uncertainty.

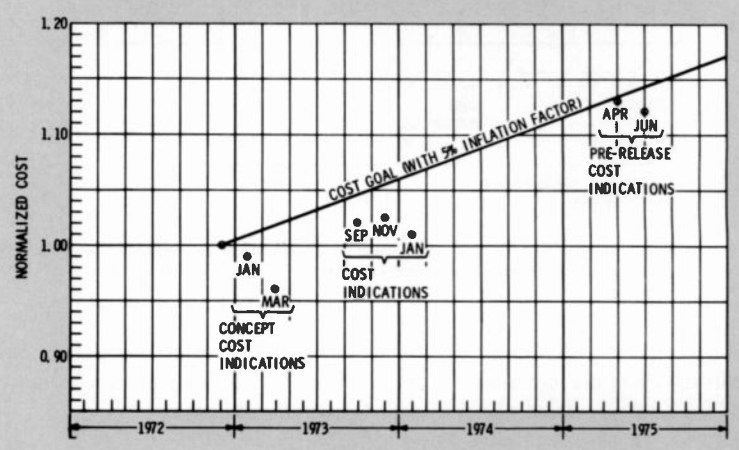


Fig. 2 — TR-600 cost history.

In late 1973 and early 1974, the design had progressed to the point where an engineering model was produced and a significant number of engineering drawings were available. More refined cost indications were then made by Cost Estimating. As shown in Fig. 2, these were still under the cost goal.

By mid 1975 the prototype was built and final engineering drawings were available. The pre-release cost indications were made from this firm data, and again, as shown in the graph, the cost goal had been met.

Conclusion

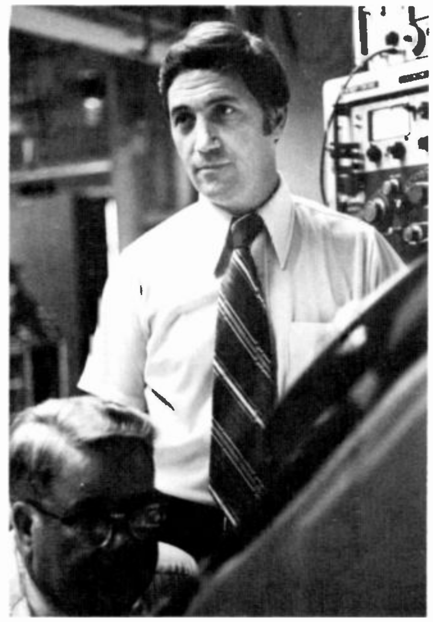
As can be seen from Fig. 2, the concept cost indications made from minimal engineering information in the early phases were very close (allowing for 5% inflation) to the pre-release cost indications made from complete engineering data two and one half years later. This is attributed both to the skill of the cost estimators and also to the ability of the product designers to utilize this continual cost feedback as an influence in making cost effective design decisions.

The success of the TR-600 program in meeting its technical and cost goals stands as an excellent example of the effective utilization of the cost estimating group in a Product Design team.

Product assurance/ quality assurance

V.F. Renna | F.D. Galey

Successful products for the broadcast industry are usually the result of an evolutionary process that integrates (1) current customer needs and expectations, (2) the capability of today's technology and components, (3) the invaluable experience based upon previous generations of equipments, and (4) a creative design engineering environment supported by a dedicated organizational team. Broadcast Assurance, one element of the team, provides continuing support of new product development from initial concept to full production. The nature of the interface with the design activity varies as the development process matures. In the conceptual phase, the Assurance task is essentially that of providing experimental input data based upon production and field experience with similar equipments. Much later, in the final production phase, Braodcast Assurance provides direct visibility into production, test, and field experience with the specific product and identifies areas of hardware or software requiring "fine tune" adjustment.



Vincent F. Renna, Mgr., Quality Assurance, Broadcast Systems, Commercial Communications Systems Division, Camden, N.J., attended Lackawanna Business College, Rutgers University, and Edison College, and is currently working toward a degree in Business Administration at Edison College. Mr. Renna has been Quality Assurance Manager of Broadcast Systems for the past three years. He joined RCA in 1960, serving in various Quality Assurance and test positions, including Manager, Quality Assurance, Information Systems Division, Printed Circuits Facility. He is a member of the American Society for Quality Control.

THE SIGNIFICANT milestones of the Broadcast product development cycle are described by A.C. Luther earlier in this issue. For this paper, new product development activity is grouped into seven distinct phases (Fig. 1) with each phase representing an essential product development step. Each is terminated with a tollgate/approval action that determines the direction of the following phase(s). Broadcast Assurance's actions are phase related.

Throughout the ensuing discussion, the Broadcast Assurance tasks are tabulated to show their relationship to each product development phase. In these tables, the interfaces with the product design activity are summarized as follows:

- *Data/input*—This indicates that Broadcast Assurance provides input data to Engineering
- *Review/control*—Meaning that Broadcast Assurance provides a reviewing and controlling function for that task.
- *Measure/evaluate*—Broadcast Assurance performs actual measurements and quantitative evaluations for these tasks.

Note that the frequency of measure/evaluate tasks increases as the development effort matures. Each measure/evaluate task is accompanied by a data/input task to ensure that the design group has knowledge of current performance in both the production and field environments.

Concept (phase I)

In concept development, Marketing and Product Management identify the customer's requirements for a particular product. In the case of the TR-600, a need was identified for a new reel-to-reel video tape recorder incorporating many of the features of a new generation of recorders but to be sold at a moderate price. The requirements were evaluated and a conceptual design was generated using detailed trade-off considerations. A formal Concept Design Review was then held, which resulted in decisions for the initial design development of the TR-600.

Reprint RE-21-4-11
Final manuscript received August 20, 1975

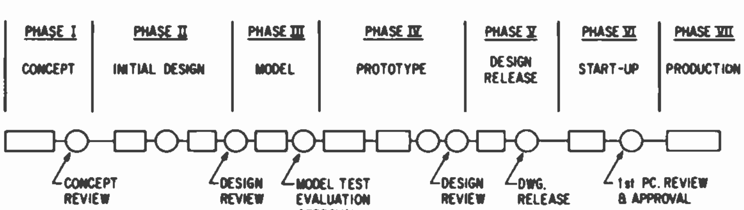


Fig. 1 — Seven phases in the development of a new product for the broadcast market.

F. Dean Galey, Mgr., Product Assurance, Broadcast Systems, Commercial Communications Systems Division, Camden, N.J., attended Capital Radio Engineering Institute, Resident Course, at Washington, D.C. He received the BSEE from the Maryland University. Mr. Galey has been Manager of Broadcast Systems Product Assurance for the past two years. He joined RCA in 1951 as Supervisor for Assembly Process Control. Since that time, he has held various positions in the Quality Control function including Quality Control Manager, Vendor Assurance Programs, and prior to the present assignment was Quality Assurance Manager for Broadcast Systems. He is a member of the American Society for Quality Control.

In the concept phase, Broadcast Assurance analyzed performance records for similar existing equipments, and conducted surveys of present users of similar equipment to obtain inputs that might be useful in product design. Analyses were made of field reports and manufacturing quality records to determine prior problems that should be addressed in the new design. Finally, Broadcast Assurance personnel were active participants in the concept design review.

Initial design (phase II)

Using the output of the concept phase (i.e., an approved listing of features, performance requirements, and design options selected to achieve the desired features and performance) an initial design was developed. Breadboards of significant elements of the design were fabricated and tested in parallel, and the results used to select detail design options for the TR-600. At this point, engineering documentation consisted of preliminary parts lists, schematics, assembly drawings, and tentative materials and component selection. This documentation coupled with the results of breadboard testing was subject to the approval of a formal Intermediate Design Review, prior to undertaking detail design and model fabrication and test.

During this phase, Broadcast Assurance continued to provide additional field and production experimental data to assist in design tradeoffs and component selection.

The Broadcast Assurance activity is represented on the *Broadcast Standards* Committee and actively participates in standards development. During the initial design phase, *Broadcast Standards* provided the TR-600 engineering team with a detailed set of part, material, process, and design options, of known reliable performance and cost effectiveness. For example, ground planes on printed circuit boards were placed on the near side rather than far side to reduce solder shorting problems in Manufacturing.

Broadcast Assurance performed an evaluation of TR-600 breadboards for performance, quality, and producibility on a continuing basis during this phase. The results of these evaluations were fed back to the design team who incorporated changes where necessary.

Again, Broadcast Assurance participated in the intermediate design review, presenting its evaluation of the breadboard designs and participating in the selection of final design options.

Model devleopment/ test (phase III)

After receiving the approval of the intermediate design review, the design was completed to the extent necessary to fabricate, assemble, and test TR-600 models that approximated the planned final configuration. Deviation from final configuration was limited to those design aspects (such as exterior finish) that were of limited performance risk. Broadcast

Phase I

Broadcast Assurance tasks	*Product design interface* *Data/ input*	*Review/ controls*	*Measure/ evaluate*
Equipment performance record analysis	X		
User experience surveys	X		
Field report analysis	X		
Manufacturing quality record analysis	X		
Concept design review participation	X		

Phase II

Broadcast Assurance tasks	*Product design interface* *Data/ input*	*Review/ controls*	*Measure/ evaluate*
Standards Committee participation (parts, materials, processes)	X	X	
Quality field historical record analysis (to support detail design decisions)	X		
Intermediate design review participation	X		
Breadboard evaluation (performance quality analysis, producibility)	X	X	X

Phase III

Broadcast Assurance tasks	*Product design interface* *Data/ input*	*Review/ controls*	*Measure/ evaluate*
Drawing review—test specification review	X	X	
Model development—review corrective action program (formal action items/response)	X	X	
Conduct model performance evaluation. Model quality/producibility evaluation.	X	X	X

Phase IV

Broadcast Assurance tasks	*Product design interface* *Data/ input*	*Review/ controls*	*Measure/ evaluate*
Final design review		X	
Monitor production testing of one pre-production unit	X	X	
Perform Q/C test utilizing factory Q/C technicians and field service technicians for producibility/ usability evaluations.	X	X	X

Phase V

Broadcast Assurance tasks	Product design interface: Data/input	Review/controls	Measure/evaluate
Action item closeout verification and approval		X	

Phase VI

Broadcast Assurance tasks	Product design interface: Data/input	Review/controls	Measure/evaluate
Review Engineering Notices		X	
Review Manufacturing processes		X	
Develop quality controls		X	
First-piece inspection	X	X	X
First-piece test	X	X	X
Q/C formal release for produciton		X	

Phase VII

Broadcast Assurance tasks	Product design interface: Data/input	Review/controls	Measure/evaluate
Vendor/subcontractor evaluation/control	X		
Purchased parts inspection	X		X
100% board inspection/test	X		X
100% systems inspection/test	X		X
Lot control evaluation—board level	X	X	X
Summary record analysis (trend review)	X	X	
Corrective action requests	X	X	
Packing/shipping surveillance by Q/C	X		X
Field installation/usage monitoring by Product Assurance	X		X

Assurance conducted extensive evaluation of the TR-600 development models, identifying quality, producibility, and performance characteristics requiring engineering attention. Resulting engineering changes were followed to successful conclusion. For example, all major subassemblies are subjected to first-piece evaluation to minimize downstream rejects.

Prototype and final design review (phase IV)

The TR-600 development models and their evaluation/change that occurred during the preceding phase resulted in the completion of essential engineering documentation. While all action up to this point had systematically eliminated design problems, our level of confidence was still insufficient to consider the configuration sufficiently free of risk to permit release. The prototype TR-600 was produced using all of the parts, materials, and processes (including inspection and test) required of the anticipated final configuration.

The TR-600 prototype was subjected to a time/stress/performance test designed to uncover weaknesses in the design and its components. Braodcast Assurance particpated in this activity, monitored all results, assured closure of all identified problems via appropriate design and process change, and approved the completion of the test after one hundred hours of failure-free operation. Broadcast Assurance participated in the final design review as presenter and reviewer, resulting in the release to the build cycle.

Design release (phase V)

This phase was limited to assuring the adequacy and completeness of all TR-600 engineering documentation, and the preparation of Engineering release documentation in advance of production startup. Broadcast Assurance verified that all corrective action identified in preceding TR-600 phases were in fact incorporated in the documentation to be released.

Production startup (phase VI)

This initial phase of the production cycle of the TR-600 was under the control of Broadcast Assurance. Each component, process, assembly operation, and test was subjected to extensive first-piece evaluation, and changes were introduced when necessary to assure cost-effective and trouble-free reproduction of the engineering design. The interface with the design group was extensive during this phase since this was the first opportunity to see the TR-600 design in the production test environment.

Production (Phase VII)

Full production of the TR-600 was undertaken only after sequential approval of each step in the flow by Broadcast Assurance. The principal assurance tasks during the full production phase were, and are, associated with the control of Quality, i.e., assuring optimum yields from each process/assembly step, and the accumulation and analysis of data from testing to accomplish this end.

Conclusions

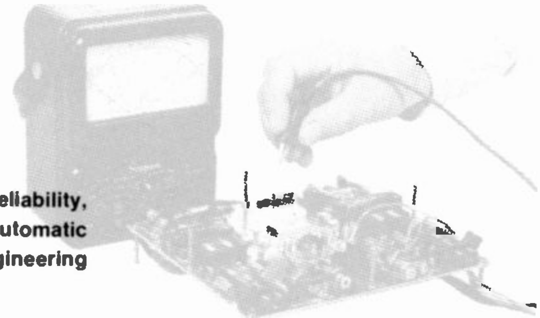
The interface of Broadcast Assurance with design continues throughout the production phase as both factory and field experience equipment factors are identified. The design, while essentially complete at the time of release, is subject to refinement and change as statistical data, only available after some experience with quantity production is secured.

The Broadcast Assurance functional elements are organized, not only to measure and control existing product, but to accumulate, store, and utilize the combined production/field experience data base in supporting the Division's new product objectives. The successful introduction of the TR-600 Video Recorder to the Broadcast Division's product line is the result of a team effort that fully integrates the unique Broadcast Assurance role as participant and judge.

TR-600 product design

Test engineering

S.N. Nasto | D.C. Smith



In concept, the TR-600 was to be a low cost product with a high degree of reliability, delivered within projected shipping schedules. To make this concept a reality, automatic testing was applied in as many manufacturing phases as possible. Thus, Test Engineering had to be involved from the start of product design of the TR-600.

TEST ENGINEERING is a support function of Manufacturing, and as such, it is responsible for developing test methods and procedures to ensure that products meet established engineering specifications. To develop these test methods and procedures, certain engineering information is necessary (i.e., schematics, parts lists, layout drawings, performance specifications, types of stimuli necessary, and types of measurements required). In gathering this information, there is a continuous interplay between the test process engineers and the product design engineers.

Automatic Test Center

Another major responsibility of Test Engineering is the operation of the Automatic Test Center. The Automatic Test Center is a computer-controlled testing facility using three RCA-1600 type computers with associated peripheral tape stations, disc stations, video terminals, and teletypewriters. The computers are used in a time-share mode. This equipment basically controls all of the automatic test equipment in the Automatic Test Center. The automatic test equipment used for the TR-600 program are the logic test set, ACET (automatic communications equipment tester), and VATS (video automatic test system).

Logic tester

Logic test set

Designed specifically to test digital functions, this equipment under computer control exercises the truth table for a module in a matter of seconds. Test programs are developed from truth tables, timing charts or test patterns and are stored on library tapes as inputs to the computer for a particular program. The system performs go/no-go and diagnostic programs. The output is in two forms: a visual display or a printout of failure information. The test adapters are quick-change plug-in type, capable of interfacing with 128-pin connections.

ACET

The Automatic Communications Equipment Tester is basically an analog system which under computer control, is capable of testing audio, rf, and power-supply modules as well as functional assemblies and radio systems. The programmable

Sal N. Nasto, Mgr., Test Engineering, Commercial Communications Systems Division, Camden, N.J. received the BSEE from Tri-State University and was employed by RCA in 1951. After a tour as a specialized Trainee on the Engineering Program, he was assigned to the Receiving Tube Division in Harrison, N.J., in Equipment Development where he designed test equipment for receiving tubes. In 1956 he was appointed Manager, Electrical Design in Equipment Development. In this capacity, he was responsible for designing Automatic test equipment for receiving tubes and computer controlled test equipment for transistors. In 1968 he transferred to the Semiconductor Division at Somerville, N.J., again responsible for design of test equipment for transistors and integrated circuits. He transferred to Camden in 1971 and held the position of Manager, Government Test Projects. He was appointed to his present position in 1974. Mr. Nasto was elected to the Tri-State University Honor Society and cited in *Who's Who in American Colleges and Universities*. He is a member of IEEE, and is a licensed Professional Engineer in the State of New Jersey.

Dale C. Smith, Mgr., Commercial Test Projects, Test Engineering, Commercial Communications Systems Division, Camden, N.J. started as a Lab Assistant in the Camden Plant in 1955. After two years in the Moorestown facility working with microwave feed systems, he joined Camden's Test Engineering department in 1966 as a Test Process Engineer and later a Test Equipment Designer. While working at RCA, he earned the BSEE at Drexel University where he received the George W. Childs scholarship and was elected into the Alpha Sigma Lambda fraternity.

Reprint RE-21-4-16
Final manuscript received September 9, 1975.

Sal Nasto

Dale Smith

Automatic communications equipment tester.

stimuli consist of:

- Audio oscillators,
- Function generations (sine, square, triangular wave, and sine-squared pulse),
- RF generators (2-MHz to 500-MHz amplitude and frequency with modulation),
- RF attenuators, and
- Power supplies.

ACET is capable of making such typical measurements as frequency response (af and rf), power output, distortion, hum and noise, and gain.

A hard copy printout is made to indicate "pass" or "fail" conditions and the exact output level for the particular parameter being measured. Test programs for modules are developed using test specifications for input and output conditions equal to the conditions that will be encountered in the system.[1]

Video automatic test system.

VATS

The video automatic test system was specifically designed to test modules as used in the TR-600. This design required a good deal of interface between Design Engineering and Test Engineering in determining test requirements for TR-600 video modules and the test needs of future video-type products. The video modules used in the TR-600 require complex waveform stimuli and measurement of these complex waveforms. The VATS system can provide pulse and complex waveform stimuli and the vital capability of automatic measurement. The system measures video parameters such as frequency response and accuracy, differential phase and gain, signal to noise, return loss, amplitude and phase response, and group delay.

Stimuli available in this system are audio signals and high frequency waveforms (rf, pulse, sweep, and video). In addition, programmable dc voltage with programmable current limiting is provided. The measurement system consists of a digital multimeter, counter, rf millivoltmeter, true rms meter, distortion analyzer, and the "waveform measurement system". This system consists of a programmable sampling oscilloscope and waveform digitizer with a sampling head multiplexer system configured to sixteen sampling heads. This system permits a unique method of not only monitoring and measuring complex waveforms, but through software development, performs waveform comparison and analysis.

Concept review participation

One function of Test Engineering is to ensure that the product designers are aware of the unique capabilities and limitations of available automatic test equipments. This will allow them to partition the product—mechanically and electrically—to take full advantage of these facilities.

During early development of the TR-600, Test Engineering and Design Engineering had numerous meetings concerning the automatic test facilities. Tours were conducted for all product design engineers assigned to the TR-600 program and all other engineering groups who might take advantage of these facilities. As a result, the product design engineers became knowledgeable of these facilities, and made numerous suggestions that led to enhancement of the automatic test facilities such that electrical measurements of parameters thought previously to be limited to manual measurement can now be performed automatically.

The success of this interface is demonstrated in the test flow diagram (Fig. 1). Of fifty-four module types contained in the TR-600, all but three are tested on automatic test equipment.

Modules

Early participation by Test Engineering in the printed-wire-board concept and standardization for the TR-600 resulted in several cost reductions. Selection of a standard board size and consistent pin assignments for voltage application significantly reduced test interface fixturing costs. Manual connections to necessary test points were minimized by interconnecting these test points to connector pins. Electronic circuits that were identified as difficult to troubleshoot were segmented for that purpose by jumpers. In system partitioning, electronic circuits within a module that are tested on a particular type of automatic test set were separated from those circuits that must be tested on a second test set (i.e., separate analog and logic circuits). This one-test-station-only technique was yet another cost reduction factor.

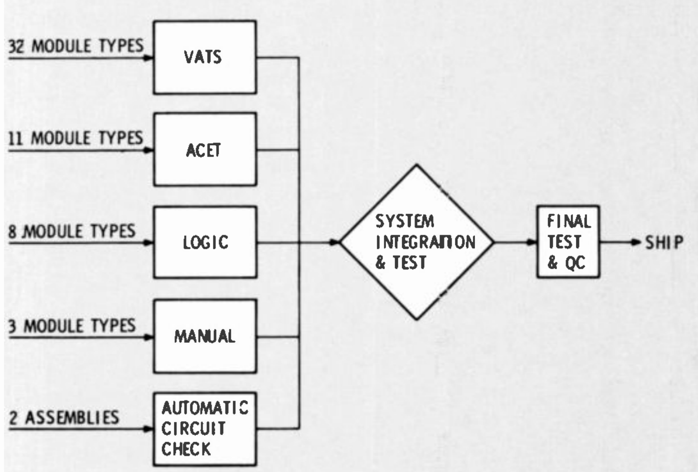


Fig. 1 — TR-600 test program flow.

Cables and harnesses

Automatic facilities for testing harnesses, cables, and backplanes are available. The interface hardware between the assembly and the test facility is the major cost item, and the the most significant recurring cost is the labor to connect the cables and harnesses to the test facility. The design of the assemblies has a direct bearing on these costs and is therefore an important consideration during the concept of any product.

Wiring information generated by product design engineers in the form of "from-to" lists must be rewritten by test process engineers in a form compatible for key-punching. Then, using a computer program, a control tape for the automatic circuit-test facilities must be generated. If the wired assembly was of a nature that required wire-wrapping, assembly process engineers would then have to follow the same route to generate control information for automatic wire-wrap equipment.

Prior to release of wiring information for factory production of the TR-600, meetings among product design engineers, test process engineers, assembly process engineers, and computer programmers were held to develop or plan to eliminate this expensive method of generating wiring information in various formats for various purposes. The object and eventual results of these meetings was the development of a format to be followed by Design Engineering in generating wiring information that can be keypunched in the specific format required to generate, via a computer program, not only the required "from-to" list, but control information for both the automatic wire-wrap equipment and automatic circuit-check facilities.

Test plan

Test Engineering must be involved in early planning so that a workable test plan may be developed; special test equipment may be planned; the required standard test equipment may be ordered; test facility requirements including the floor plan, may be determined; test process, test equipment design, test maintenance, and test personnel manpower loading may be forecast; and an initial test cost estimate may be made.

Prototype participation

It is during the prototype phase of the program that Test Engineering can become familiar with the product and the preliminary test procedures. During the assembly and initial testing of the first prototype, Test Engineering does not play a major role; however, when Design Engineering has verified the performance of the prototype, it can be made available for Test Engineering to develop their preliminary test procedure. If subsequent prototypes are built, as was the case in the TR-600 program, this preliminary test procedure can be used as a vehicle by Product Design Engineers to test these additional equipments. The procedure can then be revised to accommodate product changes or to correct errors in the original document. Thus, by the time the production piece is available for test, the procedure should be a reliable document. This is a valuable way to shorten the time cycle. The advantage in developing a correct test procedure and familiarizing test personnel with the product before product test is that Design Engineering's "factory-follow" time is reduced.

First-piece review participation

The first assemblies produced by normal manufacturing methods must be followed closely to ensure that drawings are correct and detailed enough to allow correct assembly; the various manufacturing processes and tools are correct; and the assembly performs to its required specifications. Test Engineering's role in this first-piece program is to determine if the various assemblies meet all their electrical specifications, and if the integrated system performs to its required specifications.

Preliminary test procedures had been developed from schematics, parts lists, layout drawings, performance specifications, and other engineering information. Special test equipment may have been designed and built to develop the stimuli and perform the required electrical measurements on the assembly. If a prototype assembly was available, the preliminary test procedure and special test equipment could have been debugged with this "known-good" assembly. Not having this prototype, the test procedure or special test equipment available prior to receipt of the "first piece" places these three items together for the first time. If an abnormality occurs, it must be determined which of these items is at fault and then corrective action must be taken. Because Test Engineering is most intimate with two of the three items (the test process and special test equipment) they necessarily play a significant role in the first-piece program.

Test procedures are verified, special test equipment is checked out for proper stimuli and measurement ability, and the assembly is tested to determine if all electrical specifications are satisfied. If there is a discrepancy in any of these items, Test Engineering initiates corrective action by determining the nature of the problem, resolving the problem or coordinating its resolution, and reporting the nature of the problem and corrective action required to the responsible parties. In accomplishing this task, Test Engineering has intimate interface with Product Design Engineering, Test Equipment Designers, Manufacturing Process Engineers, Quality Control, Assembly, etc. This first-piece program demands teamwork, close follow-up, and quick resolution of problems to prevent costly repetitive problems.

Conclusion

What benefits were derived from the early participation of Test Engineering with Product Design?

The team spirit that evolved allowed free exchange of information resulting in both groups always being aware of what the other was doing with regard to test. This awareness prevented unnecessary and costly rework. When neither group makes a move unilaterally, it minimizes those "surprises" when the first production piece is assembled.

The transition from prototypes to first-piece production units, to final delivery of systems was not without problems. However, the close cooperation between Product Design Engineering and Test Engineering resulted in resolution of problem areas in minimum time, allowing shipment of a reliable product while still maintaining schedule requirements.

Reference

1. Pfifferling, F. and Williamson, D.H.; "Automatic communications equipment tester," RCA Reprint PE-554; *RCA Engineer*, Vol. 17, No. 5 (Feb-Mar 1972) pp. 70-73.

COS/MOS product design

If the term "classic" can be applied to any solid-state product design, it must fit RCA's COS/MOS product line. Spawned by innovative research and development; molded into a product by market exigencies; and produced using processes, controls and procedures established through more than a half century of electronic component experience, COS/MOS represents some of the best product design thinking RCA has to offer.

The case study contained in the following five papers is, therefore, a natural addition to this "product design" issue.

In the first paper of the series, Gerry Herzog, Staff VP, Technology Centers, describes the research heritage of COS/MOS; in the last paper, Mel Saunders of SSD's Findlay plant describes the actual production process. Within this context, the three other papers address the specific problems, issues, and controls involved in COS/MOS product design—from planning through release to production. Thus, our COS/MOS story is a complete case history of a successful product design.

—J.C.P

COS/MOS product design

COS/MOS from concept to manufactured product

Giving birth to a new technology requires conviction, dedication, support and the many other demands of parenthood. The struggle to implement the CMOS circuit concept into a product line is a specific example of how a laboratory development was transferred to a product division and ultimately led to the establishment of a market.

G.B. Herzog

THE metal-oxide-semiconductor transistor is based on a relatively old idea. A patent was issued to Lillienfeld in 1930 on the basic concept. The Bell Telephone Laboratories' Research Staff was exploring this concept when the point-contact transistor action was discovered. However, it was not until the semiconductor industry had progressed to an understanding of silicon surfaces that the modern MOS transistor became possible. In 1960 Dr. Webster, as Director of RCA Laboratories' Device Research Laboratory, initiated a project on MOS transistors. By the end of 1960, Charlie Mueller and Karl Zaininger of the RCA Laboratories had shown control of conduction in an insulated-gate structure. A team ultimately consisting of Steve Hofstein, Fred Heiman, and Karl Zaininger began serious research efforts to understand the physics of MOS structures and to build devices with significant gain. Ground work for this effort had been initiated by T. Wallmark, who had been investigating silicon direct-coupled unipolar transistor logic (DCUTL). Tom Stanley of the Laboratories, had shown that DCUTL with its two-dimensional planar structure rather than the three-dimensional bipolar structure was ideally suited to what today is known as large-scale integration. His analysis indicated that the devices could be scaled down yet retain their speed capability.

NMOS devices

Based on this work, some Government contracts were obtained which had the objective of fabricating large arrays of MOS transistors. Unfortunately, the importance of impurities in the silicon dioxide insulator was not known at that time; and although arrays of individual transistors were made with remarkably good functional yield, their characteristics were unpredictable and unstable. Since the n-type device gave higher gain and higher frequency response due to the higher mobility of the electron carriers, the research work was concentrated on solving the stability problems of n-type transistors.

Because the MOS transistor had a square-law type of transfer characteristic as opposed to the bipolar exponential characteristic, the MOS was better suited to the low distortion requirements of radio and tv amplifier service. Consequently, the first serious production efforts were on transistors for high frequency and very high frequency amplifiers and mixers. These were depletion-mode MOS devices; i.e., normally conducting. Since they could be self-biased in a manner similar to vacuum-tube design, a certain amount of variability or drift in their characteristics was acceptable. Interestingly, these n-type transistors tended to be depletion-mode devices because of the impurities in the oxide. As the production equipment improved and cleaner oxides were grown, it became harder to achieve the depletion-mode conduction specified by the data sheets. Today, essentially the same devices are being produced, but the "impurity" is added by the controlled process of ion implantation.

MOS for large arrays

While the depletion-mode devices were being produced for use in consumer products, the potential of the MOS device was being evaluated for use in other fields. While Stanley had predicted its usefulness in large arrays, the instabilities, the low gain, and the slow switching speed made it unattractive for use in general-purpose computers. The square-law characteristic that reduced cross modulation and made it useful for rf amplifiers, made it a poor switching device as compared to bipolar transistors. It was hard to define when the device was "on" and when it was "off". With characteristics that drifted, a circuit might well produce an output representing a "1" for the same input that previously had given a "0" output. In fact, some of the n-type devices were so bad that they would change state while their characteristics were being observed on a curve tracer.

With the hope that MOS arrays would eventually play a role in terminals and other peripheral computer euipment, research efforts were directed toward improving the speed, stability, and switching characteristics of the MOS transistors. Work concentrated on the n-type devices since they were about double the speed of p-type. The device research groups worked on the physics of the problem; and in a cooperative program, the application groups ran extensive tests on the devices in various ambients (vacuum, nitrogen, etc.) to determine what was causing the characteristics to shift. Sodium in the oxide was eventually

Reprint RE-21-4-1
Final manuscript received August 26, 1975.

labeled the culprit; and ultra-clean processing, plus phosphorus gettering in the oxide, provided a solution.

Faster circuit speed and a more sharply defined switching characteristic were shown to be possible, both analytically and experimentally, when depletion-mode n-type transistors were used as loads for enhancement-mode n-type switching transistors. Unfortunately, a simple way was not available to accurately and selectively change the surface conduction to provide both depletion-type and enhancement-type devices on the same wafer. Today, the needed control is achieved with ion implantation.

Complementary symmetry—another approach

An alternative and preferable circuit approach was complementary symmetry. This concept, pioneered at RCA Laboratories in the early 1950's, had many boosters, including the author. Consequently, efforts were made to build n-type and p-type devices on the same wafer. While this concept was actually more complex in principle than depletion-mode load devices, the circuit form was more tolerant of differences in transistor characteristics resulting from variations in doping levels. Complementary-symmetry MOS circuits also had many other desirable characteristics which today are well recognized. Still, in the early 1960's it was not clear that the effort to develop such circuits would be worthwhile in terms of RCA's product needs. The Computer Division insisted on the highest speed ECL for main-frame logic and used discrete bipolar devices in its peripherals, etc. There did not seem to be a need for slow logic arrays.

While RCA was concentrating on solving the stability problems of NMOS devices in an attempt to achieve high-speed performance, a venture company was formed to exploit the virtues of arrays of PMOS transistors. Strangely enough, one of the entrepreneurs behind the company was a previous Government employee who had monitored the RCA contracts and must have taken to heart our descriptions of the virtues of MOS transistor arrays. So while we struggled to make n-type devices stable, and virtually ignored the basically more stable, but slower p-type devices, other companies began announcing products. As pioneers in MOS research, we felt awed and frustrated as various small companies publicized their plans to produce electronic desk calculators containing hundreds of devices in just a few small PMOS chips. Stanley's prediction had come true, but we were not participating. Still, we worried about the soft switching characteristics of the p-type device, the instabilities, and the complex clocking schemes that people were depending on to increase speed.

As history shows, our concerns were well justified. Most of these early, overly ambitious programs ultimately failed, causing severe financial losses to one major calculator company and the complete collapse of the PMOS-array vendor. Nevertheless, it was clear that there would be applications appropriate to the speeds and integration complexity of MOS transistors when the technology was better in hand. How could the RCA Laboratories play a part? Since we were trying to be responsive to the wishes of the Computer Division, we didn't propose work on MOS logic. At that point in time, however, there was considerable interest in content-addressable memories. This was an area of interest to our Computer Division that required logic of modest performance, memory system capability beyond that easily possible with cores, and low standby power. Complementary-symmetry MOS structures were ideal. If only we knew how to make them.

Fortunately, in 1960 Paul Weimer had started work on a different form of device. It was known as the thin-film transistors (TFT) because it used evaporated thin films of compound semiconductor material on a glass substrate. Most of the early TFT devices were so unstable they made silicon MOS devices look like Bureau of Standards references by comparison. They had the great virtue, however, of being easy to make in large arrays and could be made in either conductivity type. Since complementary-symmetry circuits tolerated large variations in device characteristics, I felt that we had a chance of making useful content-addressed memory arrays. I also felt that if real applications could be shown, a substantial device physics effort would be mounted to solve the stability problem. In fact, Paul and his co-workers achieved significant improvements in the stability of both n- and p-type devices. Although RCA dropped its TFT effort in favor of a silicon-on-sapphire (SOS) thin-film program, other companies are currently pursuing TFT research for physically large-area array structures.

To more rapidly exploit the circuit advantages of complementary arrays for content-addressed memories, I requested a member of my circuit group to work with Paul Weimer's device-processing people. We provided some digital circuit help to Weimer's group while they in turn helped us set up equipment to make arrays of complementary TFTs.

Meanwhile, MOS technology skills were developing in the Somerville Electronic Components semiconductor product group. The Laboratories had been funding efforts to help them learn how to make complementary silicon devices,

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bipolar, and MOS. Initially, very few people in the product group believed useful complementary devices could be built economically on a common substrate, and almost all agreed it wasn't worth the effort! After all, slow-speed applications could be handled by PMOS transistor arrays, and high speed would require bipolar devices, so why bother with CMOS? Fortunately, the Laboratories' Applied Research Program, which funds divisions to work on long-range problems, kept the effort alive.

By 1965, the need for computer-aided design (CAD) to lay out the artwork for structures such as TFT memory arrays had been recognized and a modest sized CAD program existed in Dr. Rajchman's Computer Research Laboratory. The CMOS effort in the Advanced Development Group also progressed to where a process was defined.

Winning a contract

These two items, CAD and a CMOS process, were RCA's major strong points in bidding for a sizable three-year contract from the Air Force to investigate the feasibility of large-scale integration (LSI). The RFQ called for studies on the feasibility of building arrays of at least 100 logic gates on a single chip and the incorporation of such arrays in an operating computer suitable for Air Force applications. This contract was considered by Dr. Webster as a crucial element in getting RCA into the digital IC business. He insisted that RCA make a valiant attempt to win the contract, even though RCA's existing skills in the digital IC business were inferior to those of Texas Instruments (TI), Motorola, Fairchild, and all the entrepreneurial MOS houses. RCA had only one unique thing to offer in the device area: complementary MOS. With the Laboratories acting as the focal point for the computer systems design skills, the computer-aided artwork generation skills, and as the broker for the Somerville technology skills, a program was formulated that proposed a computer be built utilizing ECL bipolar arrays for logic, and CMOS arrays for memory. The result was that the Air Force awarded three contracts, one to TI for an all-bipolar approach, one to General Microelectronics for an all-PMOS transistor approach, and one to RCA. Only TI and RCA completed the program, and both delivered operating computers, although approximately one year late.

A boost from the outside

With a three-year contract from the Air Force, RCA had a legal obligation to pursue its work on CMOS. I am convinced that without this commitment stretching over an extended period, the CMOS array effort would have been killed at some point as we experienced one failure after another. In 1965 it was only too clear to everyone with any marketing experience that semiconductor memories would never be cheap enough to compete with cores and that nobody really needed the low power of CMOS logic! Although CMOS logic had many performance advantages, the only one that most people recognized was the low power requirement. Thus, it was that the discipline of an outside agency provided the means for the Laboratories' staff to keep alive a project in which they believed. Finally, as failures turned to partial success and then to complete working 64-bit memory arrays, people in the semiconductor product group of EC began to show interest.

In 1967, I made a presentation to EC's manager of the IC product line. I stressed all the circuit advantages of CMOS arrays and pointed out that CMOS should be able to capture a good percentage of the growing T^2L market. This prediction was met with considerable disbelief. Fortunately, the space program was getting a lot of attention in those days, and the low power consumption of CMOS was an important consideration. Consequently, the Advanced Development group in Somerville, which had been doing most of the CMOS technology work on the Air Force contract, began receiving CMOS array contracts from NASA. Perhaps that fact helped sell CMOS as a potential product line for EC. At any rate, based on circuit probe yields, failure rates, and costs, a decision was made to introduce CMOS as a product. By the end of 1967, developmental samples were being sold.

The CMOS market

It is an over-simplification to say that the rest is history. For a long time RCA was the only CMOS supplier, and many people considered CMOS a specialty product, high priced and only available as medium scale integration, not the LSI of PMOS. Finally, as the circuit virtues of CMOS were recognized, other vendors entered the market, giving credibility to RCA's CD4000 product line. Now RCA has over 180 standard CMOS products in its line and most are second-sourced by the major semiconductor houses. A recent survey by a major trade publication indicated that CMOS is the preferred logic family for all new digital designs. RCA is still the leading supplier of CMOS integrated circuits and has supplied more CMOS than all the other vendors combined.

The CMOS future

While the CMOS circuit concept was being implemented in bulk silicon as a product line in Somerville, the Laboratories focused its efforts on the SOS program initiated by Charlie Mueller under Bill Webster's direction. After many years of development at the Laboratories, this new technology has been transferred to Somerville and is being incorporated in the COS/MOS product line of the Solid State Divison. Presently, watch circuits, general-purpose counters, and memories are being sampled to the industry.

Acknowledgment

While this article mentions only a few key people at the RCA Laboratories that were involved in the early CMOS development, obviously many other people were involved over the decade of time from concept to product. They are too numerous to mention individually, but attention should be called to the fact that nearly all of the Somerville Advanced Development group under the direction of Bob Janes contributed in some way to proving the feasibility of CMOS technology. In addition, many people in Dr. Rajchman's Computer Laboratory contributed to specific circuit designs. One of the fundamental complementary-symmetry storage cell patents, however, is due to Paul Weimer. Finally, of course, all the people who eventually put CMOS into production deserve the greatest recognition. Without the effective accomplishment of that final step, no amount of research and development will benefit a company.

COS/MOS product design

Product planning

G.A. Riley

The increasing size, complexity, and competiveness of the CMOS business has made it imperative to systematize and formalize the process of selecting and defining products and bringing them to market. The product planning process includes seeking and evaluating inputs from Marketing, Engineering, Applications, Manufacturing, and Sales to account for the various business and technical considerations.

In 1968, RCA announced commercial availability of the first integrated circuits using the new CMOS technology. The product line described in that announcement comprised five circuits. In June, 1975, when RCA announced availability of the new, high-performance "B" series of COS/MOS IC's, the product line consisted of 124 circuits. By January 1976, the commercial product line will include 188 circuits. In addition, more than 100 custom circuits and 15 special-purpose circuits have been developed since 1968.

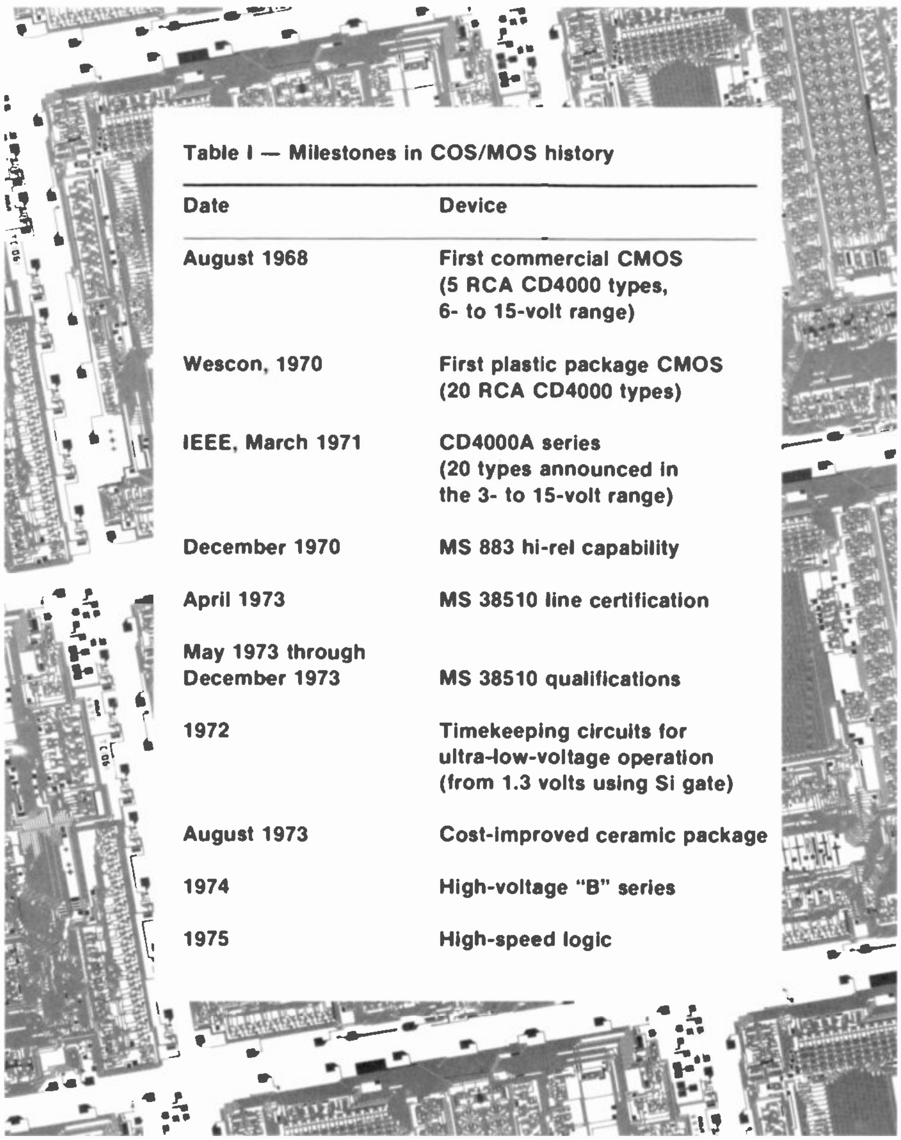


Table I — Milestones in COS/MOS history

Date	Device
August 1968	First commercial CMOS (5 RCA CD4000 types, 6- to 15-volt range)
Wescon, 1970	First plastic package CMOS (20 RCA CD4000 types)
IEEE, March 1971	CD4000A series (20 types announced in the 3- to 15-volt range)
December 1970	MS 883 hi-rel capability
April 1973	MS 38510 line certification
May 1973 through December 1973	MS 38510 qualifications
1972	Timekeeping circuits for ultra-low-voltage operation (from 1.3 volts using Si gate)
August 1973	Cost-improved ceramic package
1974	High-voltage "B" series
1975	High-speed logic

George A. Riley, Mgr., Business Planning and Market Development for High Reliability COS/MOS Integrated Circuits, Solid State Division, Somerville, N.J., holds the BS in physics from Providence College and the MS in physics from Cornell University. He is currently enrolled in the Graduate School of Business at Rutgers University. Mr. Riley joined RCA in 1960 as a field engineer on systems integration and testing for the ballistic Missile Early Warning System (BMEWS), where he spent two years on assignments at the BMEWS site in Clear, Alaska. Subsequent assignments included that of research physicist at the RCA Laboratories, Princeton, New Jersey, and Marketing Manager, Advance Product Planning, for the Graphic Systems Division in Dayton, New Jersey. In 1971, he moved to a similar position in RCA Corporate Marketing, where his area of specialization was semiconductor products. In 1973, he joined the Solid State Division as Product Planning Manager, COS/MOS Integrated Circuits. In 1974, he was named Product Marketing Manager for COS/MOS IC's, a position he held until his most recent assignment.

Reprint RE-24-4-2
Final manuscript received August 27, 1975.

The growth of the product line matches closely the growth of the CMOS industry. In 1968, world-wide industry sales of CMOS were 139,000 units; 1975 industry sales are estimated at over 150 million units. In 1968, only RCA offered CMOS. In 1975, CMOS is available from more than 25 suppliers. This growth, from 5 to more than 300 circuits, from 100,000 to 150 million annual units, from one supplier to many, shows the dimensions of the product planning task in COS/MOS. The product planning choices that were made in this period—which products to offer, with what specifications, for which applications—have shaped the growth of the CMOS industry and established RCA's position in it.

Table I is a chronology of the major events in RCA's COS/MOS history. The first CD4000 products introduced in August 1968 were rated for operation in the 6-to 15-volt range. In March, 1971, the CD4000A series was introduced; it was rated at 3 to 15 volts and became the industry standard which every other manufacturer has second-sourced. In 1970, RCA announced the Mil-Std-883A high-reliability capability. RCA has continued to develop capability in this area until, at present, it has the only Mil-M-38510-qualified CMOS line. One hundred and twenty-three high-reliability types will be available by year-end. In 1972 the first low-voltage silicon gate circuits were produced. There circuits operate from a 1.3-volt supply and are particularly suited to watch and clock use. At the other end of the voltage scale, the RCA CD4000B series now carries a maximum rating of 20 volts. The first "B" series products were brought out in 1974 and set a new industry standard. In 1975, RCA introduced high-speed silicon-on-sapphire versions of some popular COS/MOS types. This technology extends the speed capability of CMOS to the 50-MHz region, and it is being used in both logic and memory circuits.

Product planning procedure

While the basic product selection responsibility is a Marketing one, the process has come to include all the major organizational functions; members from Marketing, Engineering, Applications, Manufacturing, and Sales constitute a Product Advisory Council (PAC).

The PAC is the starting point in the planning process. The Council has the responsibility to solicit suggestions for new standard products, to evaluate the suggestions, and to recommend to product-line management specific products for development. The inputs to PAC come from many sources. Customers are a key source since they define needs which result in sales opportunities. Engineering inputs for proposed new products originate both from Applications contacts and technological advances. Marketing inputs include examinations of competitive products and technologies and of specific market segments offering growth opportunities. For example, an intention to penetrate the telecommunications market may lead to delineating an entire family of products.

The evaluation of product suggestions by the Council encompasses both technical and business aspects. The technical questions include the basic one of whether the proposed circuit can be manufactured with existing technology at a reasonable cost. Technical examinations of proposed features and possible performance tradeoffs are considered along with anticipated technology improvements and their business consequences.

Just as the fundamental technical question is, "Can it be made at a reasonable cost?" the fundamental business question is, "Can it be sold at a reasonable profit?". In the evaluation phase, Marketing inputs contain an estimate of the sales potential of the proposed circuit, including selling price assumptions and identification of potential users. Other considerations include the "fit" of the proposed product of the rest of the RCA line and a comparison with similar competitive products.

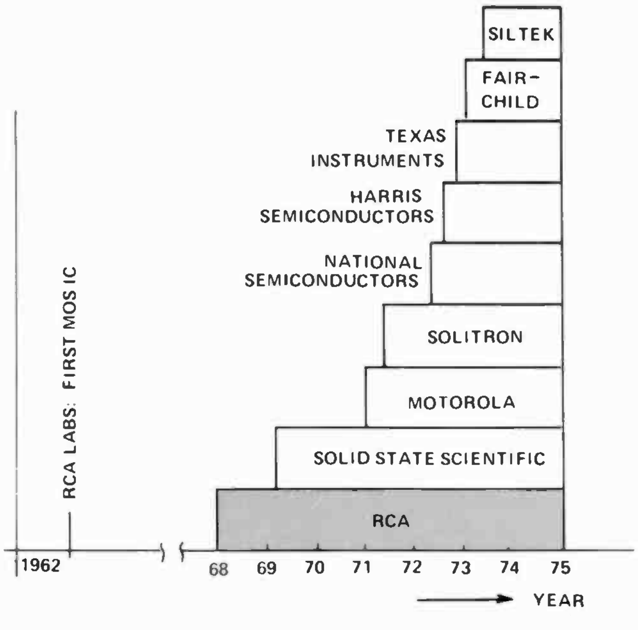


Fig. 1 — Entrance of CMOS standard parts producers into the market.

The selection procedure consists of an assessment of the evaluations of the proposed products. The candidates are assigned priorities, and a list is prepared recommending those for design and those for further consideration. Because the choice of products to be made is crucial in determining the total future capabilities of the line, the recommendations are reviewed with product line management to assure their concurrence with the selections.

Selection Criteria

Breadth of line

As CMOS devices have gained acceptance in general digital uses, customers have expected to be able to buy the usual broad range of digital functions provided in other technologies. Thus, a family of CMOS devices including gates of various configurations, flip-flops, buffers, multiplexers, counters, and other functions has been provided. Table II shows the RCA family by category.

Breadth of line is also a competitive feature. RCA has always offered the industry's broadest line of CMOS products in the belief that this approach is a key element in maintaining a leadership position.

Family makeup

New products must be designed and specified for compatible operation with existing products in the line. The new RCA CD4000B series, for example, has uniform output drive with equal source- and sink-current capabilities; one data sheet provides technical data for the entire series.

Often, one member of a series or family will suggest a variant type for future development. For example, the COS/MOS multiplexer family includes a 16-channel, a dual 8-channel, and dual 4-channel differential types. Counters include up-down, binary, decade, and various combinations of these types. Gates include NAND/NOR, AND/OR, and multilevel variants. All of these variations are requried to offer designers flexibility and to minimize package count.

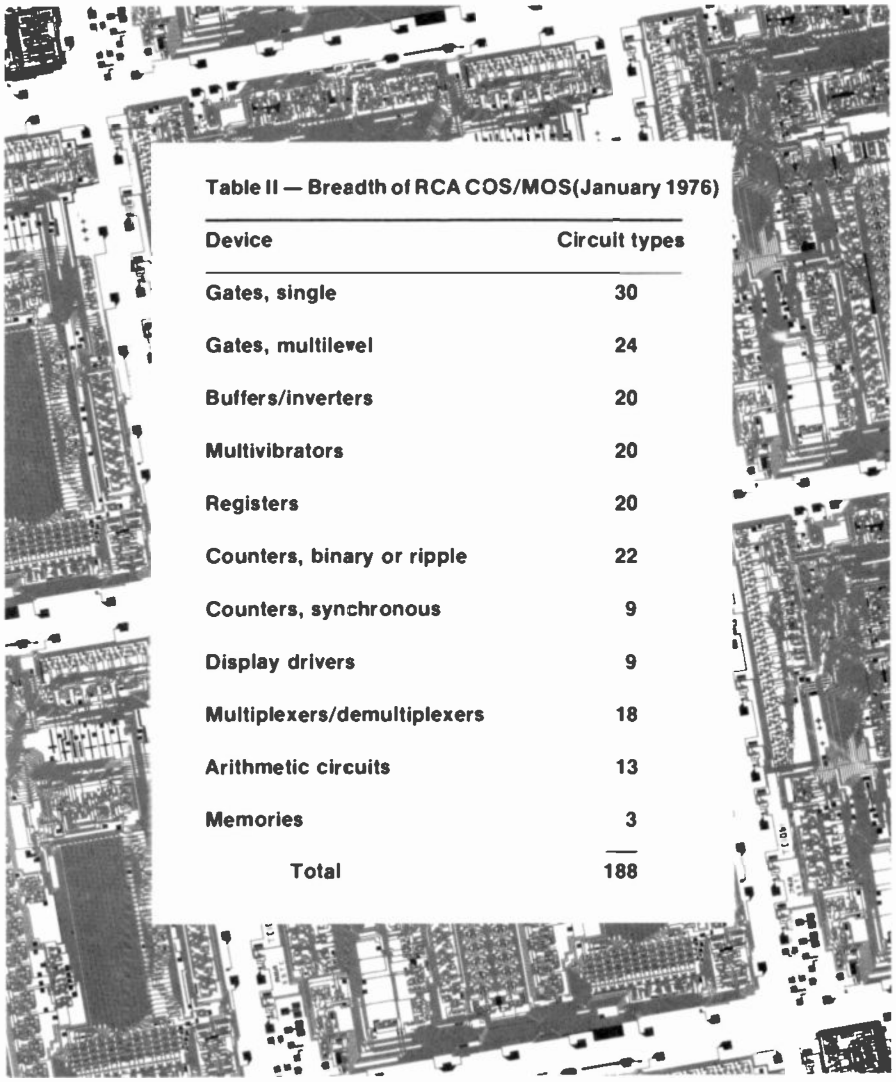


Table II — Breadth of RCA COS/MOS(January 1976)

Device	Circuit types
Gates, single	30
Gates, multilevel	24
Buffers/inverters	20
Multivibrators	20
Registers	20
Counters, binary or ripple	22
Counters, synchronous	9
Display drivers	9
Multiplexers/demultiplexers	18
Arithmetic circuits	13
Memories	3
Total	188

Competitive products

Fig. 1 shows the entrance into the market, by year, of CMOS standard-parts producers. All of these manufacturers second-source the RCA CD4000 line. In addition, several have introduced types of their own design. In those cases where the competitive product is clearly beneficial to a customer and fits in with the rest of the RCA line, it is considered for second-sourcing by RCA. At present, RCA second-sources 15 competitive types.

Competitive technologies

A growing proportion of CMOS sales originate because of the substitution of CMOS devices into equipment which had formerly been built using the older TTL logic. The TTL family offers more than 200 circuits; designers accustomed to this breadth expect the same in competing technologies. Consequently, the TTL family has been carefully examined to identify popular logic functions which would be desirable in CMOS.

Competing technologies are also examined with a view toward exploiting their weaknesses. For example, a number of COS/MOS standard products, such as the 14- and 21-stage counters, bilateral switches, and long static-shift registers, are not possible in the older bipolar technology. The low-power MSI (medium-scale integration) capability of COS/MOS has provided many new functions which benefit customers.

Technological advances

The continuing advances made by RCA in CMOS technology have expanded product horizons. The progression in lowering minimum operating voltage from 6 volts to 3 volts to 1.3 volts and in raising maximum operating voltage to 20 volts are good examples. Each change opened new application areas to COS/MOS and caused the development of products to exploit them. The accumulated RCA design and production experience has permitted the fabrication of larger and larger chips with acceptable yields. A family of complex standard products, such as tone encoders, first-in first-out (FIFO) buffers, and memories is evolving as a result of these advances.

Customer needs

The key selection criterion is and will continue to be customer need. Designers of sophisticated digital systems are much more skilled than component manufacturers in finding creative applications that exploit new product capabilities. Customer inputs count heavily in all product selection decisions. These inputs have been the determining factor in planning COSMOS products that will realize the full potential of this growing digital technology.

COS/MOS product design

Engineering

R. Fillmore | R. Heuner

Product design of a COS/MOS circuit involves a number of critical phases in design and development before the device is ready for manufacture. Beginning with the definition of the product and culminating with a master specification sheet, the steps in between call for a good deal of interaction between Marketing, Applications Engineering, and Design Engineering to develop a circuit that ultimately becomes a successful product.

THE DESIGN and development of a COS/MOS product consists of a number of phases. First the product to be developed must be defined, and objectives set. Then the logic and circuit design is finalized and reviewed. The layout or integration of the circuit is completed and followed by the generation of the photomasks (tools for manufacture). Processing of the silicon wafers, the testing of the initial samples, and the evaluation and characterization of the prototype units result in the documentation of the product by a commercial data sheet and a standardizing notice of instructions to the factory for manufacture. This article will present some of the general considerations which impact each of the above phases of the design and development.

Richard P. Fillmore, Ldr., CMOS Custom Circuit Design, Solid State Division, Somerville, New Jersey, received the BSEE from the University of Massachusetts in 1965 and the MS in Electrical Engineering from Rutgers in 1969. In 1965, Mr. Fillmore joined Electronic Components and has worked in a variety of production and design engineering assignments in both bipolar and MOS integrated circuit product lines. Since 1970, he has been engaged in circuit design of COS/MOS standard and custom integrated circuits. He assumed his present position in October 1974.

Robert C. Heuner, Ldr., Standard Circuit Design, COS/MOS IC Design Engineering, Solid State Division, Somerville, N.J., received the BSEE from the City College of New York in 1959. He received the MSEE from Newark College of Engineering in 1967. Before coming to RCA, Mr. Heuner worked on digital equipment and terminals for ITT Laboratories. He joined the RCA Defense Microelectronics in 1964, where he was responsible for the circuit design, analysis, and evaluation of a low-power family of bipolar monolithic logic circuits produced by Electronic Components. Mr. Heuner became Group Leader of the Defense Microelectronics Integrated Digital Circuits and Subsystems Group in 1965. In 1968, he became Group Leader, MOS Circuit Design and Applications in the Solid State Division. In this, his present position, he has had prime design and application responsibility for the CD4000A COS/MOS Logic/MSI/LSI line as well as for several custom COS/MOS integrated circuit products. In 1969, Mr. Heuner was co-receiver of the Solid State Division "Significant Achievement" award for engineering contributions to the design, application, and manufacture of integrated circuits. Mr. Heuner has 15 patents issued and several others pending in the solid state circuit, device, and logic design areas. Mr. Heuner is a member of the IEEE.

Authors Heuner (left) and Fillmore.

Product definition

The definition of the product to be developed arises in two distinct ways depending upon whether the circuit is to be a standard product for inclusion in the CD4000-series product line, or if it is to be a custom circuit for a particular customer's application.

Standard products

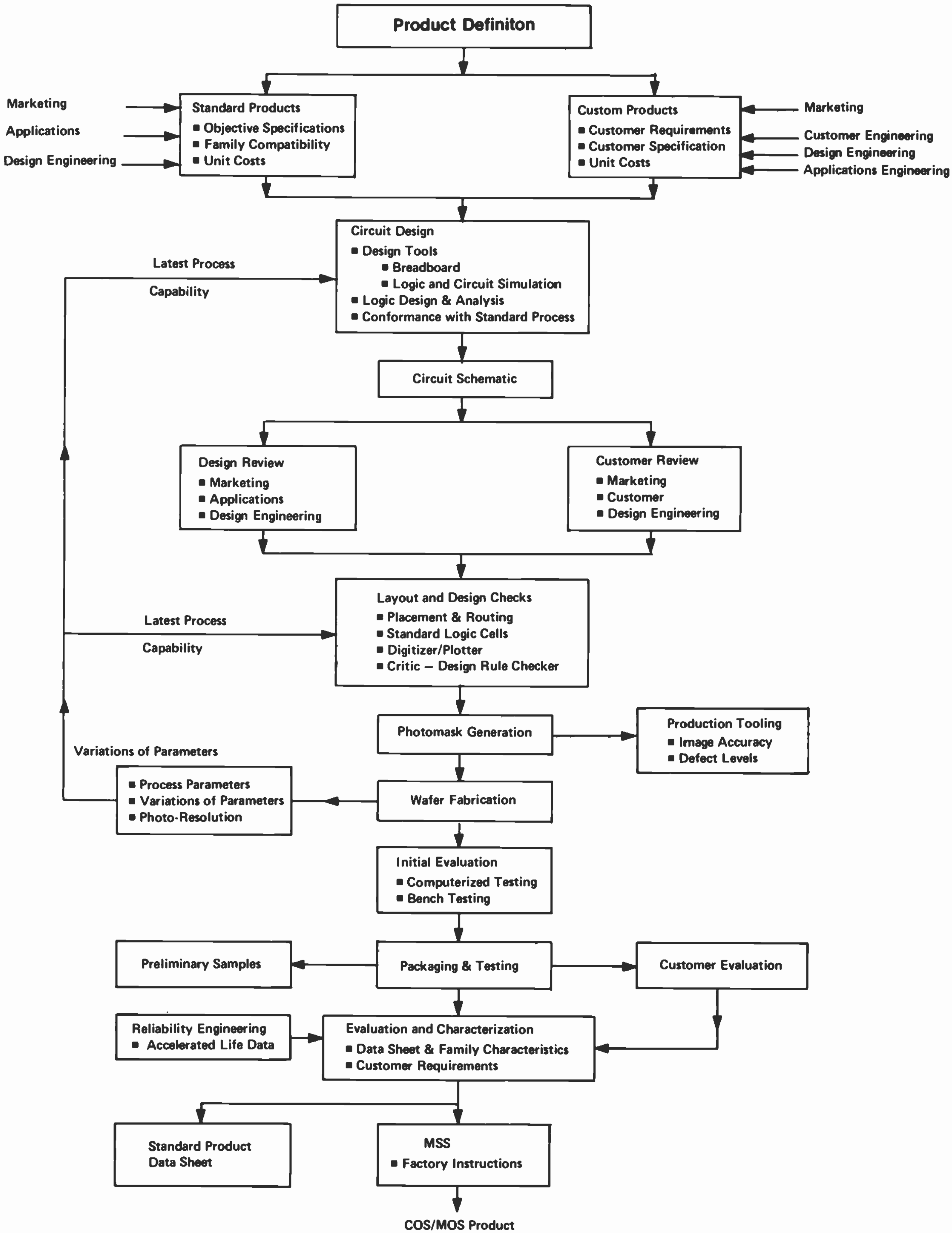
Standard product definition is a joint effort of Marketing, Applications Engineering, and Design Engineering. Normally, Marketing inputs pertain to the sales potential, expected pricing, and competitive situation. Applications Engineering inputs pertain to specific application areas where integration of functions would be desirable. Applications Engineering also evaluates competitors parts and defines the general objective performance specifications for new RCA products. Design Engineering must scope the design goals and determine if integration is possible, as well as provide cost estimates based on chip size estimates and manufacturing yields, which ultimately determine the economic feasibility of the product. It is the interaction of these groups that determines the function, sales potential, and technical feasibility of a COS/MOS product.

Custom products

Whether the circuit in question is a profitable business opportunity is determined by Marketing, based upon the expected sales potential and the Design Engineering cost estimates. Custom COS/MOS integrated circuit (IC) designs are normally defined as a result of interaction between Design Engineering, Applications Engineering, and the customer. In custom circuit design the primary objective is to evolve a mutually acceptable specification of the IC. This specification must delineate the absolute maximum ratings and environmental conditions for the IC as a component of the customer's system. The specification will also precisely define

Reprint RE-21-4-3
Final manuscript received October 24, 1975.

Product design process



functional and parametric requirements of the IC under mutually acceptable test conditions. In some cases, the level of integration of a customer's system is the initial topic of discussion. In particular, the discussions decide how much of the system interface circuitry can be integrated, where and how to partition the logic if more than one IC is required, and whether standard parts would be more cost effective to perform certain functions.

In either a standard or custom circuit design, the performance goals of the circuit must be realizable by utilizing one of the standard production processes. In the product definition phase, Design Engineering in conjunction with Applications Engineering must be able to accurately predict the device performance and the ultimate chip size of the circuit. The chip size, in many cases, determines the packaging capability irrespective of the number of active interconnections required. If all of these goals appear to be realizable, then schedules are developed and the detailed logic and circuit design can commence.

Circuit design

There are three major aspects to a design of an integrated logic circuit. They are logic design, circuit performance design, and integratability.

The logic design is the realization and minimization of the logical requirement of the circuit. Most medium (MSI) and large (LSI) scale IC's require both combinational and sequential logic. The combinational logic is primarily the control portion of the IC, while sequential (counters and registers) circuitry forms the bulk of the circuit. One major area of COS/MOS applications is in the timekeeping/frequency reference area, where a high-frequency quartz crystal reference is successively divided to provide low-frequency signals for analog and digital clocks and watches. A digital watch circuit, for example, is a complex system of control and sequential circuitry, requiring several thousand MOS transistors on a single chip.

Circuit performance design deals primarily with the capability of the circuit configuration to interface with other components or configurations within the system. Unique designs are required for crystal, RC, and LC oscillators, as well as detector-type circuits for power-on reset and hysteresis. Other circuit performance criteria involve circuit speed and operating currents. To achieve the necessary propagation delays and maximum frequency of operation, it may be necessary to re-configure the logic and properly size the individual n and p transistors, while low-current requirements would dictate the inverse.

The final phase of the circuit design is the review of the circuit requirements to determine the possibility of integrating the circuit in monolithic form. It must be determined if the performance is achievable with the parasitic capacitances normally present on-chip. The unique configurations must be evaluated for proper operation under the expected range of parametric variations and the temperature and voltage requirements of the circuit. Care must be exercised to keep the final size within bounds set in the definition stage to maintain cost effectiveness and package compatibility.

The circuit designer has available design tools for verification and simulation of the design. The logic may be breadboarded using standard COS/MOS CD4000-series parts and IC performance data extrapolated from breadboard performance. Computer programs are available on time-sharing systems for MOS device analysis and logic simulation and fault detection. The culmination of the circuit design is a schematic drawing containing the interconnection and device sizing of all transistors as well as any geometrical information for configurations of devices, resistors, capacitors, or diodes which are not included in the library of COS/MOS standard circuit elements.

The circuit is now ready for a design review, which is a review of the initial objectives of the circuit and the designer's circuit configuration for meeting these objectives. At this stage a standard part is reviewed by a committee for conformance with the family requirements of input protection, output drive capability, noise immunity, speed objectives, and cost. The committee represents Marketing, Applications, and Design Engineering.

A custom design review with the customer engineering representatives might also include a demonstration of the circuit breadboard as well as a general review of the approaches to the system requirements.

Layout

Once the circuit schematic and the pin locations have been determined, the layout can begin. If there are no special considerations, such as high-speed performance, analog-type functions, or high-current outputs, the layout can consist of the placement and interconnection of standard logic cells. These standard logic cells are proven elements, with no design-rule violations, which have been used in a number of IC's previously and which have been minimized in area. A layout consisting entirely of these standard library elements is simply a scale drawing indicating the fiducial or reference point of the standard cells and explicit metal interconnects between the cells and bonding pads of the IC.

But if the circuit interfacing requires configurations or device sizes not present in the standard cell library, these elements must be customized. In these cases all the information pertaining to the geometries of the various diffusions, oxide steps, and metallization must be drawn to scale on the layout.

A completed layout must be translated into the geometrical information pertaining to each of the processing photoengraving steps. For example, all areas on the IC which are p+ diffusions, whether they are PMOS sources or drains, resistors, tunnels, diodes, or guardband areas are processed simultaneously and all geometries must be defined on that particular photomask. In the past, this information was extracted manually and a scale drawing of each layer was created from which a rubylith pattern was generated. RCA COS/MOS IC's utilize many computer aids for artwork generation, and this manual extraction is not necessary.

Digitizer-plotter

The RCA Digitizer-Plotter and its associated design file language (DFL) form the nucleus of the computer aids. Using the digitizer, the verticies of all polygons on a particular photomask layer are entered and stored in a file (usually magnetic tape cartridges) and then re-plotted on quality mylar paper at any scale factor. The individual layers can be overlayed to form a composite layout, or all information may be plotted on a single sheet in different colors and a composite generated.

The DFL has a library of standard cells with all the geometrical information for all layers referenced from a fiducial point. When using a standard cell, only the fiducial point and rotational information need be entered and then all the geometrical information is available for a particular job. The use of standard cells insures that all design criteria pertaining to locations and spacings within the area of the cell are satisfied and reduces the time required for digitizing the layout. The metallization interconnecting the cells and any special geometries are digitized explicitly as polygons creating a file containing all the information for fabricating an IC.

One additional software feature used in the COS/MOS design cycle is CRITIC—the design rule checker. This software is utilized to satisfy design spacing requirements. For example, CRITIC is used to guarantee that all polygon information comprising the metallization layer satisfies minimum width and minimum spacing requirements compatible with the metal photoengraving capability. The same checks are performed on the diffusion information, and design rule violations of cell placements are detected at this stage.

After all design rule violations have been detected and edits to the file have been completed, the file can be reformatted to be compatible with the equipment for photomask generations. This completes the layout phase.

Photomask generation

The photomasks are the tools used in the fabrication of an IC. These masks are the actual size of the circuit. An array of actual size geometries is created which allows an array of IC's to be fabricated on a single slice of silicon. Briefly, the steps involved in photomask generation consist of reticle generation,photorepeater master generation, and actual working-plate photomask generation.

The reticle is created from the information file by means of a computer-controlled pattern generator. The reformatted file information consists of aperature information for the pattern generator. An enlarged version of the geometries for each layer (usually 10×) is created by exposing a photosensitive plate. This 10× representation is then the reticle used in fabricating the array.

The reticle is reduced to actual size and stepped and repeated precisely to create a photorepeater master. The photorepeater master is then used to print working photomasks for use in wafer fabrication. In actuality, the steps and the technology to create defect-free images suitable for wafer fabrication are quite involved and could be the subject of a lengthy paper alone. But basically, the photomasks used to fabricate the initial product and the photomasks for subsequent production must originate from common sources and be comparable in image resolution and defect levels.

Wafer fabrication

The wafer fabrication process is itself the fundamental process around which any IC technology evolves. The capabilities of the process define the layout criteria in terms of spacings and line width resolution. In addition, the circuit design criteria in terms of performance, parameters, variations of parameters, and the extent to which the circuit can be integrated relate to the "state of the art" present in high-yield wafer fabrication.

Present COS/MOS technology utilizes three basic processes. They are the standard "A" series, the high voltage "B" series (extended voltage), and the LSI (reduced voltage and large-scale integration) process.

As an example, the standard "A" series process is a technique requiring seven photomasking operations as follows:

1) P-well definition—The areas of the circuit in which NMOS devices are to be formed must have a p-type diffusion as a substrate, so selective areas of the n starting wafer are defined using this photomask and an appropriate diffusion is performed.
2) P+ definition—All PMOS sources and drains, tunnels, resistors, and guardrings for n-channel devices are defined and diffused.
3) N+ definition—All NMOS sources and drains, tunnels, and guardrings for p-channel devices are defined and diffused.
4) Stepped oxide etching—The channel regions and all regions which have contact diffusions are selectively etched to permit the growth of the channel oxide.
5) Contact area etching—All areas which require metal to make contact are selectively etched down to the silicon below.
6) Metallization covering—The wafer is completely covered with a thin layer of aluminum metallization which is then etched away where interconnection is not required.
7) Protective coating—The completed circuits are covered with an oxide and only the bonding pad regions and test devices have the oxide removed to allow connections.

The completed wafers are now ready to undergo circuit probing.

Initial evaluation and testing

The IC's in wafer form must be electrically tested to confirm the circuit design. In some cases the tests for functionality and parameters are performed using probe equipment and bench or specific test equipment. This is the general rule for LSI and most custom circuits. Automatic testing for prototype quantities is performed using computer-controlled test sets such as the Teradyne J283. This general purpose tester has power supplies, measurement systems, and functional pattern generators under software command. Parametric measurement times of 1 to 10 ms and clock rates of 40 kHz are realizable. Typical complete test times range from approximately 100 ms for MSI types to several seconds for complex LSI types.

For limited production or stocking quantities, the circuit design engineer must complete a design specification sheet which consisely defines the electrical requirements of the integrated circuit. The normal categories of requirements include:

- Quiescent leakage—The static leakage of the IC under a variety of input configurations is tested as well as the state leakage of sequential circuits.
- Input leakage—The MOS inputs are tested for leakage to either supply level.
- Functionality—A logical test of the IC is performed at the minimum and maximum rated voltages. For an "A" series standard part, functionality is verified at both 3 and 15 volts, and noise margin is verified by functional exercising with noise levels at 5 and 10 volts.
- Parameter testing—Output drive currents are tested as well as device thresholds.
- Special tests may be required for certain custom types. These special tests could include; power-on reset with ramp-type supply voltages, tests for voltage gain, resistor tolerance, reference voltage, and transfer voltages.

These requirements are translated into a test program and product is generated for the evaluation and characterization phase.

Evaluation and characterization

The initial packaged samples of any IC, whether a custom or standard part, must be evaluated and characterized in the Lab to insure that the design is capable of satisfying all the electrical requirements throughout the specified range of voltage and temperature of operations.

Additonally, custom circuits must be evaluated for compatibility with the variation of interface elements. Special interface problems are encountered in automotive, consumer, and military environments which may necessitate additional production testing. In many cases, static parameters must be identified which will guarantee dynamic or functional operation in a particular environment, and adequate tests must be implemented in production.

The characterization of standard parts must include the evaluation of units with worst-case parameters to generate the data sheet extremes. Complete characterization of dynamic performance over the full voltage and temperature range is required. Initial data pertaining to the reliability of the design is obtained by accelerated testing in the Lab. Finally the data is compacted into a device sheet which contains descriptive information, precise minimum and maximum parametric and performance limits of operation, and application information. The *RCA COS/MOS Databook* (SSD-203C) is a compilation of the individual data sheets of the CD4000-series COS/MOS standard parts.

The evaluation and characterization phase culminates with the generation of the Master Specification Sheet (MSS) which is a standarized internal document providing all the necessary information for the manufacture of the IC in the Findlay, Ohio, COS/MOS factory. An initial production run of product is scheduled, and the test program incorporating the latest MSS requirements is transferred to the factory.

When the factory is successfully running product and achieving cost-effective yields, then the development is complete, and the resultant IC is a product.

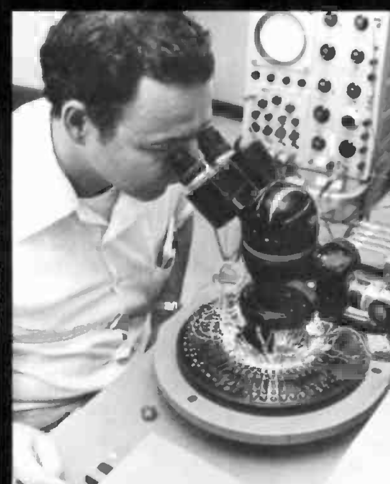
CIRCUIT DESIGN

Culmination of the circuit design is a schematic drawing containing the interconnection and device sizing of all transistors.

Designs may be breadboarded using CD4000-series COS/MOS devices and then IC performance predicted from breadboard performance.

TESTING

Computer-controlled automatic test equipment is used for prototype and production quantities.



Multiple probes are used to make connections to the IC for testing.

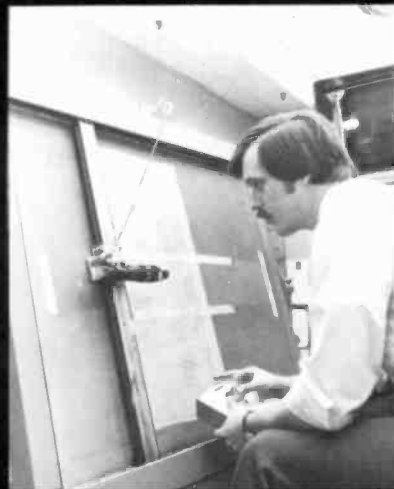
EVALUATION AND CHARACTERIZATION

Complete characterization of dynamic performance over the full voltage and temperature range is required.

Steps in the product design process

LAYOUT

Layout consists of the interconnection of standard logic cells as well as device geometries created for a specific circuit.



A completed layout is translated into the geometrical information pertaining to each of the processing photoengraving steps on the RCA Digitizer-Plotter.

PHOTOMASK GENERATION

Photomasks are the tools used in the manufacture of an IC.

WAFER FABRICATION

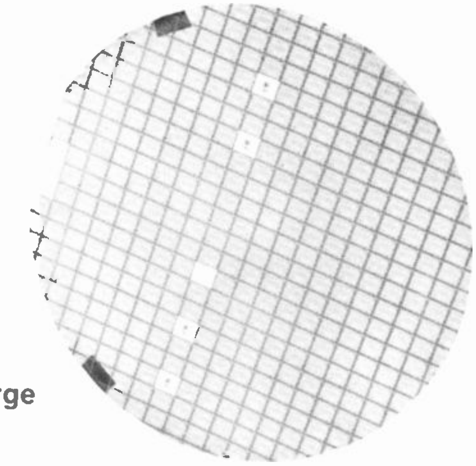
Diffusion of n- and p-type regions are performed in furnaces similar to the one pictured.

INITIAL EVALUATION

A completed IC wafer is ready for electrical verification of the design.

COS/MOS product design

Documentation, testing, and quality control



E.C. Crossley | R.E.Funk | J. LaBerge

Applications engineering, test engineering, and production quality control experts collaborate to describe the many instruments, functions, and supporting services used for documenting, testing, and controlling a successful IC product line.

THIS three part paper deals fundamentally with IC product integrity through internal and external documentation, testing for conformance to specifications, and quality control. The specific examples are drawn from the COS/MOS product line.

Documentation

Successful development of the COS MOS product line has required that Engineering and Manufacturing groups operate within a well-controlled standardizing system which uses Master Specification Sheets to communicate official product information. Success has also depended on keeping COS/MOS users (customers) and Sales and Marketing personnel well informed via commercial data sheets and educational software.

In general, COS/MOS product-line documentation falls into five categories:

1) Master specifications
2) Data sheets
3) Supplementary COS MOS literature

Edward C. Crossley, Ldr., MOS Test Technology, Solid State Division, Somerville, N.J. was awarded National Certificates in Electrical Engineering at Ordinary Level in 1957 and at Higher Level in 1959 at Bath Technical College, England. He obtained a post graduate endorsement in physics in 1960. From 1955 until 1974, Mr. Crossley has been employed in the design and development of equipment for manufacturing and testing solid-state devices. From 1955 to 1962 he was with Westinghouse Brake and Signal Company in England. In 1962 he was with General Instrument Corporation in Newark, N.J. He joined RCA Electronic Components in 1963. Mr. Crossley received an Electronic Components Engineering Achievement Award in 1967 "for significant contributions to integrated circuits processing and control." From early in 1967 until 1970, he was associated almost exclusively with real time computer-controlled systems and was promoted to Engineering Leader of the Systems Engineering Group in the Equipment Technology Department, Solid State Division. In 1970 Mr. Crossley was made responsible for all aspects of electrical, electronic, and systems engineering in the Integrated Circuits Equipment Technology Department. In 1974 he transferred to the MOS product line with responsibility for MOS Test Technology, recently assumed the additional responsibility for MOS Design Automation.

Richard E. Funk, COS/MOS Applications, Solid State Divison, Somerville, N.J., received the BSEE and MSEE from Drexel Institute of Technology in 1956 and 1961, respectively. Mr. Funk joined RCA in Camden, as a co-op student in 1953; he specialized in analog-computer circuit design for airborne radar systems from 1953 to 1959. In 1959 he began his digital-logic design career with responsibility for data-link system logic design during the era of RCA 2N404 discrete logic. In the early 1960's Mr. Funk was responsible for high-speed code-generator logic design for real-time digital communication systems. In the mid 1960's, he applied saturated-logic digital IC's in Minuteman modular test systems. Between 1966 and 1970, he was responsible for logic and circuit design for digital frequency-synthesizer and control functions in the Defense Communications Systems Advanced Technology section in Camden. In 1968, Mr. Funk began working closely with Electronic Components, Somerville, in pioneering use of the new ultra-low-power COS/MOS logic for the next generation of man-pack and hand-held radios. In 1970, Mr. Funk joined the Solid State Division with responsibility for COS/MOS standard-part applications, including device specifications, custom and standard part definition, test technology, and general application materials for the fast-paced COS/MOS business.

John C. LaBerge, Mgr., Quality and Reliability Assurance, Integrated Circuits, Solid State Division, Findlay, Ohio, received the BSchE in 1953 from the University of Maryland and has done graduate work in Business Administration at Wilkes College and Bowling Green State University. He served for two years in the Air Force in Japan. After graduation in 1953, Mr. LaBerge became a Process Supervisor for E. I. DuPont in New Jersey. He joined RCA in 1958 as Process Engineer in Somerville and transferred to Mountaintop in 1959. At Mountaintop, he was a process engineer working in silicon crystal growing and wafer preparation and in silicon power rectifiers. In 1966, he was promoted to Manager of Reliability Assurance and High Reliability for power transistors. In 1970 he became Leader, Technical Staff, for Medium Frequency Products. In 1971, he became Leader, Technical Staff, for Silicon Power Products. In 1972, he was sent on temporary assignment to RCA Plant, Liege, Belgium as Engineering Manager of Silicon Power. Mr. La Berge was appointed to his present position in April of 1973.

Reprint RE-21-4-4
Final manuscript received September 23, 1975.

4) Educational aids

5) Advertising

The Master Specifications govern internal information; the latter four media are geared to the user. To respond to user questions not covered by this documentation, a very active direct customer telephone service is provided via a "COS/MOS Hotline."

Master specifications

Master Specification Sheets (MSSs) are the standards used by the Solid State Division to cover all aspects of how to make, test, and quality control COS/MOS integrated circuits. Production operations follow the Master Specification sheets exclusively for wafer fabrication, assembly, test, and quality control. Additions and changes to these sheets are introduced into Solid State Division's standards file via a Product Change Notice that requires cognizant management review and sign off. The flow of information related to the Master Specification Sheets is diagramed in Fig. 1.

Since the MSSs contain thousands of pages for each product line, the Engineering and Manufacturing groups that require ready access to specifications use microfiche systems located in their area. The Engineering Standards Department keeps the microfiche file updated for each department's needs; thus, COS/MOS Engineering has all MSSs pertinent to COS/MOS devices. If needed, hard copies of an MSS page can be ordered from Standards. However, MSSs for custom COS/MOS ICs proprietary to RCA equipment divisions or outside customers are kept separate and private by the Standards Department; they are not available in department microfiche readers. Hard copies are obtained only via RCA product management approval on a need-to-know basis.

Data sheets

Commercial data sheets are exactly governed by the functional requirements, circuit diagram, dc and ac parameter limits, packages, and maximum ratings in the MSSs. The Commercial Engineering Department at SSD publishes a complete data sheet for each different COS/MOS type. Data sheets are available for a single type, but are most commonly used as a

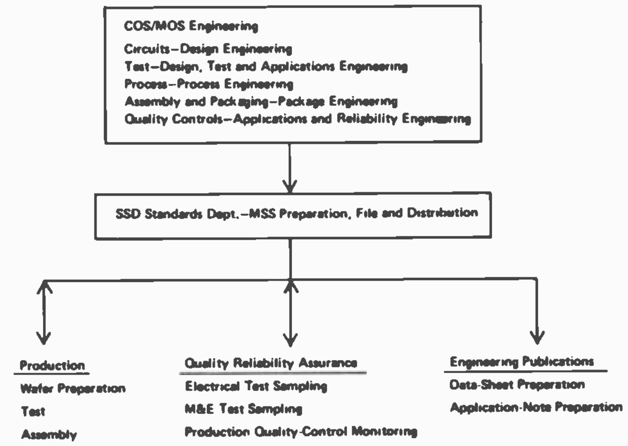


Fig. 1 — Master specification sheet information flow. Note that the production and quality assurance groups are not only recipients of engineering specifications, they also contribute to MSSs. Quality Control procedures are, to a major extent, based on applications (customer) requirements for successful use, with specific quality control tests of final product developed by SSD's Reliability Engineering Laboratories in Somerville. While this series of COS/MOS articles focuses on product development and production, R.E.L. plays a major role in testing all aspects of the COS/MOS ICs to ensure reliable product design before manufacturing.

family of over 110 different types in the Data Book (SSD-203C).

Each data sheet contains the following information required for COS/MOS IC logic type understanding and successful application:

- Title, with list of features and applications
- Maximum electrical, mechanical, and environmental device ratings
- Recommended operating conditions
- Operating description and logic truth table
- Circuit diagram and interconnect designation
- DC and ac parameter limits and test circuits
- Characteristic performance curves
- Available package outlines and dimensions
- Example application diagrams
- Safe operating and handling guidance

Although data sheets are the primary commercial document officially specifying the product being merchandized, the rapid market success of COS/MOS has been greatly enhanced by an excellent set of supplementary commercial publications, educational aids, and advertising.

Supplementary commercial publications

Engineering Publications Dept. publishes and updates several types of supplementary documents useful to COS/MOS customers:

Applications Notes (*ICANs*) are written by application and design engineers and edited by technical writers in Engineering Publications. ICANs fall into two categories:

1) Those dealing with the use of specific COS/MOS types, and

2) Those highlighting important system uses of many COS/MOS types.

COS/MOS Manual and *SSD Product Manual* educate COS/MOS users on device fundamentals, structure, layout, applications, etc.

Product Guide is a periodically updated list of all available (and soon to be announced) COS/MOS Standard ICs giving logic diagrams, features, and application areas of each type. Cross references to similar industry CMOS types and TTL types are also included.

Reprints of papers and commercial press articles authored by COS/MOS engineers are distributed to customers via Sales.

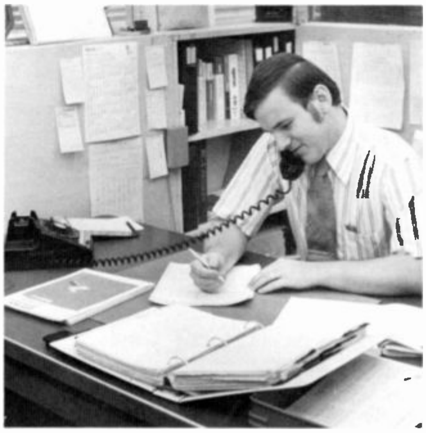
Reliability Reports (*RICs*) contain data gathered during accelerated life tests, and mechanical and environmental stress tests on COS/MOS ICs run by SSD's Reliability Engineering Laboratory (REL). This data is charted and periodically updated for customer use in these published RICs.

Reliability Notes are written by reliability and product engineers to highlight the relationship between the application environment and device performance.

Educational aids

Three additional types of aids are used to educate customers to the COS/MOS story:

Seminar series provides comprehensive coverage, including fundamentals, characteristics, type descriptions, custom design and layout, reliability, system use, and other topics tailored to each audience's needs. COS/MOS application engineers and market planners regularly give slide presentations before sales, customer, and university groups. Slides are generated by




Left: COS/MOS Hotline gives timely answers to tough technical questions. Right: MSS Microfiche in use.

applications engineering and professionally produced by SSD's Engineering Publications. One hour to two full days of presentation are available on slides, and experienced speakers are ready to pack their bags for any part of the world.

Programmed Instruction Manual was developed for the person with little IC, logic or MOS device understanding. This simplified self-teaching book has been ordered in quantity for university use.

Advertisements are placed in engineering periodicals and management-directed newspapers on subjects covering COS/MOS product advancements.

COS/MOS hotline

Real-time answers to technical questions about COS/MOS are handled via the COS/MOS application engineering Hotline which is manned by an application specialist in Somerville. What is not clear, apparent, or available in the various COS/MOS publications is available quickly via the Hotline.

Testing

Two conflicting requirements dictate the philosophy of almost any commercial testing operation:

1) There must be a high probability that when the device reaches the customer it will perform according to his specification, in the case of a custom device, or according to the published data sheet, in the case of a standard device.

2) The cost of such testing must not remove the profit which can reasonably be expected from the sale of that device at a competitive price.

Testing commercial COS/MOS integrated circuits is, therefore, a compromise based on engineering characterization and field experience. Those characteristics that are known to fall well within the specification for the device may safely be tested by the manufacturing Quality Control Department on a sampling basis. The more common failure modes or critical parameters must be tested for on each device. Historically, COS/MOS has not been promoted as a fast technology; therefore dynamic characteristics such as propagation delays and transmission times have been specified generously and are tested on a sampling basis with a high degree of confidence. Conversely, special characteristics of COS/MOS devices, such as very low power consumption, high noise immunity, and operation over a wide voltage range, are tested on each device, usually at least twice. As variations on the COS/MOS theme emerge, with speeds that challenge other technologies, then it is expected that dynamic characteristics will be specified more realistically and 100% testing of those characteristics will be necessary.

Early testing

Testing starts in the embryonic life of the COS/MOS device with a series of in-process checks and tests at various stages of the wafer processing operation. Sheet resistance is measured after each diffusion; the thicknesses of the gate oxide and metalization and the length of channels are measured optically. An indication of the cleanliness of the oxide and metalization is obtained by plotting the capacitance/voltage relationship at two different temperatures. Some of these tests and checks are made on each wafer, or on one wafer from each process lot or on a chip of silicon which travels through a particular operation with a lot of wafers. The most elaborate series of in-process tests is made on special test keys of which there are at least two on each wafer. Two or more normal device locations are sacrificed for these test keys. Before the final silane overcoat is applied, test transistors and other devices which form part of the test keys are measured for threshold voltages, breakdown voltages, drain-to-source current and other parameters which provide an insight to the quality of the processing up to this stage. Data may be logged for future reference and also to be fed back into the process line.

Circuit probe

The first time that a COS/MOS device is tested as a complete functional entity is at circuit probe. At this stage, the wafer is still intact with perhaps a thousand or more identical but separate and independent COS/MOS devices in pellet form, neatly arranged in rows with identical spacing along each row. Each device has a number of contact pads, 0.004-inch square, which vary in number from five or six to as many as forty, depending on the device type. The wafer is held by vacuum to a chuck which can be caused to move a precise distance in any direction in a horizontal plane. When the horizontal movement is complete, the chuck rises vertically (typically 0.05 inches) which creates a physical contact between each of the 0.004-inch contact pads and one probe of any array fixed just above the surface of the wafer. Each probe is electrically connected to appropriate test equipment, usually a complex computer-controlled testing system.

The tests performed at this stage are exhaustive and more stringent than the tests performed on the finished device. The reason for this is that the manufacturing cost per device of producing the wafer up to this point is relatively low—typically only a few cents. The major cost of the finished device is in the package and the labor required for assembly; therefore, it is preferable to risk discarding occasional marginally good devices at circuit probe to achieve a reasonable final test yield. Even the finest test and measuring equiment has an uncertainty band about the set (or measured) point which must be guarded against.

The tests performed at circuit probe include functionally exercising the device logic through its complete truth table at voltages 10% higher than the maximum and 10% lower than the minimum specified operating voltages. Total device current is measured, usually with the logic in a number of different states, so that all internal elements are stressed and any leaky ones detected. Leakage currents at the device inputs are measured with the inputs in the logic high and logic low state and voltages 10% greater than the specification maximum. Similar over-stressing is used to measure the "off" leakage of tri-state outputs where applicable. Sensitivity to electrical noise is checked with inputs high and inputs low at both ends of the normal operating voltage range. Additional noise immunity and margin checks at each end of the specified voltage range are made if the device has tri-state outputs. The drive capabilities of the n- and p-channel output devices are measured and compared to limits. Tests which are not, strictly speaking, device tests are made to ensure the integrity of the connection between the probes and the contact pads of the device under test.

The time to execute the full series of tests on a good device ranges from less than 100 ms for a simple gate type to a few seconds for a complex MSI or LSI type. In a production operation, the test system controller is programmed to abort the test on that particular device when a failure is recognized. In that event, the failing pellet is marked with a spot of ink deposited on it in response to a command from a controller. The chuck carrying the wafer is then signaled to index one pellet pitch and make contact with the next pellet. A mechanical sensor detects the edge of the wafer and signals the chuck to move to the next row and reverse direction.

It is normal practice at the completion of each wafer to request, from the controlling computer, a summary of the yield and failure modes. More detailed data is available but is generally not requested as the volume would be too great for manual digestion.

Final test

The series of tests performed on the COS/MOS device at circuit probe is repeated after the device is packaged into a finished unit. The limits on parameters such as leakage current and drive capability are slightly less stringent than those imposed at circuit probe but they are still more severe than the published data sheet or customer's specification. In volume production, automatic feeding and sorting equipment is used.

Test equipment

Examination of the nature of the tests performed on a COS/MOS device makes it clear that two separate capabilities are required of the test equipment:

1) The ability to execute truth tables with widely different programmable voltage swings ranging from one volt to twenty-two volts.
2) The ability to perform dc parametric tests (i.e., to force a current or voltage on any pin of the device under test and measure the resultant variable on the same or some other pin). For COS/MOS devices, voltages must go up to at least twenty-five volts and current measuring capability down to at least the tens of nanoamps.

Since the early days of COS/MOS, the Teradyne Model J283 has been used by RCA for engineering characterization, circuit probing, and final testing. Systems are installed and operating in Somerville, N.J.; Findlay, Ohio; Taiwan; and Malaysia. The rate at which truth tables can be executed is 50,000 words/second with words up to 12 bits wide, slower for words with more than twelve bits. The parametric testing capability has met all requirements for commercial COS/MOS. Adaptations have been made to measure very low currents (in the low- and sub-nanoamp region) to satisfy special requirements such as are met when testing high reliability COS/MOS.

The emergence of COS/MOS variants with significant speed capabilities is expected to increase the need for equipment with dynamic test capability.

Test program preparation

While the test programming languages for most advanced computer controlled systems are not difficult to learn, they must be applied constantly for the user to remain proficient and to develop the more subtle and sophisticated techniques which the systems are capable of executing. For this reason, skilled test programmers work with the Manufacturing and Engineering operations.

For each new type, a test program is written in conjunction with, and according to, the requirements specified by the device designer. This program will include tests not normally included in production but which yield valuable information to the device designer. These include threshold tests, tests for functionality and leakage at intermediate voltages as well as extremes, and breakdown tests. Similarly, special programs are written for the Reliability Engineering Lab which include diagnostic features for their needs.

Generation of a test program is fairly straight forward. The tests are hand-written in a high level, nmemonic, language by a test programmer, working from the designer's specification. The program is typed directly into an off-line (no real-time test capability) computer system which translates the code into a binary format that is executable by the test system. This is written onto a magnetic tape cartridge. A printed expansion of the source coding can be obtained, as well as a source listing. This expansion, called a simulation, indicates the total condition of the test system at any instant and is a useful aid to desk debugging of the program. When devices become available either in wafer or packaged form, the binary-formated program is entered into the test system computer from the magnetic tape cartridge. Any special hardware such as loads, pulse shapers, etc. which the test programmer may have found necessary to design is connected to the test deck. Ideally, the START button on the test system can then be pressed and the device tested. This, of course, rarely happens. Program debugging can be very time-consuming, particularly if the quality of the device being tested is uncertain, and may include a number of editing and retranslating operations on the off-line system.

Eventually, the device designer and the test programmer are both satisfied with the program. If it is a circuit-probe program, copies of the finished program, duplicates of the special hardware, and correlation devices are released from Engineering to Manufacturing.

Final test and quality control versions of the program are created by the test programmers in the Manufacturing operation.

Special test requirements

Certain device families do not lend themselves to efficient testing on general purpose, slow speed, digital test equipment such as the Teradyne J283. The largest of these families is that of integrated circuits for solid state clocks and watches. These devices perform the same basic functions as the balance wheel and reduction gears of the mechanical clockwork timepiece. The balance wheel is replaced by a crystal oscillator, which may run at megahertz frequencies; and the reduction gears by a series of frequency divider stages. Three difficulties are presented to the test engineer.

1) The device must initiate oscillation at minimum battery voltage. (The traditional shaking of the watch won't help).
2) Very long strings of precise numbers of pulses are required to ensure correct frequency division.
3) There is usually no 'RESET' function on this class of device; therefore the only way to initialize it into a known state before testing can start is to apply an unpredictable number of pulses to the input while examining the output for some change which indicates that the device has just switched into a recognizable state. It may be necessary to apply only one pulse or very many thousands of pulses. And, of course, a bad device may never switch at all.

Below left: The Teradyne J283 computer controlled test system in COS/MOS Engineering in Somerville. This system is equipped with four test decks or testing stations. Similar systems are used for COS/MOS testing in RCA plants in Ohio, Taiwan and Malaysia. Below right: A Daymarc test handler and sorter for finished units. Units are fed from a carrier stick into the upper carousel where they may be heated prior to testing. After testing, each unit is released into one of the three lower chutes selected by the test controller from which they pass into unloading carrier sticks.

Above left: An array of precisely adjusted probes making contact with a COS/MOS integrated circuit on a three inch wafer. Each contact area on the I.C. is .004" square. Above right: Mary Lysy of COS/MOS Test Engineering using the off-line computer system with video keyboard to edit a test routine. This system is also used to translate written routines into test system language and to simulate the operation of the test routines.

Four different solutions were created for this class of device. A new computer controlled test system was designed and built by SSD's IC Equipment Technology Group, in conjunction with COS/MOS Test Technology, specifically to solve these problems. A novel feature is the ability to functionally exercise and check as many as six devices simultaneously, but independently. A second solution is an active electronic attachment to the Teradyne J283 test deck. This unit contains an oscillator and presettable pulse counters which can be controlled by the computer of the basic Teradyne system. A very successful approach for clock or watch types in large volume production has been the simulation of the device's final electrical operating environment.

Finished units inserted into this simulated worst-case environment are checked for oscillator start-up, output drive, total device current, and other characteristics. Correct timing of the output signals is checked against an independent crystal-controlled clock. A fourth approach to testing timekeeping ICs has been via the Macrodata MD154 test system in SSD, MOS Engineering, Somerville. This system is a general purpose machine for high speed functional, parametric, and dynamic tests and has the capability required for clock and watch devices of generating pulse trains and detecting transitions at rates up to ten megahertz.

New directions

As COS/MOS has matured into a widely accepted technology, techniques for testing SSI and MSI have become well established. As the technology expands into more complex and faster LSI, new techniques must evolve. New systems must be created by test equipment manufacturers working closely with the device manufacturer. Device simulation by computer must be continually developed as an aid to test routine definition and generation.

Quality control

In general terms, quality control in support of the COS/MOS product line is directed toward ensuring that the products meet the performance demands of the internal specifications and that they satisfy the performance and reliability claims conveyed to the customer via the external media. Basically, this involves four areas of effort:

1) Correlate test equipment to assure consistency, accuracy, and repeatability of test results.
2) Reduce handling errors (during processing, testing, marking, branding, packaging, and distribution).
3) Monitor reliaiblity.
4) Analyze failures and provide feedback for corrective action.

Correlation during test

The quality level of a semiconductor device is usually measured by its ability to pass a certain series of electrical tests designed to duplicate its functional end use. These tests, by their nature, are sometimes too long to be practical from a cost standpoint; thus simulated tests, designed to correlate with the longer functional cycles, are often used. Herein lies the major quality problem for the manufacturer. How can he rapidly (economically) test the main parameters that define the IC? Often in solid state device production, process control parameter information is also included in the test programs. On COS/MOS, the measurement of dc parameters at low voltages and very low currents makes the correlation of test equipments of major importance. For SSD, this correlation task falls to the Quality Control operation.

To this end, a dual system of controls is used to assure conformance to the electrical specification. Samples of units exhibiting stable characteristics are developed as correlation units. These units are then used as standards when checking the test equipment. This allows comparison between similar pieces of test equipment and can be used to compare against functional "black box" equipment often used by the customer. This type of correlation control will establish the consistency of the test programs and equipment.

Handling

A second quality problem area is the handling equipment associated with the test set. The handling of the tested units, whether manual or automatic, provides another opportunity for error. A faulty decision by the handler will result in a correctly analyzed circuit being placed in an incorrect category. Failures of this nature, although rare, still contribute to the "percent defective" of any 100% tested product. The probability of a failure of this nature is also associated with the testing yield for the selection being made. If the yield for the particular selection is low, the error potential is high because a high number of decisions must be made per 100 units tested. In addition to the handling decision errors, the subsequent handling of units during marking, branding, and packaging also provides possibilities for product mixing. Errors of this nature are generally human errors.

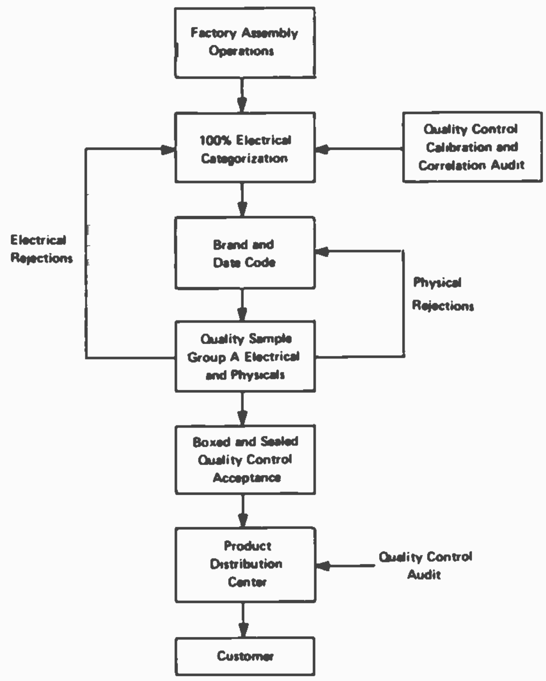


Fig. 2 — Quality control flowchart.

To minimize equipment and human error, RCA uses a dual system of finished product Quality Control. Correlation and calibration checks are made daily as well as an AQL sampling procedure to audit the 100% factory testing of all product (see Fig. 2).

At the completion of the final electrical screening and categorization, finished devices are branded and boxed for sale to the Product Distribution Center. At this point, a sample of the day's production, by type, is taken and retested by QC inspectors to verify conformance to the Master Specification Sheet.

Product failing to meet the electrical or physical appearance screening is returned to the Manufacturing operation for retesting and resubmission to Quality. Products satisfactorily passing the Group A electrical tests and the physical examination are then sealed in intermediate shipping cartons and sent to the Proudct Distribution Center. Periodic audits also are made of the P.D.C.

Reliability

Product reliability in the COS/MOS product line is monitored in two ways: real-time monitoring and sampling tests.

Critical process operations are monitored by using a systems of Real Time Indicator (RTI) tests that give rapid feedback on both the design and process parameters. In the real-time method of determining reliability, the continuous flow of data is interpreted to determine how well the manufacturing process is producing product that meets established criteria. This comparison can be made on a day-to-day basis. The real-time indicators (Table I) are selected on the basis of extensive reliability engineering work during the design of new product. Each package configuration has its own set of in-process Q.C. (RTI) monitors to assure mechanical integrity. Plastic product is sampled daily after the molding operation for moisture resistance and thermal shock capability. Frit and white ceramic packages are sampled daily for hermeticity with additional testing for seal strength. These tests are in addition to daily process control tests for pellet mounting integrity and bond pull strength.

The electrical evaluation of product reliability can be performed in many ways. The test conditions can be as varied as the number of customer applications. In the past, reliability life tests were performed routinely as an after-the-fact evaluation of product capability. The length of time necessary to complete the life test, generally from 6 to 8 weeks for a 1000-hour test, provided historical data for the design and process engineers to use in evaluating the process. The long-term life tests were generally conducted at or near the normal operating conditions for the device under test.

Today, integrated circuits see a much wider spectrum of environmental conditions than ever before. Therefore, reliability evaluations must be performed at maximum rated and overstress conditions within device technology limitations to determine all possible causes of failure. When a major failure mode is determined, the reliability test that will best exercise that failure mode is selected as a process monitor. These accelerated tests are then used to provide a rapid feedback to design and process engineering.

Of the two methods (bias life and operating life) used to life test COS/MOS, devices, bias life is generally used to accelerate the chip-related mechanisms which are more sensitive to time, temperature, and voltage conditions.

For COS/MOS, a high temperature reverse bias at 80% of the maximum voltage has been selected as the best monitor of device reliability. This test is then used on a sample of each family of COS/MOS types manufactured during the month.

In addition to the bias life test, monthly samples of each package configuration are subjected to the environmental tests for the conditions listed in Table II.

As a longer range product reliability measurement, a sample of each product family is selected every six months and placed on operating life test at moderately accelerated temperature conditions for a period of 3,000 hours. A second sample of the same product lot is placed on high temperature storage for 3,000 hours. These long term tests then provide the Reliability Assurance Group with the necessary information to establish the mean-time-to-failure estimates.

Table I — Real-time indicators.

Package configuration	*Frequency*	*Test conditions*
Dual in-line plastic	Once/day	Pressure cooker—30 units for 48 hrs. at 15 psig steam and 121°C.
	Once/day	Thermal Shock—30 units for 200 cycles at −65°C to + 150°C (liquid to liquid).
Ceramic-white	Once/shift	Gross and fine leak tests
Ceramic-frit	Once/day	Gross and fine leak test Seal torque test

Table II — Environmental test conditions monthly by package type.

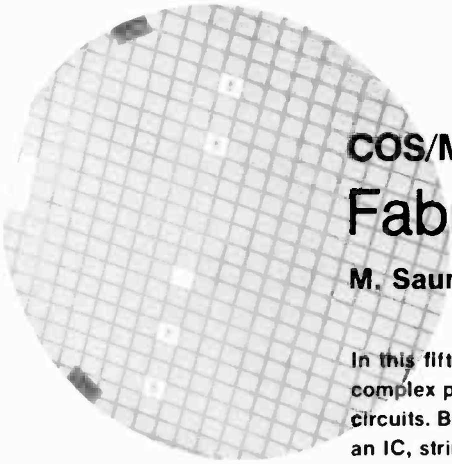
Test	*MIL-STD-883 Method*	*Specific requirements*
Solderability	2003	260°C. Visual insp. for 90% coverage of lead surface
Thermal shock	1011 Cond. A	5 cycles, −65°C. + 150°C.
Temperature cycle	1011 Cond. C	5 cycles, −65°C. + 150°C.
Moisture resistance	1004	240 hours (10-24 hr. cycles)
Lead fatigue	2004 Cond. B_2	Three 90° bends
Salt atmosphere	1009 Cond. A	24 hours
Flammability	Mil-STD-202 Method 111	

Failure analysis

The Quality Control operation also provides the failure analysis service for the Manufacturing operations and the customer. Customer problems associated with test correlation, specification interpretation, and analysis of defective devices from the customer's assembly operation are routinely processed. Results of the analyses are used to identify failure modes and provide feedback to Manufacturing, if the failed device came from internal reliability stress testing, or to the customer, if an application is overstressing the IC.

Conclusions

COS/MOS integrated circuits, as well as other RCA solid state devices, are manufactured using a strict set of internal standards. Customers are provided with the most complete data sheets, educational literature, and application services in the solid state industry. Devices are thoroughly tested to specification using advanced computer controlled test equipment at all levels of device assembly. The Quality function not only verifies specification integrity, but also runs mechanical and environmental accelerated stress tests to assure COS/MOS product reliability.



COS/MOS product design
Fabrication

M. Saunders

In this fifth and final paper of the series on COS/MCS product design, we look at the complex processing and control problems faced in manufacturing COS/MOS integrated circuits. Because the fabrication process directly affects specific electrical parameters of an IC, stringent process control is of primary concern in obtaining cost-effective yields. Yet even as manufacturing techniques mature, the growing complexity of COS/MOS devices requires continual development of newer and improved methods of producing the circuits.

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Reprint RE-21-4-5
Final manuscript received September 19, 1975.

While the processing of integrated circuits has matured over the last ten years, there are still areas of dynamic change. COS/MOS device fabrication presently blends the mature with the new. Building originally on experience from bipolar circuit processing, COS/MOS fabrication has many of its own unique processing and control problems.

Fig. 1 shows the major processing steps for COS/MOS circuits operating in the 3- to 17-volt range and having transistor turn-on voltages of 1.0 to 2.2 volts.

As a result of the sequential processing

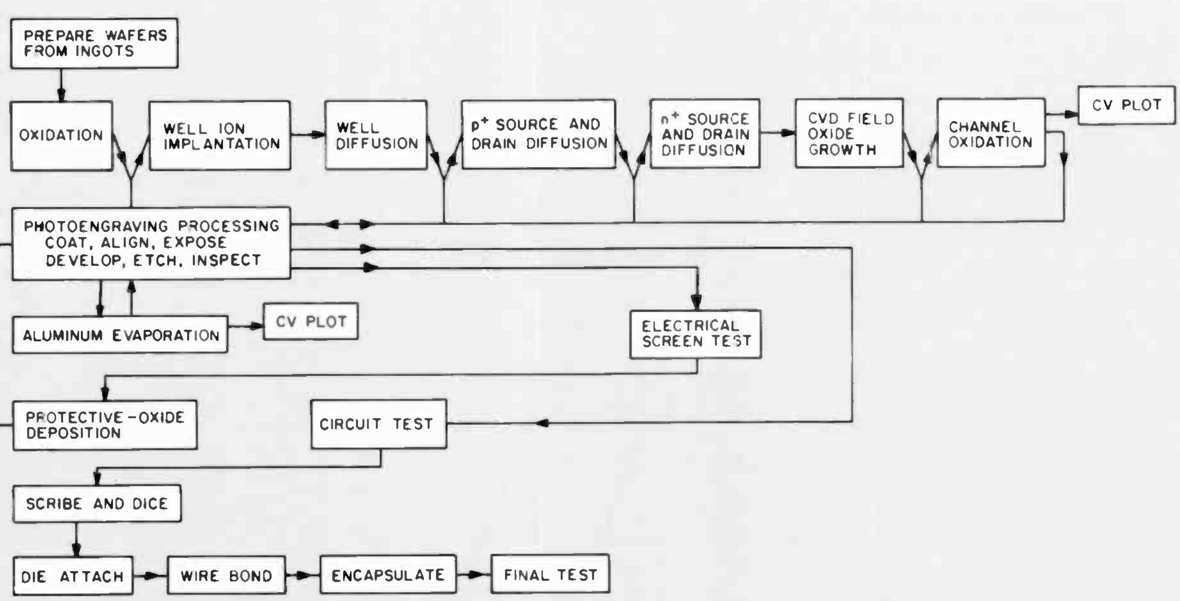


Fig. 1 — Major processing steps for COS/MOS circuit fabrication.

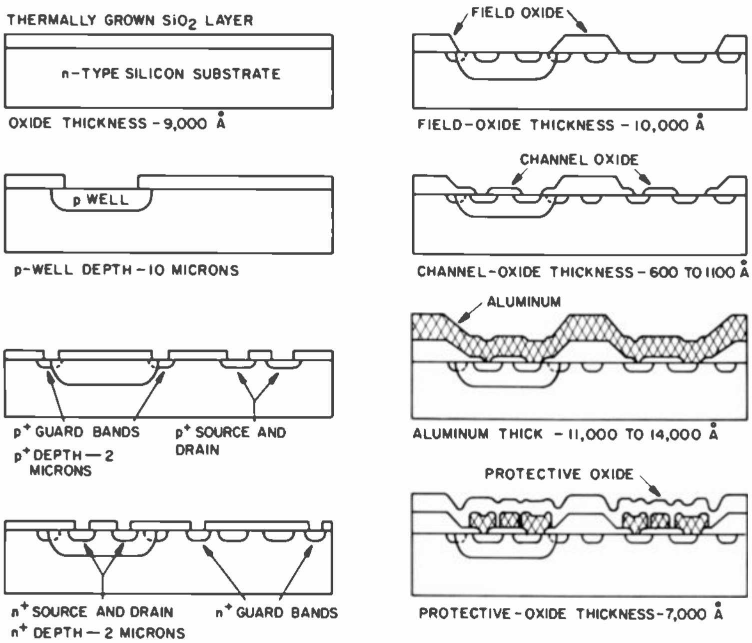


Fig. 2 — Cross section views of COS/MOS devices at various sequential process steps.

Table I — Physical results of processes and their effects on electrical properties.

Physical parameter	*Electrical effect*
Substrate resistivity	P transistor V_{th} P transistor V_B P transistor gain
Well-doping profile and level	N transistor V_{th} N transistor V_B N transistor gain Parasitic transistor action
P^+ doping level and profile	P transistor V_B Well V_B
N^+ doping level and profile	N transistor V_B Parasitic transistor action
Photoengraving reproducibility for channel lengths	Transistor V_B and gain
Photengraving alignment accuracy	Transistor gain, specific diode breakdown voltages
Channel oxide thickness	Transistor V_{th} and gain
Channel oxide cleanliness	Transistor V_{th} Transistor leakage Transistor life stability
General wafer processing cleanliness	Transistor V_B Circuit leakage
Protective oxide composition	Transistor life stability

steps that are performed, oxide, diffused impurity, and metal layers are built into the onto the original silicon wafer as shown in Fig. 2. After initial wafer polishing, the processing of the wafers is built around an exchange of thermal treatments and photoengraving operations as follows:

1) The wafer, which is n-type by virtue of phosphorus ingot doping, is oxidized at high temperature in a steam atmosphere.
2) A photoresist coating is applied to the wafer. This coating is exposed with a mercury-vapor light, high in ultraviolet output, through a photo mask containing the well pattern. Developing the resist, etching the oxide, and removing the resist completes the photo processing steps for this single operation and leaves an opening in the oxide coating where the wells are to be placed.
3) Boron is placed into the well area by ion implantation. This boron is redistributed by thermal diffusion while at the same time a new oxide is grown over the well area.
4) Regions for p+ source and drain areas for the p-type transistors and for guard bands are defined by the photoengraving process. These local regions are inverted from n substrate to p-type areas by thermally diffusing boron into the silicon, this time from a boron nitride source.
5) Additional oxide is deposited by CVD (chemical vapor deposition) and the regions for n+ source and drain diffusions plus guard bands are defined by the photoengraving process. These n+ regions are thermally diffused into the silicon using phosphorus oxychloride as the dopant source.
6) The existing oxide is removed and a field oxide is deposited by CVD techniques. This oxide is opened over transistor regions using a specific photoengraving process which slopes the oxide step at an angle to the silicon surface. This slope enhances coverage of the oxide steps by the deposited aluminum layer.
7) The channel oxide is thermally grown over the existing openings in the field oxide.
8) Contact windows are photoengraved into specific areas through the channel oxide.
9) Aluminum is evaporated over the entire wafer surface. A photoengraving operation defines this aluminum into a complete interconnection pattern.
10) The final step of depositing a phosphorus doped/undoped protective oxide sandwich by CVD techniques over the entire wafer is performed. This layer is removed from the bond pad areas of the circuit by the photoengraving process.

Fabrication and process control

The primary control problems in COS/MOS fabrication can be listed under those which are directly related to the basic electrical parameters of the n and p transistors; these are: breakdown voltages, threshold or turn-on voltages, and transistor gain. While there are interrelations between different process results and electrical parameters, some process results affect specific transistor parameters stronger than others. While not including all the interrelations, Table 1 gives a comparison of fabrication effects *vs* electrical parameters.

Since the basic process is well established, and to a certain extent mandated by the circuit design, it follows that the primary task in COS/MOS fabrication is to control the process, and the secondary task is to introduce new and improved methods of producing the circuits.

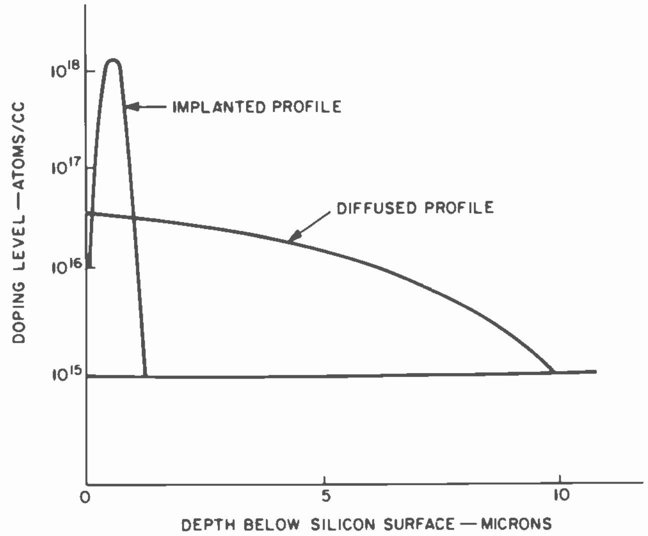


Fig. 3 — Approximate boron distribution in ion implanted wells.

Thermal treatments and their control

Considering the various physical parameters and their controlling processes, a good example of a relatively recent change with increased yield and improved control is the introduction of ion implantation for well structures. Well diffusion, before the introduction of ion implantation, consisted of a four-step thermal treatment plus intermediate etching steps. The process gave good results in most cases but the results were subject to rather wide variations with only small changes in process conditions and, subsequently, a large amount of time had to be spent assuring control. Using ion implantation, the thermal treatments were reduced to one. The initial profile of boron implanted in the silicon is accurately controlled by wafer positioning and by the implanter accelerating voltage and beam current.

The thermal treatment serves to redistribute the boron to the desired profile, electrically activate the implanted boron, and grow an oxide layer for subsequent processing. The impurity profiles obtained from the ion implant process and approximating those in COS/MOS circuits are shown in Fig. 3.[1,2] As is shown in Fig. 4, the wafers are loaded for implantation on a rotating carousel, assuring uniform ion implanation distribution from wafer to wafer.

All diffusions are performed in hot-wall furnaces whose front center and back zones are controlled by a differential thermocouple technique with the end zones slaved to the center. Temperature profiles on the furnaces are checked weekly or twice a week and all diffusion runs are checked for sheet resistivity either on the product wafers or on control chips. As much as possible, wafers are loaded into diffusion boats using a transfer system which avoids tweezer handling (Fig. 5).

Thermal oxides are grown in the same type of furnaces using a dry O_2 or steam atmosphere. The most critical oxidation in the process is the channel oxide. This oxide is grown in a steam atmosphere with HCl gas included. There are several proposed explanations for the beneficial effect of HCl, some describing neutralization of Na and some decribing gettering effects. Oxides grown with HCl in the atmosphere exhibit good stability with respect to mobile ion movement under high-temperature bias conditions. Immediately after channel oxidation, the wafers are transferred to an annealing

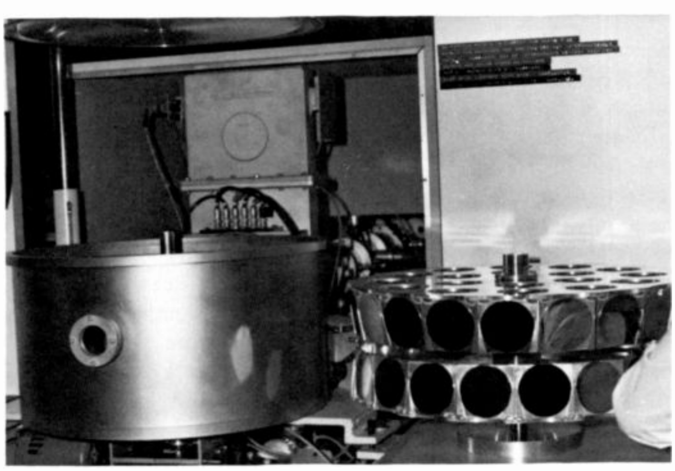


Fig. 4 — Ion implant loading station.

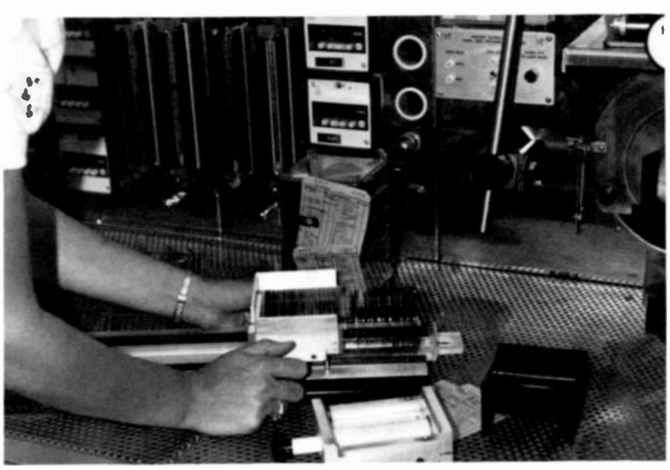


Fig. 5 — Furnace boat loading using transfer system.

furnace to reduce the number of positive charge states existing at the Si-SiO_2 interface. The reduction of the charged states after steam oxidation is done in a neutral or reducing atmosphere such as argon, nitrogen, or nitrogen hydrogen mixtures.

The control of the charge residing at the Si-SiO_2 interface or within the oxide bulk as ionic charge is perhaps the one most important aspect of wafer fabrication, because it affects life stability as well as initial electrical properties. To control this charge, the following procedures are maintained:

1) Use of 100-oriented-silicon in the process,
2) Cleaning of all wafers in basic and acid peroxide solutions before channel oxidation,
3) Channel oxidation using HCl-steam,
4) Annealing at elevated temperatures in inert atmosphere following channel oxidation, and
5) Use of low-sodium chemicals and materials, particularly in operations immediately preceding and during evaporation of aluminum on the wafers.

Every channel and annealing furnace run is monitored with a silicon control chip which is then checked for fixed charged and mobile ion charge by the capacitance-voltage test technique. In addition, every evaporation run, where aluminum is evaporated on the wafer surface, is also monitored with the capacitance voltage technique. In this case, the control chip is an oxidized silicon chip whose oxide characteristics have been predetermined by sampling before aluminum evaporation (so-called known clean oxide control chips). To reduce the total time at elevated temperatures and prevent unwanted diffusion of source and drain areas, two oxides are deposited using CVD techniques. In our operations, 3% SiH4 in N_2 or 100% SiH4 gases are used as the source of silicon for the deposited SiO_2. Deposition temperatures run in the 400 to 425°C range. These oxides are densified for a short period of time following the deposition; they closely approximate thermally grown oxide after densification. Pin-hole testing has shown them to be equal to thermally grown oxides in the thickness range in which they are used in our circuits.

A third vapor deposition grown oxide, which is the phosphorus doped oxide grown over the wafer at its final processing steps, is not densified. The phosphorus content of this protective oxide is monitored every process run.

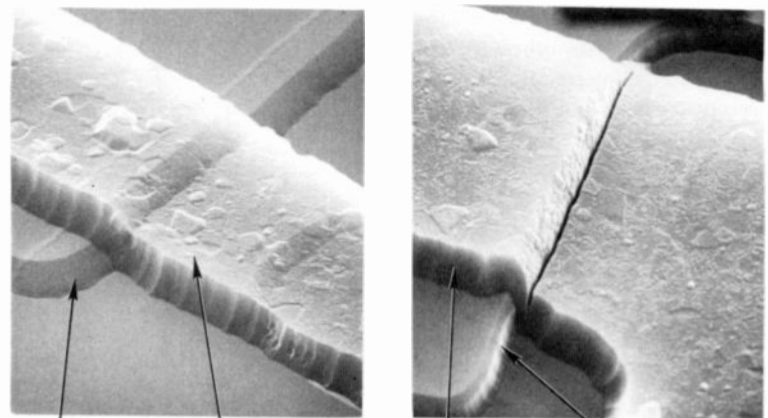


Fig. 6 — Good and bad slope in field oxide windows showing the resulting aluminum step coverage.

Photoengraving treatments and their control

Depending upon the sequence from which the wafers come to the photo processing steps, a precoat bake may or may not be employed. Wafers coming directly from furnace operations are not baked. The wafers are coated with photoresist in automatic machines using a spin-on technique. Control of spin speed and resist viscosity is important for resist layer thickness control. Alignment of the mask to the wafer pattern is performed on manually operated machines. Mask pressure to the wafer and light intensity must be closely controlled. Mechanical maintenance of aligning machines is a major concern in the process, as equipment performing this operation must be properly "tuned" or poor resolution and alignment may result with necessary reprocessing or a subsequent down-line drop in circuit probe-yield. Control of dirt and dust is a necessity for good alignment operation.

Transistor source-to-drain spacing and its effect on the subsequent transistor electrical properties of drain voltage breakdown and transistors gain are con trolled by the photoengraving process. Light intensity, mask dimensions, exposure time, developing, and etching conditions must all be properly controlled for correct source-to-drain spacing.

One of the most difficult operations in the photoengraving process to control is the etching of sloped edge windows in the 10,000Å-thick field oxide. Because of the nature of the aluminum evaporation process, discontinuities in metal interconnects are liable to form if the angle of the etch cut in the field oxide window is too steep.

Exposure conditions, pre-etch bake temperature and the etching solution temperature must be precisely controlled to achieve the proper slope. Subtle changes in resist composition, sometimes not detectable by chemical analysis, may completely change the sloping characteristic. Slight changes in the oxide surface may also affect the slope. As a consequence of this, the sloped etch process is constantly monitored using optical microscopes and a percentage of the product is monitored for aluminum interconnect continuity over the field oxide steps using a scanning electron microscope. Fig. 6 compares scanning electron microscope pictures of aluminum interconnects over both good and bad oxide windows.

Photoengraving of the metal interconnects offers different problems than those associated with oxide window etching. The metal over various oxide steps acts as a reflector of the ultraviolet light and slight misalignment of the metal mask may lead to bridging of the metal due to polymerization of the resist from laterally reflected light. In addition, special etching techniques to eliminate the effect of gas generation during the metal photoetching must be employed.

All wafers are inspected after each photo operation to assure proper alignment, complete etching, and the absence of other yeild-detracting defects in the wafer.

Special processes

In addition to the wafer processes described above which are basic to all COS/MOS product, special processing sequences have been established for making circuits utilizing silicon gates and silicon interconnects. While silicon gates are used primarily for threshold voltage control and silicon interconnects are used for double-layer interconnect patterns, the basic process used to form the material for both silicon gates and silicon interconnects is the same. Silicon is deposited in polycrystalline form on the wafers at temperatures of approximately 700°C from an SiH4-inert gas mixture. Layers of 2000Å to 4000Å thick are grown at rates of 1000Å/min. Uniform growth control requires constant monitoring in this process and every product run is sample tested for thickness using a profile-step height measuring instrument.

Electrical testing

Before moving product on to the circuit-probe operations, each individual wafer is electrically tested utilizing specific test locations which have been processed into the wafer along with the circuit type. Each wafer must pass threshold voltage and diode breakdown tests, while certain types must also pass transistor gain tests. Wafers are also tested at this step for mobile change by the capacitance voltage test technique.

Final electrical testing, which in some cases includes dynamic tests, is performed on the packaged devices.

Wiring and encapsulation

Circuit-probed wafers are diamond scribed and diced into individual pellets. Bad pellets, inked with a red dot at the circuit probe operation, are discarded. The pellets are then ready to be bonded onto lead frames for plastic encapsulation or directly onto a package header.

To bring the electrical connections from the circuit chip to the leads on the lead frames or headers, gold or aluminum wire bonding is used. For a time, gold wire ball bonding was used very little in our operations, but with improved machines this technique is once again a major means of making circuit-to-package connections. Ultrasonic bonding of aluminum and gold wires is also used for COS/MOS devices. Gold wire is presently used only in plastic packages. The elimination of wire bonding altogether by using techniques such as beam leads or similar methods has proved an elusive goal to date but it is not to be ruled out, even for the near future.

Following bonding, circuit pellets, which are mounted onto lead frames for plastic encapsulation, are then covered with a special formulation junction coating material. The coating is applied as a safety factor in preventing future electrical degradation under extreme environmental conditions. The lead frame, with its attached and wire-bonded pellet, is then encapsulated by injection molding techniques with an epoxy plastic. This plastic material is forced into a mold at elevated temperature where it flows around the lead frame and completely encloses the circuit. This operation is performed at 180°C with a final pressure of 200 lbf/in^2. Fig. 7 shows a plastic encapsulation frame, with the press in the background.

Fig. 7 — Plastic encapsulation frame and press.

Other types of packages include 14, 16, 24, and 28 lead dual in-line ceramic packages and flat ceramic packages. COS/MOS circuits can also be obtained in TO-5 packages, frit-seal packages, and leadless inverted chip packages. All of the above except molded plastic packages and the inverted chip package are hermetic packages.

Summary

Fabrication of COS/MOS circuits is a complex process, one that has many opportunities to give low yields unless detailed monitoring is performed. Over the past several years the complexity of some of our newer COS/MOS circuits has increased many fold. It would not be possible to produce these devices economically without three basic factors having taken place during that time. These three factors are:

1) Introduction of improved and finer controlled processes.
2) Increase in process monitoring with improved test and quality equipment.
3) Consistent improvement in circuit design techniques which have taken into account certain presently unavoidable process limitations.

Present-day COS/MOS processing is helping to reshape the future design and manufacture of the very devices it produces. COS/MOS circuits are being used and will continue to be used in production and test equipment which, in turn, allows more complex and improved circuits to be designed and manufactured.

Acknowledgments

The writer wishes to thank M. Meehan for his suggestions and review of this paper. He also wishes to thank G. Pokrivchak for his helpful discussions on encapsulation techniques.

References

1. Douglas, E.C. and Dingwall A.F.; "Ion Implantation for Threshold Control in COS/MOS Circuits."
2. Wu, A.L., "Experimental Results of Ion Implanted P Wells."

Recent books by RCA authors

RCA authors who have recently published books and who were not cited in this listing should contact the editors, Bldg. 204-2, Cherry Hill, Ext. PY-4256. Engineers who have contributed parts of books will be cited in the next issue.

Image Quality

A Comparison of Photographic and Television Systems

Otto H. Schade, Sr.


Schade

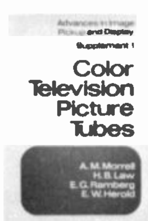
This unusual book gives a technical overview of the concepts developed by Dr. Schade, and now in universal use, that permit a quantitative evaluation of image quality. He describes in some detail the three basic parameters that determine image quality: the intensity-transfer function, which is a measure of the gray scale; the modulation-transfer function, which is a measure of sharpness and definition; and the particle or quantum density that can be stored in the sensor of the camera, which is a measure of granularity, or noise.

A unique feature of the book is a series of 54 unusually high-quality reproductions of photographic and television images that dramatically illustrate the effects of various parameters on image quality. The story told by these illustrations will be readily perceived by the expert and the layman alike. *(Scientific Publications, RCA Laboratories, Princeton, N.J.; 1975; 84 pages;* $20.00)

Dr. Otto Schade, (retired) RCA Electronic Components, Harrison, N.J., has been active in the field of television for more than thirty-five years. His pioneering work in the 1940's and 1950's led to the concept of Modulation Transfer Functions and Noise Equivalent Pass Bands, which can be applied equally to amplifiers, lenses, and the human eye. He made the first measurements on the human visual system in terms of these parameters. Dr. Schade's work has received worldwide acclaim.

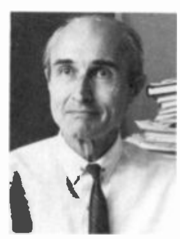
Color Television Picture Tubes

A.M. Morrell | H.B. Law | E.G. Ramberg | E.W. Herold




Morrell


Law


Ramberg


Herold

This book, a supplement to *Advances in Image Pickup and Display*, is the first comprehensive and cohesive treatment in the literature covering the entire subject of color television tubes. Included are not only a broad discussion of the basic principles and operation of shadow-mask tubes, but also an extensive analysis of the electron-optical factors determining tube brightness and a detailed analysis of the interrelated factors involved in the design of the mask and screen and their influence on color purity. Also included are important (heretofore unpublished) details of construction and fabrication of shadow-mask tubes.

A significant portion of this book has also been devoted to reviewing and analyzing other types of color tubes which have also been extensively studied over the years, and comparing them to the shadow-mask tube. *(Academic Press, New York; 322 pages; $18.50.)*

Albert M. Morrell, Manager, Design Laboratory and Engineering Standards, Picture Tube Division, Lancaster, Pennsylvania, received the BSEE from Iowa State University in 1950. He joined the Electron Tube Division of RCA at Lancaster in 1950. He has specialized in color picture tube design and has been associated with most phases of their development. Mr. Morrell holds 16 patents related to color tubes. He has published a number of technical papers and is a co-author of *Color Television Picture Tubes*, published by Academic Press in 1974. He is a member of Phi Kappa Phi, Eta Kappa Nu and the IEEE. In 1964, he was named as a recipient of the David Sarnoff Team Award for Engineering for development of color picture tubes.

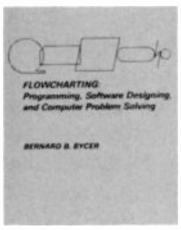
Dr. Harold B. Law, Staff Adviser, RCA Laboratories, Princeton, N.J., received the BS in liberal arts and in education in 1934 from Kent State University. In 1941, he received the PhD in physics from the Ohio State University. He taught mathematics for five years prior to joining RCA, Camden, in 1941. In 1942 he transferred to RCA Laboratories where he became a Fellow of the Technical Staff in 1960. In 1962 he became Director of the Materials and Display Device Laboratory, Electronic Components, and continued as its Director until it was integrated into RCA Laboratories in 1975. Dr. Law has worked in the field of television camera tubes and on direct-view display devices for both black and white and color television.

Dr. Edward G. Ramberg, Materials and Device Research, RCA Laboratories, Princeton, New Jersey, received the AB from Cornell University in 1928 and the PhD in theoretical physics from the University of Munich in 1932. After working on the theory of x-ray spectra as research assistant at Cornell, he joined the Electronic Research Laboratory of RCA in Camden in 1935. He has been associated with the RCA Laboratories in Princeton since their establishment in 1942. He has worked primarily on electron optics as applied to electron microscopy and television, various phases of physical electronics, thermoelectricity, and optics. In 1949, he was visiting professor in physics at the University of Munich and, in 1960 and 1961, Fulbright Lecturer at the Technische Hochschule, Darmstadt. Dr. Ramberg is a Fellow of the IEEE and the APS and a member of Sigma Xi and the Electron Microscope Society of America.

Dr. Edward W. Herold was Director, Technology, Research and Engineering at the time of his retirement in November 1972. Dr. Herold joined RCA in 1930 in Harrison, N.J., where he engaged in tube research. In 1942 he transferred to the newly established RCA Laboratories where he served as Director of the Radio Tube Laboratory and, later, the Electronics Research Laboratory. In 1957, he was placed in charge of the RCA group working on Princeton University's C Stellarator project for research on controlled thermonuclear fusion. In 1959 he was appointed Vice President, Research, for Varian Associates, returning to RCA in 1965, where he was a member of the Corporate Engineering Staff for the past seven years. Dr. Herold received the BS in Physics in 1930 from the University of Virginia and the MS in Physics in 1942, from the Polytechnic Institute of Brooklyn.

Flowcharting: Programming, Software Designing and Computer Problem Solving

Bernard B. Bycer



Bycer

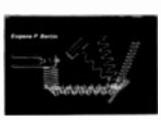
This book is both text and reference for persons in or preparing to enter computer programming. In addition to teaching the techniques of flowcharting, it gives the reader an understanding of the power, rigor, versatility, and elegance of flowcharting as a discipline. By means of text and sample problems, it presents flowcharting as an aid in logic and exposition, as well as a vital tool for computer programming.

Highlights include a dictionary of flowchart symbols using ANSI standards, flowcharting details and conventions (including the multilevel concept), an outline of the major computer hardware elements and an explanation of serial and parallel operations, a discussion of program flowcharting, problem solving by flowcharts, and a summary of the current state and future prospects for flowcharting (including automatic program writing and hardware design). *(John Wiley & Sons, Inc., New York; 1975; 300 pages, paper-bound; $9.95).*

Bernard B. Bycer, Senior Member, Engineering Staff, RCA Software Design and Development, MSRD, Moorestown, N.J., received the BSEE from the University of Pennsylvania in 1945, the MSEE in 1959, and is currently enrolled there in the doctoral program in computer science. Since joining RCA in 1956, he has specialized in the design of various data processing and control systems. His current assignment is in computer software development for the AEGIS ORTS (Operational Readiness Test System) data base design and the ORTS operating system. Mr. Bycer has published eight papers on computer-related subjects and authored another book, *Digital Magnetic Tape Recording: Principles and Computer Applications* (Hayden, 1965). He holds two U.S. patents. He is a senior member of the ACM and IEEE and holds membership in several other professional computer groups. He is listed in *Who's Who in Computers and Data Processing,* 1971.

Principles and Practice of X-Ray Spectrometric Analysis
(Second Edition)

Eugene P. Bertin



Principles and Practice of X-Ray Spectrometric Analysis

Bertin

X-ray fluorescence spectrometry is a rapid nondestructive instrumental method for qualitative and quantitative analysis for chemical elements by measurement of the wavelengths and intensities of their x-ray spectral lines. This book treats the subject in seven major divisions: the nature of x-rays and x-ray spectra; the x-ray spectrometer, its components and their functions; qualitative and semiquantitative analysis; experimental and mathematical methods of quantitative analysis; performance and interference, including precision and error, sensitivity, resolution, matrix effects, and spectral interference; specimen preparation; and related x-ray analytical methods, including a chapter on electron-probe microanalysis.

Called the most comprehensive book in print in its discipline, it has been revised, updated, and greatly expanded from the first edition published in 1970. Much of the expansion is devoted to the rapidly developing field of energy-dispersive x-ray spectrometry. *(Plenum Press, New York; 1975; 1079 pages; 248 illus., 4 color plates; $75).*

Dr. Eugene P. Bertin, Process and Applied Materials Research Laboratory, RCA Laboratories, Princeton, N.J., received the PhD in Analytical Chemistry in 1952 at the University of Illinois and remained there as an Instructor in Chemistry until 1953. In 1953, he joined RCA in Harrison, N.J., where he applied x-ray spectrometry, diffraction, and radiography to the development, manufacture, and testing of electron tubes as well as semiconductor, thermoelectric, and cryogenic materials and devices. In 1969, he joined RCA Laboratories in Princeton, N.J., where he has charge of electron-probe microanalysis. Since 1967, he has lectured at an annual two-week summer course on x-ray spectrometry at the State University of New York at Albany. He is a member of 14 scientific societies and has authored 30 technical papers on x-ray spectrometry.

Fisica de Aislantes (Insulator Physics)

Dr. Richard B. Williams

Williams

This is a Spanish language book on the physical and electrical properties of insulators. It covers the subjects of charge transport in insulators, Ohmic and blocking contacts, internal photoemission, Schottky barriers, electrolyte contacts and negative affinity materials. *(Editorial Trillas, Mexico City, Mexico; 1974; 160 pages; Mex$20.)*

Dr. Richard Williams, Member, Technical Staff, RCA Laboratories, Princeton, N.J., received the AB from Miami University in 1950 and the PhD in physical chemistry from Harvard University in 1954. In 1958 he joined the technical staff of RCA Laboratories in Princeton, N.J., where his research has been in studies of the photovoltaic effect, semiconductor-electrolyte interfaces, high electric fields in insulators, ferroelectrics, liquid crystals and insulators surfaces. He was elected a fellow of the American Physical Society of 1967 in recognition of research contributions. In 1969 he was a Fulbright Lecturer in Sao Carlos, Brazil where he wrote a textbook on the electrical properties of insulators. He is the recipient of three RCA Achievement Awards, shared the David Sarnoff Award for 1969, and is a Fellow of the RCA Laboratories.

Introduction to Liquid Crystals

Eldon B. Priestley | Peter J. Wojtowicz| Ping Sheng

Priestley

Sheng

Wojtowicz

This book, edited by three scientists at RCA Laboratories, is a tutorial introduction to the science and technology of liquid crystals. It serves as a useful primer for those interested in the physics of liquid crystals as well as those using or contemplating the use of liquid crystals in practical devices. Emphasis is given to areas generally ignored in other texts—the statistical mechanics of the molecular theory and various aspects of device fabrication. The book is based on a series of lectures given at RCA divisions by several RCA scientists, including the editors. *(Plenum Publishing Company, New York; 370 pages, hard-cover; $22.50.)*

Eldon B. Priestley, Member, Physical Electronics Laboratory, RCA Laboratories, received the BSc in Chemistry from the University of Alberta in 1965 and the PhD in Chemical Physics from the California Institute of Technology in 1969. He spent two years as a Research Fellow in the Department of Engineering and Applied Physics at Harvard University, and in 1971 joined the technical staff of the Physical Electronics Laboratory at the David Sarnoff Research Center, Princeton, N.J. At present he is using Raman scattering and inelastic electron tunneling spectroscopy to investigate chemisorption of liquid crystal and surfactant molecules on a variety of substrates in an effort to understand the forces responsible for surface alignment of liquid crystals. He is a member of the American Physical Society and the American Association for the Advancement of Science.

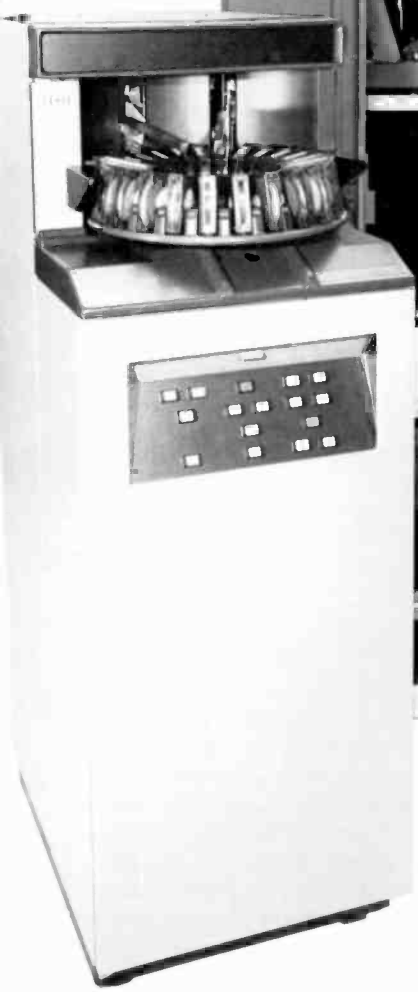
Ping Sheng, Member, Physical Electronics Research Laboratories, RCA Laboratories, received the BSc in Physics (with honors) from California Institute of Technology in 1967. He received the PhD in Physics from Princeton University in 1971. After spending two years at the Institute for Advanced Study, Princeton, N.J., as a visiting member of the School of Natural Sciences, Dr. Sheng joined the RCA Laboratories as a member of the Physical Electronics Research Laboratory where he is engaged in research on the physical properties of granular materials and the theory of liquid crystals. He is a member of the American Physical Society.

Peter J. Wojtowicz, Member, Physical Electronics Research Laboratory, RCA Laboratories, received the BSc in chemistry (with highest honors) from Rutgers University in 1953. He received the MS in chemistry in 1954 and the PhD in physical chemistry in 1956 from Yale University. Dr. Wojtowicz joined RCA Laboratories in 1956 as a Member of the Technical Staff of the Physics and Chemistry of Solids Group of the Physical Electronics Research Laboratory. During 1966 - 1967 he was acting head of the General Research Group. He is currently engaged in the theory of liquid crystals and liquid-crystal phase transformations. Dr. Wojtowicz is the recipient of two RCA Laboratories Achievement Awards for the years 1962 and 1966. He is a fellow of the American Physical Society and a member of Sigma Xi and Phi Beta Kappa.

Producibility and the TCP-1624 automatic film projector design

L.D. Ciarrocchi | A.E. Jackson

Positive results of a combined design and manufacturing engineering program for the development and production of the TCP-1624 automatic film projector are described herein. Close coordination in the early design stages was followed by joint engineering-manufacturing reviews of facilities, skills, tooling, tolerances, critical parts inspections and assembly according to established schedules. Such a cohesive and critical approach led to a higher degree of producibility which has had considerable impact on the reliability of the product.



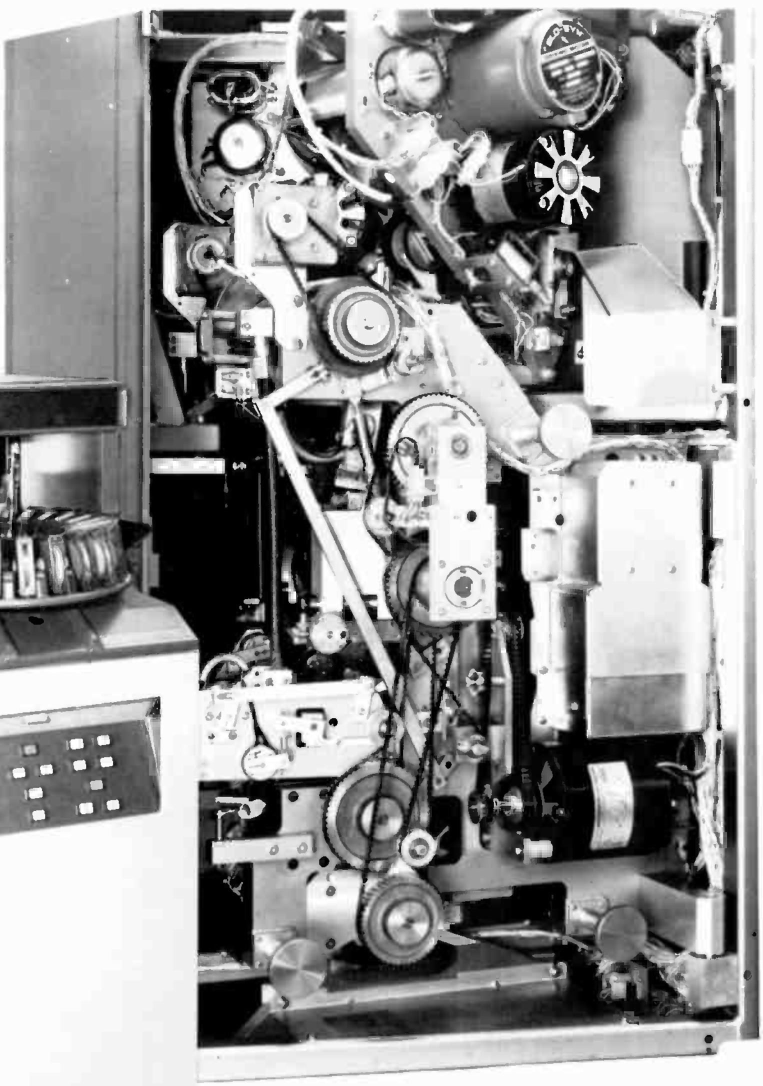


Fig. 1a (left) — Overview of TCP-1624 automatic film projector. Fig. 1b (above) — An internal view of TCP-1624 transport mechanism.

CONSIDER the day-to-day demands placed on an automatic film projector by our customers—the television stations here and abroad. Literally thousands of short pieces of 16-mm film on small reels or hubs are received by the tv stations every year. Occassionally, short films are spliced together and wound on commercial reels, but, in most instances, small reels are played back one at a time.

Programming demands

Such film programming requires a great deal of handling during incoming inspection, identification, cataloging, storage and retrieval for playback. To play back a reel, it must be loaded, threaded, cued, played, rewound, unspliced and spliced. Thus, the TCP-1624 cartridge-loading automatic film-handling projector is an obvious and logical answer to these problems.

Reliability and producibility

Because of the around-the-clock usage and wear to be placed on an automatic cartridge film projector, high product reliability was adopted as a primary goal. Probably the most critical factor affecting reliability is *producibility*.

Editors' note: Fig. 1b gives the readers an idea of the degree of mechanical complexity of the TCP-1624 film projector—and the challenge faced by design and production engineers. For readers desiring a brief functional description of the film projector (prior to reading this paper), see the "how its works" appendix at the end of the article.

Therefore, considerable attention was directed, during all design phases, to manufacturing considerations such as facilities, skills, practical tolerances, critical parts inspections and assembly, special equipment and tooling concepts. All of the factors are integrated to achieve producibility; this has had a substantial impact on the Automatic Cartridge Film Projector cost and reliability.

The TCP-1624 design program

For the TCP-1624 Automatic Cartridge Film Projector design program (Fig. 1), a target was set at the outset to establish procedures and checks to assure adequate consideration of the producibility factors noted above and to prepare in advance for a coordinated start-up of production.

A key element in implementing these procedures was the involvement of the manufacturing organization in the design program; this paper describes that involvement. In addition, a description of the "TCP-1624 Automatic Film Cartridge Projector and how it operates" is given in an appendix to this article.

Coordinated plan

The program for manufacturing involvement on the TCP-1624 project during design and pre-production stages to assure meeting producibility and start-up goals was as follows:

1) Production participation in pre-engineering model concept reviews.
2) Production participation in design reviews after construction of the engineering model.
3) Review of all fabrication drawings for producibility factors by Production Engineering.
4) Assembly and evaluation of one prototype model by Production Engineering.
5) Production start-up guidance by Design and Production Engineering.

Initial concept review

The initial or concept review phase of this producibility program involved design engineering, production engineering, assembly process, test process, fabrication, electrical and mechanical purchasing, quality control and quality assurance. Engineering sketches and subsystem feasibility models were reviewed in detail in a series of review meetings.

Arnel E. Jackson, Ldr., Telecine Projector Engineering, Broadcast Systems, Camden, N.J., received the BS in Mechanical Engineering from the University of Pittsburgh. In 1948 he joined the Equipment Development Section of RCA as a design and development engineer. In this position he worked on the development of various production equipments and helped to perfect an automatic voice coil lead cutting and tinning machine. In 1949 he moved to Broadcast Equipment Engineering and contributed to the development and design of various broadcast equipments including telecine projection equipment, audio and video tape recorders. Mr. Jackson was project engineer on the TP-7 Slide Projector, the RT-21 Tape Recorder, and the TP-66 Motion Picture Film Projector. In 1964, he became Leader of Audio and Telecine Projection Equipment Engineering. (The Audio Equipment responsibility which covered microphones, speakers, and tape recorder has since been transferred to Meadowlands.) Mr. Jackson continues responsibility for the telecine projection equipment engineering. In this capacity he is responsible for the specification and design of the entire line of S-8, 16-mm and 35-mm motion picture projectors, slide projectors, and multiplexers marketed by RCA for broadcast usage. Under his direction, this group pioneered Broadcast Systems' first application of solid-state machine control with the design and introduction of the TP-55 Optical Multiplexer. The lastest major group endeavor was the development and design of the TCP-1624 Automatic Film Cartridge Projector.

Louis D. Ciarrocchi, Mgr., Production Engineering, Communications Systems Division, Camden, New Jersey, graduated from Drexel University in 1937 with a diploma in electrical engineering. He served in the USAF from 1941 to 1946; his last assignment was Staff Ordnance and Armament Officer for the 9th Air Force. From 1946 to 1956 he was employed as a project engineer by the Baldwin Lima Hamilton Corporation responsible for Diesel-Electric and Electric Motive Power Controls. His latest design covered in-motion automatic switching of locomotive power from third-rail power to diesel electric power and back again to meet environmental pollution limitations in the New York City area. Prior to joining RCA in 1959, he was employed by Selas Corporation as Senior Design Engineer with responsibility for instrumentation and controls in heat treating and fluid processing systems. In his present assignment, in addition to production engineering support for Broadcast and Government Communications Systems Products, he has the responsibility for the direction of the Equipment Design, Development, and Tool Design Engineering Group.

Reprint RE-21-4-17
Final manuscript received September 26, 1975.

Qualified representatives from each group were encouraged to look for and point out potential problems in their area of specialization. All identified problems and suggestions were tabulated into an *Action List* (Fig. 2) by the Chief Engineer's staff member who was designated Co-Chairman of the meetings. This action list was published with scheduled resolution dates for each action item. Periodic monitoring and up-dating of the list was conducted by the Chief Engineer's staff. As items were resolved, the description of the action taken was incorporated in the list.

The action lists were distributed to all participants in the review after each updating, to inform everyone about tentative decisions reached; thus, timely appeals by review members were possible if their suggestions had been missed.

Such reviews assisted in establishing basic packaging concepts compatible with RCA state-of-the art capabilities in each production discipline. A typical example concerns the final design of the film projector's main structural frame which was greatly influenced by the equipment available for machining the reference and bank points; the adopted design eliminated a requirement for special locating tools for in-house and service use, when mounting major assemblies in the main frame. It was decided early that very close co-ordination would be required with fabrication and production engineering during the design to assure that practical methods could be developed for economical tooling and inspection.

Engineering model design reviews

The second phase of the producibility program involved the same groups and was conducted in the same manner as in the initial phase. However, the reviews were now concerned with the detailed implementation of the concepts, as represented on the drawings. The reviewers were now looking at preliminary manufacturing drawings for completeness of specifications, tolerances, inspection criteria, assembly methods, tooling concepts (Fig. 3), test access, vendor acceptability, and anything else that may affect their organization's interest. Insofar as possible, the suggestions from these reviews

	PROJECT	ACTION REQUIREMENTS	RESPONS	SCHEDULE/REMARKS
0	37E830	Review Mounting Plate Drawing	CEP	Ready for review - Done.
	38E907	Review Dimensioning and Wear on Magazine Disc (3487095)	DKL	Done per recommendations; Wear investigation not done. Review 11/15.
	39E907	Investigate with Purchasing costs of rolled edge on Magazine Disc	*DKL WAC	Awaiting Purchasing. Still waiting Purch. Review 12/1
	40E907	Investigate hot-stamped numbers vs decals on bin partitions	DKL	Model will be silk-screened. Will discuss with vendor. 12/1 review.
0	41E907	Check tolerance on indexing boss on partition	DKL	Tolerance changed to ±004. Changed per recommendations.
	42E907	Review material on cam follower	DKL	Under investigation. Stress analysis made. Review 12/1.
	43E907	Investigate wear characteristic of driving slots	DKL	Under investigation. Stress analysis made. Review 12/1.
0	44E907	Examine use of investment casting for partition	DKL	Decision to stay with plastic (metal requires finishing and wear problem with cartridge).
0	45E907	Evaluate use of rubber roller on detent arm	DKL	Changed detent to delrin
0	46E907	Review index plate dimensioning	DKL	Done per recommendations & continuing for further improvement
0	47E907	Drive motor should specify vertical operation	DKL	Will be done. Motor drawing not out.
0	48E907	Indexing flags to be redesigned to avoid accidental jam-up	DKL	Done
	49E907	Review magazine latch design	DKL	Latch redesigned. Review 12/1
	50E908	Investigate problems, if any, caused by power interrupt. during thread	BFF	Review 12/1.
	51E908	Calculate timing tolerance and accuracy of cam shaft	BFF	Review 12/1.
	52E908	Use of Star discs to hold cam shaft should be evaluated	BFF	Review model performance eval. for product design. Review 1/15/73
	53E908	Evaluate possibility of purchasing cam assembly complete	BFF	Review 1/15/73.
0	54E908	Eliminate 0° line on cams & provide [illegible]	BFF	Will be done.

* INDICATES PRIME RESPONSIBILITY SHEET 2 OF ___ DATE 10/16/72
0 THESE ITEMS WILL BE DROPPED ON FUTURE REPORTS. REVISED 11/1/72

Fig. 2 — Sample sheet — design review action list.

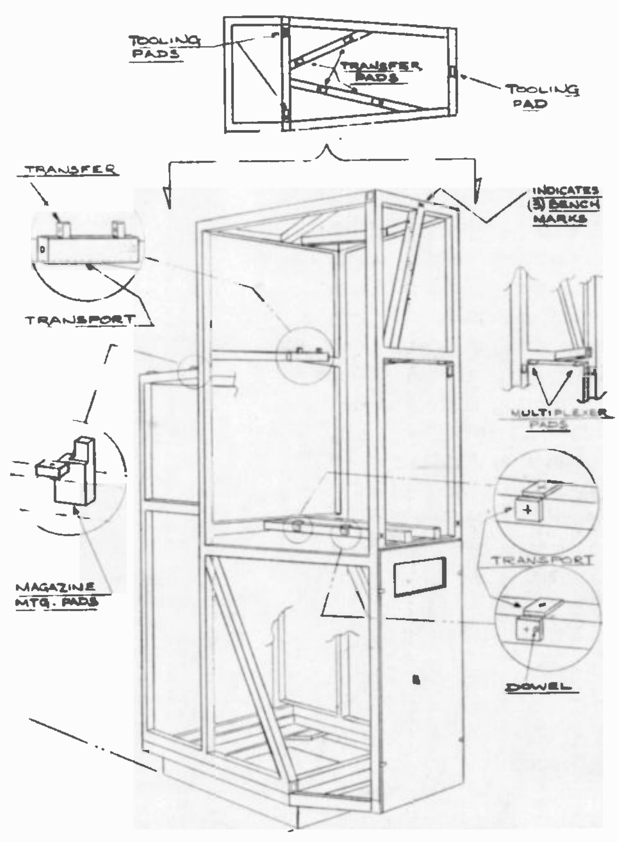


Fig. 3 — Main frame bank points.

were incorporated in the drawings prior to commitment for prototype parts fabrication.

Fabrication drawing reviews

The third phase of the producibility program involved the assignment of a production engineering specialist on a full-time basis to work with the design engineering team; all fabrication drawings were reveiwed to:

1) Assure that tolerance budgets were maintained.
2) Assure that tolerances were achievable.
3) Determine that the design was not overly complex for the function.
4) Establish a preliminary listing of "make or buy."
5) Establish preliminary listing of special tooling required for fabrication and/or inspection.

Evaluation of design and production engineering prototypes

The fourth, and probably the most unique phase of the producibility program involved the assembly and evaluation of two preproduction prototypes, one to be assembled by Design Engineering and the second assembled concurrently by Production Engineering using preliminary drawings. The units were to comply as closely as possible to the expected production design releases. Prerelease funding was also provided so that Manufacturing and Test Process Engineering could participate in the assembly and evaluation of the second model. The uniqueness of this program was not in the assembly of two prototypes, but in the timing, management, and evaluation of the second or Production Engineering unit. Previous practice was to fabricate two sets of parts, one set of which was assembled and tested by Design Engineering; the second set of parts was supplied to Assembly Process after production release and concurrent with the procurement of production parts.

For the TCP-1624 project, Production Engineering managed the assembly and evaluation of the second unit, concurrent with, but independent of the Product Design Engineering model and prior to release of drawings for production. This gave time for additional adjustments to be made on drawings prior to parts fabrication.

(TCP-1624) PRODUCTION ENGINEERING REVIEW

PE #26	REV.	DATE 1/18/74	TREE ASSEMBLY NO. 16	DWG. NO. E3448107
			DWG. TITLE: MAIN ASSEMBLY	

COMMENTS:	KEY	
1. Bumpers (Item 18) cannot be assembled into trim (Items 38, 29 & 40). Had to increase slot width in trim.	E	1/20/74
Engineering changed design Tool required #C125-AC-30	PE ME	COMPLETED 2/7/74
9. Oversize welds on frame are a problem at "Light Baffle" (Item 57) and could become a problem in the following areas: Bracket (Item 140 Mag-Catch) Support (Item 7 Transport) Multiplexer (A3) Plate Assy. 3488016.	PMI QC PE	1/20/74
Vendor states weld beads of 1/8" are feasible and will comply.	PMI	COMPLETED 2/7/74

KEY CODE:
E - Engineering 10-2 N/A - No Action
PMI QC - Quality Control TE - Test Engineering
PE - Production Eng. ME - Mfg. Engineering

Fig. 4 — Sample sheet — "P.E." report.

(TCP-1624) ASSEMBLY INSTRUCTIONS

PE # 59	REV.	DATE 6/19/75	TREE ASSEMBLY NO. 9, 10	DWG. NO. 3488073
			DWG. TITLE Cam Shaft Assembly	

COMMENTS: KEY

The following sequence was used for assembling subject parts for the pre-production model and, as such, is made a matter of record. (Temporary tooling used.) ME

A. Assemble on the Shaft (Item 2) the following:

1. Item 5
2. " 6
3. " 7
4. " 8
5. " 10
6. " 21
7. " 24 (do not tighten)

Using a tool (C125-AC-7) to locate parts & dim. 4.30 tighten bolts (Item 24)

B. Assemble the following:

1. Item 15
2. " 20
3. " 17
4. " 19
5. " 15
6. " 11
7. Item 9
8. " 21
9. " 14
10. " 18
11. " 13
12. " 4
13. " 23 (do not tighten)

Using a tool (C-125-AC-8) to locate parts & dim. 5.025 $^{+.010}_{-.0}$ tighten bolts (item 23)

C. Assemble remaining items locating item 3 to dim. 1.35 by using tool (C-125-AC-9)

KEY CODE:
E.-ENGINEERING 10-2 R - REVIEWED ER - ENG'RG 10-2, REVIEW
PMI QC - QUALITY CONTROL TE - TEST ENGINEERING
N/A - NO ACTION PE - PRODUCTION ENG. ME - MGG. ENGINEERING

Fig. 5 — Sample sheet — assembly instructions.

Production engineering function

Production Engineering responsibility during this phase resulted in the following actions to satisfy numerous production and engineering needs.

1) A Production Engineering Review Report was inititated on each subassembly, assembly and specification drawing. Each report was keyed for action by Design Engineering, Production Engineering, Test Engineering, Manufacturing Engineering, PMI and/or QC (Fig. 4). The reports were distributed after having been reviewed at periodic meetings between Design and Production Engineering and included Design Engineering's comments and recommended action. The reports covered Production Engineering's final check of part conformity to functional design, tolerance budget with respect to mating parts, critical part dimension tolerances that required special handling in PMI or QC, and special equipment or skills required for assembly and tooling design concepts. These actions were in addition to recommendations on possible revisions to simplify fabrication and/or assembly, to correct drawing errors and to delineate special instructions to assure repeatability of all units in meeting specifications. Over 70 review reports were issued, covering some 200 items.

2) A sequence of assembly instructions was furnished on each major assembly to assist Process Engineers who were now in a position to process the assembly with advance knowledge of actual performance (Fig. 5). There were seven major assemblies and over 160 sub-assemblies considered, as well as, over 100 miscellaneous parts less hardware.

3) The tooling concept was developed and a list of required tooling was prepared. Thus, tool design and fabrication proceeded simultaneously with assembly and test process. Also, special tooling required by PMI and QC inspection was developed.

4) A plan was initiated to code all purchased parts and/or subassemblies for inspection by PMI and/or QC. Critical dimensions that required 100% inspection, 10% inspection or 2% inspection were delineated; the code took into consideration the relative importance of the part or assembly to the total, as well as, the risk factors in assembly. This eliminated excessive and unnecessary inspection checks and substantially reduced the faulty parts uncovered during assembly on the production floor (Fig. 6).

5) Production Engineering support on the pre-production unit after assembly through Test Engineering and through the complete test cycle was continued. Production Engineering was responsible for making changes as recommended by Design Engineering for updating manufacturing data and to assure distribution of pertinent information to all interested activities.

Manufacturing engineering

Manufacturing Engineering was responsible for similar functions related to the electrical hardware required for assembly of their model. Manufacturing engineers assumed responsibility for the pre-production evaluation and/or fabrication of all the wiring of harnesses, nests, and pushbutton panels, and the assembly of logic boards. While electrical items, as standard practice, are reviewed with Manufacturing Engineering before release, considerably more attention resulted in this case due to the assembly of the pre-production unit. In most cases, the effort was coordinated by and run in parallel with the efforts cited above by Production Engineering.

Test Process had the responsibility for debugging and evaluating the prototype assembled by Production Engineering, concurrent with developing and checking out preliminary test procedures.

Fig. 6 — Sample — inspection coding system.

Inspection coding system TCP-1624 cartridge film projector: Production Engineering will furnish to **PMI** and **QC** a material list and assembly drawings appropriately coded. The code takes into consideration the relative importance of the part or assembly to the total, as well as the risk factors in assembly in order to avoid excessive and unnecessary inspection checks.

All parts and/or assemblies will be divided into three categories: **A**, **B**, or **C**, each of which will be prefixed by **P** for **PMI** or **Q** for **QC** to denote area of responsibility.

PA —100% inspection of critical areas
10% overall

PB — 10% inspection of critical areas
1% overall

PC — 2% overall and at vendor change

QA —100% functional check
10% workmanship

QB — 10% functional check
10% workmanship

QC — 2% functional check
2% workmanship

Any discrepant material accepted as is (**MRB**) by Design Engineering is to be reviewed by Production Engineering to determine impact on tooling and assembly methods.

Final producibility phase

The final phase of the producibility program involved all disciplines with primary support from Production Engineering in the subassembly stages. Production Engineering effort during this period was primarily directed toward instruction and coordination to provide assurance that fabrication and assembly methods developed during the pre-production phase were implemented. Production Engineering also provided instructions to factory personnel in the sequence of assembly and processing; in the development and use of tooling; and in the proper settings and adjustments in accordance with engineering specifications.

As the production sub-systems reached the testing stage, increasing involvement was required by Design Engineering. At the systems level checkout, Production Engineering was used on a consulting basis only.

Complexities of the program were such, that when the systems debugging and testing phase was reached, a program manager was appointed to expedite problem solving in a tightly co-ordinated manner—for completion of the final step in the production cycle of the first 12 units.

Producibility benefits

The benefits derived from the producibility program include: 1) a design compatible with the Production department's policies and capabilities; and 2) an early familiarity developed by key Production personnel with the functional requirements and design goals of the TCP-1624 film projector project.

The advantages and effectiveness of the more unique parts of the program, such as Production Engineering assembly of the pre-production model, may not be so obvious. Many variables and intangibles are introduced in any attempt to measure effectiveness of this type of activity. For example, the reject rate of purchased parts that were returned to vendors or reworked and *billed back* to the vendor approached 70%. With normal statistical inspection in PMI, the number of reject parts with uncollectable labor charges added to rework costs would have been appreciable.

There were savings as a result of incorporating simplified assembly techniques in the basic design before its release.

There were savings and secondary benefits to the Production department and Product Management in the knowledge that the majority of uncertainties in manufacturing had a thorough preliminary review of the product and that the factory (with some assurance) could now consistently build units meeting engineering specification.

There were the advantages that accrued which permitted Design Engineering to concentrate on the technical aspects of product performance speifications, life and reliability.

Conclusion

None of these savings, nor the advantages, would have been possible without the total cooperation of all the concerned activities working as an integrated unit. Specific individuals were assigned to the

The TCP-1624 and how it operates

TCP-1624 cartridge concept

Closeup of TCP-1624 upper section.

The cartridge loading concept has been well established for achieving rapid and convenient handling of tape media in tv station applications. For the TCP-1624 system, this concept has been applied to film; a compatible 16-mm reel enclosed in a plastic case has been designed specifically for the tv broadcast application. The new reel is compatible with currently used 16-mm reels and thus can be loaded on existing 16-mm reel-to-reel projectors, in addition, the film loaded reel can be quickly placed in the cartridge case without using tools; once loaded in the case, no further physical contact is required for the usage life of the film.

Reel capacity is 75 feet of 16-mm film; or, in other words, two minutes plus leader and trailer at a 25-frame projection rate. A preformed Mylar stiff leader, approximately 13.5 inches long, is attached to the film for automatic threading in the projector. The Mylar leader, as an outside wrap-around of the cartridge film, adds further protection to keep dirt from reaching the film. The stiff leader does not preclude threading the film on a reel-to-reel machine, since the width is the same as the 16-mm perforated film; and, the leader is sufficiently flexible that it will wind on a take-up reel quite readily.

Reel in open case.

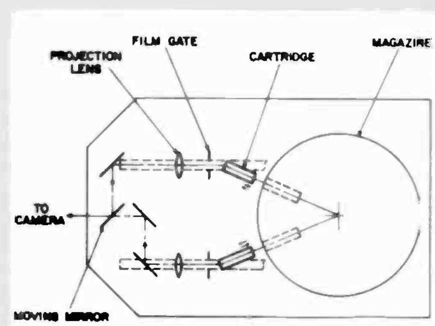
The reel is designed for a maximum film-program load of two minutes, but it can contain any length of film down to one frame of program material. However, the reel was designed for an anticipated minimum of 10 seconds of program materials, slightly more than the maximum recycle time when a two-minute cartridge is used. Thus, with program segments ranging from 10 seconds to two minutes in duration, it is possible to intermix programs in any desired manner and still provide continuous picture output from the automatic projector.

Cartridge loading projector

Film cartridges are loaded in a circular magazine having a capacity of 24 cartridges. The magazine (removable from the projector) is convenient to load either on or off the machine. The projector is a

Magazine onto projector.

two-channel machine with internal optical multiplexing, to combine the optical outputs into a single telecine-island multiplexer input. The dual-transport design provides continuous picture output from the projector with sequential playback of cartridges, as loaded in the magazine. The projector design provides easy access to cartridges in the magazine for rapid last minute changes, except for the two cartridges that are in the playing stations



Plan view, projector mechanical schematic.

within the projector housing. Any intermix of program material between 10 seconds and 2 minutes is possible while retaining continuous picture capability.

The sequence of events in the operation of the automatic projector is as follows:

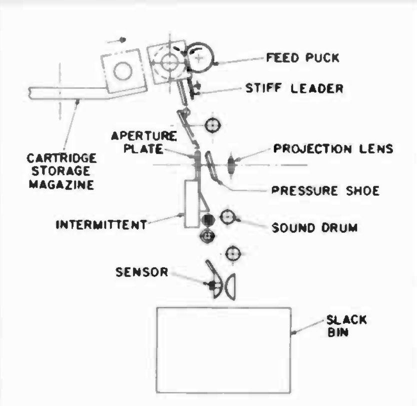
1) The cartridge is transferred from the magazine to its play-back station where

task, and the support of top management in both engineering and manufacturing was complete.

Although the decision for Design and Production Engineering to assemble a prototype unit independently had considerable merit, a review at this stage indicates the possibility of additional benefits. There should be closer coordination between the two groups during the step-by-step assembly to review each major sub-assembly functionally. This would be less time-consuming in trouble shooting than would be the case later in system evaluation.

Time should also be made available earlier in the schedule to design and construct production tooling during the prototype assembly phase. This method would provide a trial for actual production tooling on the prototype assemblies and permit complete review of tooling methods with Design and Production Engineering, prior to release of the shop order for construction.

We believe that a more reliable and producible equipment was achieved, at less expense, by following the program described in this paper.

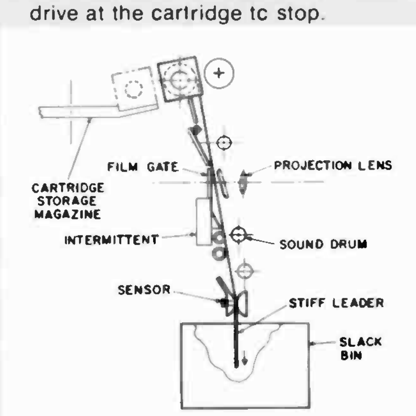


a — Down movement of stiff leader.

a motor-driven puck moves the stiff leader vertically downward into and through the film-transport loading path.

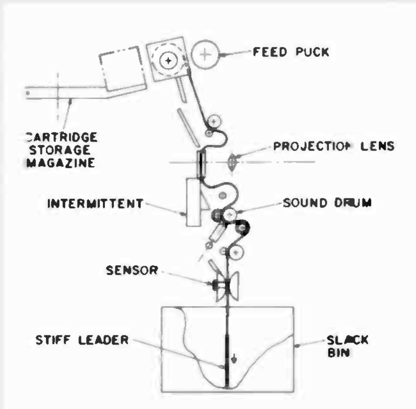
2) The path for loading films through the transport is an open, unimpeded chute with strategically placed guides to channel the stiff leader through the projector and into a slack bin at the bottom of the machine.

3) The slack bin serves as a receptacle to collect film as it leaves the transport during playback. A proximity sensor detects the presence of the leader when it enters the slack bin and causes the film drive at the cartridge to stop.



b — Film feed; sensor detects stiff leader.

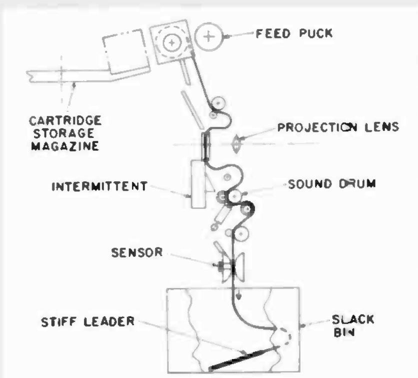
4) The sensor also initiates the film-threading cycle which starts at the lower sound sprocket and establishes the film-running path progressively back toward the cartridge.



c — Sensor starts film-threading cycle

5) The film is then run at normal projection speed to a cue mark which stops it with the first "on air" frame in the gate.

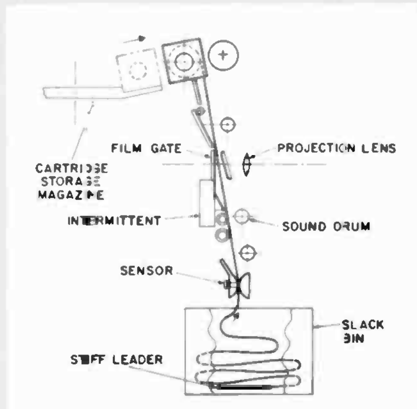
6) The film is now ready for on-air playback on command. The same loading action occurs on the second transport with film cartridge #2.



d — Normal projection and cue stop.

7) At the conclusion of the initial loading, both transports are brought to a film cued, ready state. After cartridge #1 has played back, cartridge #2 is available for continuing picture output and the automatic cartridge change cycle for cartridge #1 is initiated.

8) The film path first opens to the load state and then the film is rewound at high speed. When rewinding is completed, the cartridge is transferred back to its location in the magazine and cartridge

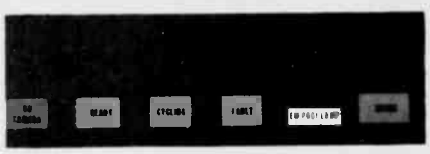


e — Unthread and high-speed rewind.

#3 is transferred to the playback station, threaded, and cued to be ready for the next play-back command. The maximum time required for the cycle from detection of the end-message cue on cartridge #1 to the cued and ready condition for cartridge #3 is less than 10 seconds.

Automatic selection

As the film is running at normal speed to the cued first-frame position, the presence of the magnetic sound track is sensed and the magnetic sound play-back channel is automatically selected. If a magnetic track is not detected, the sound channel remains in the optical play-back mode. Both the sound exciter and the optical projection lamps have standby lamps as back-up with automatic changeover mechanisms to shift them into service whenever the primary lamps fail. This changeover is displayed on the status readout panel of the projector to remind maintenance personnel that the primary lamp has failed.


f — Status indicator.

Consumer product design

P.C. Olsen | E.W. Curtis

Consumer product design is a science and an art. Science helps us meet the performance, reliability, manufacturability, innovation, and safety requirements. The art involves compromising these requirements as little as possible in filling the customer's needs while squeezing the best cost and profit from the effort. The ultimate judges of this marriage of art and science are the customers by their purchases and the stockholders by their profit.

PRODUCT DESIGN in an established line (such as color television) is a continuous process with each new design being a different solution to the basic ground rules outlined above. Many new product developments result from actions or desires of the consumer — product costs too high for the needs filled, a new look or style in furnishing, a desire for a feature which is not presently available, a desire for a known competitor's feature which is not available in current product, a desire for smaller size or increased portability, or a reduction in available income with which to purchase the present product. All of these and many other factors can result in the consumer communicating with Marketing and Product Planning and the Corporation through sales, profits, and market research. These inputs are used by Marketing and Product Planning to develop a new product specification — a new technology to reduce cost or increase reliability, a new feature to meet an unfulfilled need (or the competition), and a totally new design with which to enter a heretofore unpenetrated or new market. Once the need has been established for a new design for next year, an entire set of questions must be answered:

- What will it look like?
- What size?
- What features?
- What cost trade-offs can be made versus performance?
- What type of picture tube?
- What safety and reliability improvements can be made?

Developing design parameters —the system approach

Even this partial list of questions shows that there must be a great deal of communication and coordination among many different RCA groups. The key objective is to make use of all of the Corporation's technical and managerial expertise to answer these questions and put together the very best and most cost effective receiver in the marketplace.

Many of the questions mentioned earlier start getting answered almost immediately. The product planners know what happened in the marketplace in the previous year so they can talk about what they think is required to meet or surpass the competition in the coming year (retail price, tube sizes, features, etc.). The styling group also has had another year's exposure to the marketplace. Couple this with some new ideas of their own and we have the beginning of RCA's new look for next year (finishes, form, cabinet style, etc.).

Quality, Reliability, and Purchaser's Satisfaction groups can look at the performance information from last year's product and provide inputs for required redesign to improve reliability and reduce warranty cost. Field data on systems can be used to pinpoint areas that have shown less than desired reliability or more than desired warranty cost.

The Product Safety Group can provide information on areas where redesign will improve the safety of the product.

Manufacturing can determine those areas which have been difficult to manufacture, thus providing inputs on areas where redesign can improve the cost effectiveness (repackaging of certain areas for ease of assembly, redesign of a circuit for easier alignment, etc.).

Purchasing can determine those areas where redesign might be required (excessively high cost on parts or low yields, etc.).

All of these groups interact with each other simultaneously and with Cost Estimating so that financial estimates of the various options can be made. With this information, Product Planning, Marketing, and Engineering can decide on the design parameters. Thus, the determination of the design parameters is made by a systems approach involving all related functions.

Development of the product —the most critical step

Guided by these decisions, the Design Engineering Department starts developing a prototype chassis. As this basic chassis begins to take shape, the initial layout of the major components starts and is reviewed and revised until something compatible with safety, manufacturing, serviceability, cost, and the original design parameters is reached.

The initial prototype is fundamentally a packaging consideration. Here is where chassis position (horizontal, vertical), size, and function (stationary, swing-out) are considered. In addition, the size of the board(s) is established. As the electrical requirements are being determined, the Solid State Division and other outside vendors are working with the designers on specifications. It is *important* to know what features are required early in the design because basic changes made later cost money, produce delays in schedules, and cause compromises in the layout of the instrument which in turn cause manufacturing problems that can completely invalidate previous cost estimates.

This fundamental step is the most important in the whole design cycle. This is the point where everyone's ideas and experiences can make the biggest impact on the new design.

Once this basic system is accepted, al! sections of the Consumer Electronics Division start getting involved. Initial drawings are made and schedules developed that include: model shop, engineering prototypes, design reviews, factory pilot runs, factory review meetings, safety review meetings, reliability, U/L and CSA reviews, preproduction and finally production runs. Close communications with the purchasing group is vital so that the right parts are available at the required time.

Development schedule — change is a way of life

The development schedule normally

Reprint RE-21-4-18
Final manuscript received August 29, 1975.

covers 18 to 24 months on a totally new design, and usually consists of three to four engineering builds, each of which successively refine the design. During each build. data from the previous build is used to correct deficiencies (performance, cost, safety, reliability or manufacturability). Design modifications are made, samples constructed, tested, and reviewed. Competitive analysis is performed. How well does this new design stack up against other RCA receivers and the competition? Cost estimates are refined, performance is reviewed.

At this stage of the development, the latest design is never in the engineering model; it is always on the engineers bench. An analysis is made based on the best available data. After analysis, the problems are listed and the engineers go back to the bench and prepare for the next engineering build. This same series of events happens for each engineering build. The build, the review, the changes are all a way of life during a new design. As the final product design is approached, the detailed nature of the reviews increases, the magnitude of the assignments and responsibilities of each group become more clearly defined, and the review committees grow.

At the completion of the fourth build and review, the final changes are made and the drawings are signed off. An engineering pilot run is made to officially prove the validity of signed-off drawings. The receivers from the engineering-pilot-run build are distributed to the various groups throughout the division that have a need at this point. For example, engineering pilot run sets are used for Technical Publications, U/L samples, CSA samples, factory (FCC and CSA tests) wiring samples, safety, reliability, life test, cost accounting, RCA Laboratories, Solid State Division, Picture Tube Division, and all design groups.

Throughout this entire process, the design is constantly being changed to make the set more saleable by improving performance and reducing costs as well as making the set easier to build and simplier to repair. Feedback from all groups that received the sets is continuous, and design changes are made as required.

Manufacturing the product —build, ship, and start over

At this point a factory pilot run is built to provide an opportunity for the factory to check the drawings, develop and prove out a process, and construct test fixtures for production. During the entire design process, two separate groups design and build test fixtures. The design group designs fixtures for Quality, PMI, and Engineering tests with emphasis on exhaustive testing. Manufacturing designs fixtures for actual production line testing. A sufficient number of instruments are produced to verify each vendor's capability of supplying production quantities of components.

A tooled cabinet is normally used for the first time; thus special attention is given to insure that all parts fit and all performance specifications are met. One-thousand-hour life tests are also made.

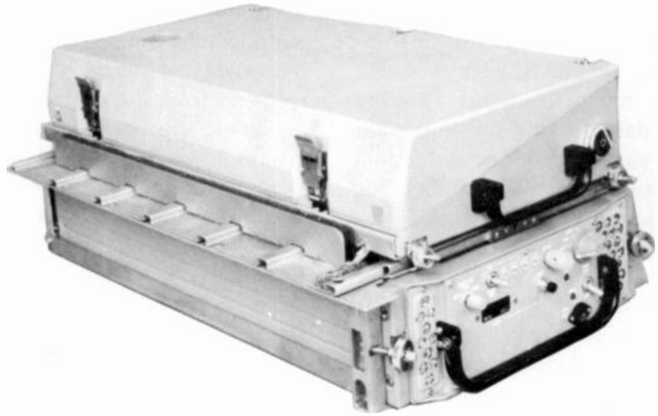
Satisfactory completion and review of the factory pilot run is the preliminary step to the preproduction run after the required design modifications are made. "A" (Appearance), "E" (Engineering), and "M" (Manufacturing) approved parts must be used in this build since these sets can be sold in the marketplace. These preproduction instruments are sent to field service personnel and RCA distributors for their comments. Once more, the instruments are reviewed and appropriate changes are made as required.

It is interesting to note the number of different groups that review the instruments, each with their own special interest and expertise, each trying to insure that we have the best possible product. Sometimes the requirements of these different groups overlap and conflict; then compromises must be made. Once all regulatory agency and internal corporate approvals have been obtained, a PSS (Product Safety Start) is signed releasing the product for production. When production starts, plant inspections are held by regulatory agencies. CAL (Consumer Acceptance Lab) tests are made and quality data is reviewed. When all data is approved a PSR (Product Safety Release) is signed allowing shipment of product.

When the product has been manufactured and distributed, the customer, by his actions in purchase of the product immediately begins to provide new inputs to Marketing and Product Planning from which new product development specifications result. RSVP (Reliability Serviceability Verification Program) field warranty data begins to come in which allows problem areas to be determined and warranty costs assessed. A new set of design requirements are determined and the product development cycle begins again.

Edward W. Curtis, Sr. Engineer, Television Product Design Engineering, Consumer Electronics Division, Indianapolis, Ind., received the BSEE from the University of Illinois in 1964. Upon joining RCA after graduation, he spent time doing circuit design in chroma processing and deflection on an advanced receiver. In 1965 Mr. Curtis began circuit design on color television product in chroma, video, IF, and deflection. Since 1965 he has worked on the circuit design, instrumentation, factory and field follow up on some 22 different chassis lines, 18 of which were produced and sold, including the first all solid state color chassis introduced by RCA. At the present time, Mr. Curtis is the project engineer on the CTC-81 console instruments. He is a member of Phi Eta Sigma and Eta Kappa Nu and the holder of four patents relating to chroma and video.

Perry C. Olsen, Member, Engineering Staff, TV Product Design Engineering, Consumer Electronics, Indianapolis, Ind., received the BSEE from the University of Illinois in 1962 and the MSEE from Purdue University in 1972. Mr. Olsen joined RCA's training program in 1962. In 1963 he started working in the Consumer Electronic Division, TV Design Group, Tuner Department and helped develop the first solid state tuner, and was responsible for the development of the first commercial printed circuit tuner for RCA. In 1969 he was transferred to the chassis design and development group and is presently the project engineer on the CTC-74 chassis which will be used in both the table model and portable instruments now going into production. Mr. Olsen is a registered professional engineer in Indiana and has three issued patents.



AN/USH-17 recorder/reproducer —a successful product design

P.F. Muraco | R.E. Jansen

The primary challenge for the AN/USH-17* product design team was to build a recorder that would be easily adaptable for an entire range of airborne recorder applications. The functional modularity concept was developed to meet that challenge and, further, to provide the customer with a high performance recorder that offered a very high system availability factor.

THE AN/USH-17(V) is a high-performance, dual-channel wideband airborne video recorder/reproducer capable of withstanding severe environmental exposures. The AN/USH-17(V) consists of two wideband (6-MHz) channels and two narrowband auxiliary channels. The information recorded is:

1) One channel of airborne ground mapping radar, including video and radar azimuth and timing information;
2) One 6-MHz-bandwidth channel of electro-optical sensor data (tv formatted);
3) One voice channel for aircraft interior or vhf communications; and
4) One channel of digital data from the navigator and fire-control computer.

The AN/USH-17(V) was developed specifically for the Navy's A-6C and A-6E family of carrier-based attack aircraft. The primary mission is to record in-flight radar, FLIR (forward-looking infrared) and LLTV (low-light-level television) optical sensors.

Reprint RE-21-4-19
Final manuscript received September 22, 1975.

*The basic USH-17 was developed for the Naval Air Systems Command under the technical direction of the U.S. Naval Air Development Center.

Product development

Early in the development of the AN/USH-17 recorder, joint meetings were held with Marketing, Design Engineering, and Production Engineering to define a recorder concept that could eventually be the nucleus of a family of recorders for all Airborne Recorder Applications. Marketing was given the responsibility to make this product known and to survey the industry to identify potential customers, design needs, and cost goals that would keep the product in demand. A product report was generated and sent to all potential customers with known or suspected needs for the new product. In addition, as hardware became available, Marketing, working with Engineering and Management, organized and held demonstrations on the East and West Coasts so that the claims in the product report could be substantiated.

At the same time, the Recording Systems Marketing Staff was reinforced so that the needed exposure to all potential customers could be accomplished.

Design goals

The AN/USH-17 was designed with three major goals in mind: high performance, high reliability, and high maintainability.

In addition, this program was treated by RCA as an opportunity to show that a video recorder could be designed that field personnel could satisfactorily utilize, maintain, and keep operational with a high system *availability* factor.

Availability is determined by both reliability and maintainability. It is the ratio of MTBF to the sum of MTBF and MTTR. [MTBF is mean time between failures; MTTR is mean time to repair.] This is the percent of total time that the system is "up", or available for use.

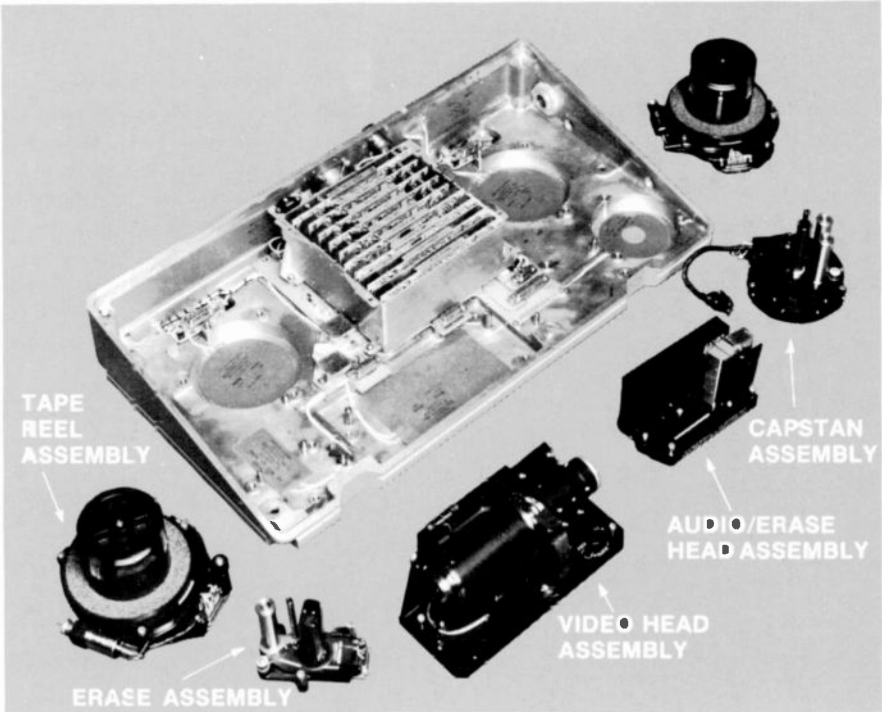
Magnetic recording equipments have historically had poor track records when it comes to maintenance and repair. Typically, the repair times are in the hours. The coupling of functions and extensive use of electromechanical systems has generated a real nightmare in the repair shop.

Functional modularity

To attack this problem, the functional modularity concept was adopted by RCA as the *key* element in the design philosophy for the AN/USH-17. Each module performs a function: complete decoupling of all subsystems is accomplished. All functional modules are easily accessed, allowing for quick and simple maintenance actions. MTTR drops to minutes, pushing the system availability to 99+%.

Product versatility

Product versatility is a natural fallout of the functional modularity design concept. During the design phase, attention was focused on the extent to which the modularity concept should be carried to provide the maximum flexibility in design of future recording systems. System functions (such as headwheel servo, capstan servo, fm processing, etc.)



Richard Jansen, Mgr., Recording Systems, Government Communications Systems Division, Camden, N.J. received the BSME from Purdue University in 1950 and joined RCA as a trainee. He was permanently assigned to the Government Sound Section of DEP, in Camden, as a Mechanical Design Engineer. In this capacity, he worked on the various electrical and acoustical elements in the Air Force Communications System AN/AIC-10. He also had production design responsibility for these items. In 1959, he joined the newly developed Recording Systems Activity within the Surface Communications Division and soon became a Leader for the Mechanical Design Group with the responsibility for several space qualified complex recording systems. He subsequently became a Project Leader for space recorders on ERTS and Skylab. In 1971, he was promoted to Manager of Recording Systems Production programs and is currently responsible for the AN/USH-17, ADVISER, and TPR-10 Recorder/Reproducer.

Paul Muraco, Ldr., Recording Systems, Government Communications Systems Division, Camden, N.J., received the BSEE in 1966 from Ohio University. He attended the University of Pennsylvania where he completed course requirements for the MSEE in 1970. Following graduation, he was employed by RCA on the training program. On completion of this program, he joined the Recording Equipment Operations Engineering Staff as a design engineer. In 1970 and 1971, Mr. Muraco was assigned as Project Engineer for the final design, testing and field support of the AN/USH-17 Airborne Recorder/Reproducer system for the Navy A6 aircraft. In 1972, he was promoted to Engineering Leader and is responsible for the ADVISER family of Video Recorder/Reproducers. He is currently responsible for the ADVISER Production Recorder, the TPR-10 Portable Color Recorder/Reproducer, and actively supporting the AN/USH-17(V) production program. He is a member of the IEEE, Tau Beta Pi, and Eta Kappa Nu.

Authors Jansen (left) and Muraco.

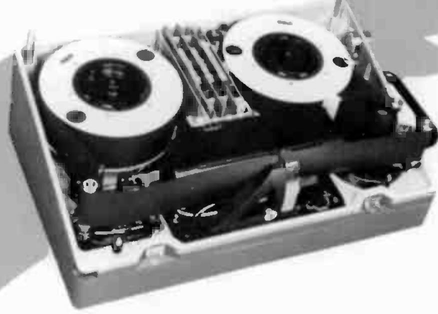
were configured such that they could be utilized with many different recording applications. Many configurations have been produced utilizing functional modules as building blocks. In addition, Marketing inputs indicated a need for short delivery cycles (4 to 6 months) and low cost. This required an ongoing inventory of these "building blocks". This need was approved by Management and a module inventory was implemented simultaneously with the first production order of AN/USH-17 Recorder/Reproducers.

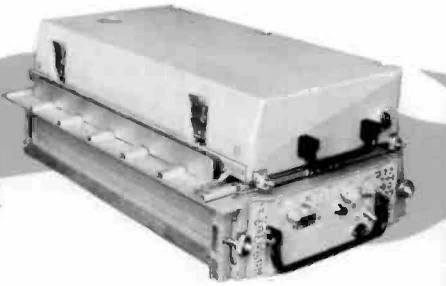
Recording equipments stressing cost, performance, size, extended bandwidths, and extended record time, have been developed to fill out a whole family of recording systems. RCA recording capabilities have reached out to address a large spectrum of applications. A few of these products are described in the accompanying illustration.

Product success—sales

To date, RCA has booked in excess of $20 million in sales on the AN/USH-17, ADVISER, TPR-10, and STAR Recording Systems. The equipments have had an outstanding record of success and have been well accepted by the users.

product versatility

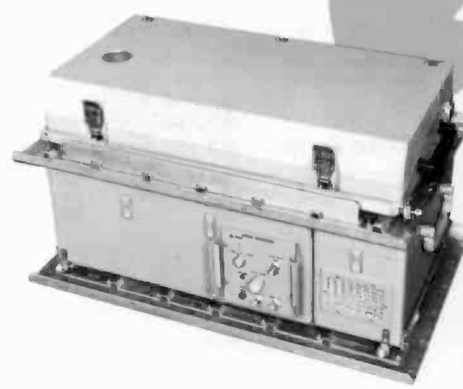




AN/USH-17

STAR I

The STAR is a single-channel record-only version of the USH-17 developed by RCA as a small low cost video tape recorder. The unit consists of a single package containing all the necessary electronics to record a single video channel. A small power supply is also required. The unit contains all the same electromechanical and printed-circuit modules used in the USH-17. Reproduce is performed by playing back STAR tapes on a compatible reproducer or by connecting the STAR to a small, portable playback unit. Again the highest degree of commonality with the USH-17 is maintained.



ADVISER 152

A further extension of the ADVISER concept is the 15-MHz ADVISER recorder/reproducer. RCA, under contract to the USAF, has expanded the video bandwidth of the two-channel ADVISER to 15-MHz/channel. The recorder-reproducer is a basic ADVISER VTR and therefore has the highest possible degree of commonality with the USH-17(V) system. With this bandwidth extension, the ADVISER family of VTR's will address a wide range of recording requirements using a common logistics support base.

STAR II

This video tape recorder provides single-channel recording capability and is identical to STAR I, except that an airborne playback capability is added.

OVTR

The Operational Video Tape Recorder has been developed by RCA, under contract to the U.S. Air Force, to be a small low cost military qualified Airborne Recorder. The OVTR is earmarked for the F-4, A-7, and F111 aircrafts. The OVTR has a single video channel and two auxiliary channels. The video channel will accept any video formated signal with horizontal scan rates from 511 to 1023 lines per frame. Recorded tapes will be played back on a Ground System which will include tv monitoring and stop-action/slow-motion capabilities.

Looking ahead

Based on the confidence in the AN/USH-17 potential and solid marketing inputs, RCA is continuing to inventory standard modules with the ongoing production of AN/USH-17 Recorder/Reproducers. The availability of these building blocks insures reasonable delivery cycles and a lower cost product.

New systems become a simple exercise in systems engineering, utilizing function modules to develop recording systems to meet a variety of customer needs and applications.

The newest members of the recorder family are the VERSABIT high density digital recorder/reproducers and the OVTR analog airborne recorder.

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1. Muraco, P.F., "Basic, highly maintainable airborne video tape recorder/reproducer", RCA Reprint RE-20-3-3; *RCA Engineer*, Vol. 20, No. 3 (Oct/Nov 1974)

2) Griffin, J.S., "Recent Advances in Wideband Recording Systems", RCA Reprint RE-19-4-16, *RCA Engineer*, Vol. 19, No. 4, Dec 1973 - Jan 1974).

ADVISER 62

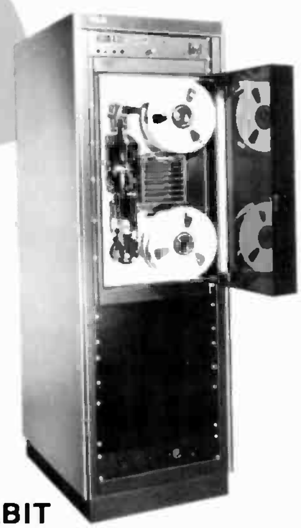
One extension of the USH-17 recorder/reproducer is called the ADVISER 62 which was developed for the U.S. Air Force. The ADVISER 62's are used in an airborne data collection and analysis system. This unit required repackaging of the basic USH-17 electronics unit to provide a servoed headwheel for improved timebase stability. It consists of two wide-band 6-MHz channels and two auxiliary channels. The power supply is a plug-in unit. Various power supply options are available with the ADVISER for use with three-phase 400-Hz, single-phase 400-Hz, single-phase 60-Hz, or 28 Vdc. The complete ADVISER Transport Unit and 90% of the printed-circuit cards used in the electronics unit are identical to those used in the USH-17 system. Complete interchangeability and commonality are preserved.

TPR-10

The TPR-10 (NTSC, PAL or SECAM) commercial recorder is a compact, portable VTR built for the production of studio-quality video tapes on location, where conventional recorders cannot reach. The TPR-10 is a complete recorder/reproducer with full-track erase, dual audio-recording channels (program and cue), monochrome or heterodyne color playback, and a system of self-generated test signals (self-test) for a complete record-playback confidence check.

ADVISER Extended Record Time

This extension of the basic ADVISER concept provides double the record time.



VERSABIT

This is a new RCA product line of high density digital recorder. VERSABIT incorporates transverse scan recording techniques. This provides a simple means for high rate, serial recording at very high packing densities. A conservative linear packing density of 10,000 bits per inch yields 24 million bits per foot of tape. VERSABIT can be purchased with many levels of options including data channel only, limited speed range, two channel (40 Mb/s), full remote control, dual auxiliary channels, 40:1 continuous speed range, and 10^{-8} BER.

Engineering and Research Notes

A device for printing thick-films onto substrates that have microminiature devices attached

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A thick-film hybrid microcircuit usually comprises thick films of conductive and resistive materials deposited on a substrate and various microminiature components attached to the films. Some of these components are active devices such as beam-lead transistors and diodes; others are passive devices such as monolithic capacitors, resistors, and inductors. If the passive devices are attached to the substrate films by reflowing screen-printed solder paste, subsequent thermocompression bonding of beam lead or equivalent devices to the substrate films often causes the solder to reflow again and release the passive devices. In addition, if the passive component density is high, it is often difficult to move the thermocompression bonding tool properly on the substrate. When the number of passive components is large, the density is usually such that the tool cannot reach active component bonding pads between them. Attachment of those active devices which require thermocompression bonding prior to screen printing and reflowing of the solder paste alleviates the problem of solder reflow during the thermocompression bonding operation.

Screen printing the solder paste with state-of-the-art flat faced masks would damage the previously attached devices. This problem is eliminated by the metal mask and screen assembly shown in Fig. 1. The figure shows a cross-sectional view of an assembly of a metal mask (10) attached to a screen (12). The metal mask has a blind cavity (14) designed to fit over and shield a beam-lead device (16) mounted on the substrate (18).

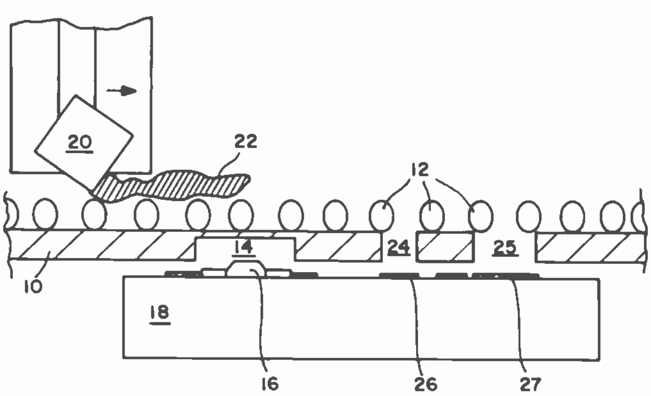

Fig. 1 — Metal mask and screen assembly.

As the usual squeegee (20) moves across the screen (12), solder paste (22) is pushed down through the screen into the apertures (24 and 25). At the same time, the assembly is deflected and the solder paste is deposited onto the lands (26 and 27) on the substrate (18). Although the solder paste is deposited after the device has been thermocompression bonded, the blind cavity in the mask protects the device from damage.

An equivalent blind cavity may be formed by closing an open cavity in the metal mask with an emulsion placed in the interstices of the screen.

Reprint RE-21-4-13| Final manuscript received September 17, 1974.

Sinewave clocking of CCDs at high frequencies

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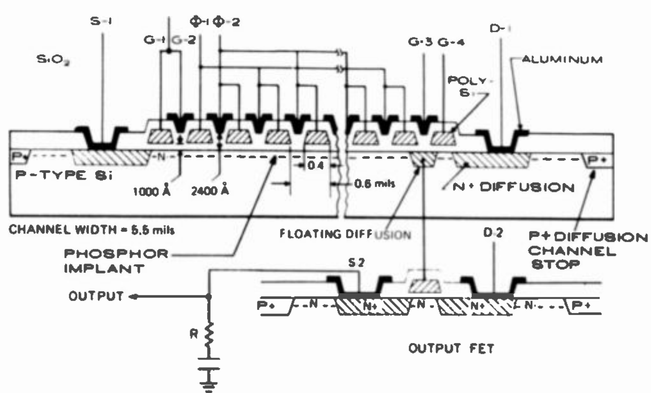

Fig. 1 — 128-stage two-phase buried-channel charge-coupled shift register (CCD-5).

Shown in Fig. 1 is an illustration of a two-phase buried-channel charge-coupled device (CCD-5). The operation of this type of device as an analog shift register has been described by W.F. Kosonocky,[1] and by

J.E. Carnes and W.F. Kosonocky.[2] Several of these buried-channel CCDs were obtained from W.F. Kosonocky of RCA Laboratories to investigate the charge-transfer characteristics of the device at high frequencies. From the investigation it was found that CCD-5 could be operated at frequencies up to 50 MHz for sinewave clocking and up to 31 MHz for squarewave clocking. At several frequencies between 1 and 50 MHz, estimates of the transfer loss were obtained, and these are plotted in Fig. 2. These data were obtained when the input signal was 64 consecutive "zeros" followed by 1, 0, 1, 0, *etc.* for 16 consecutive clock cycles. At each clocking frequency, the estimate of transfer loss was obtained from the relation

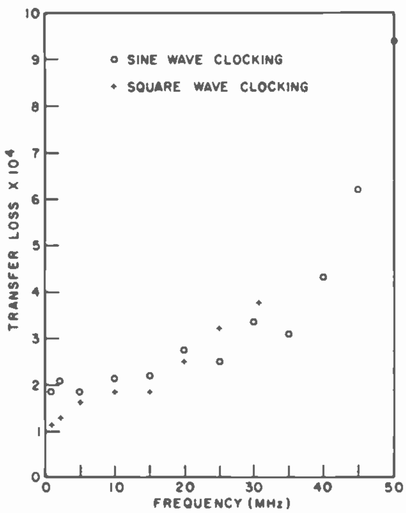

Fig. 2 — Transfer loss vs. frequency.

$$n\epsilon = A_0/(A_1 + A_0)$$

where ϵ is the transfer loss per transfer, n is the number of transfers (two times the number of stages for a two-phase device), A_1 is the amplitude of the output for the first "1" of a sequence, and A_0 is the amplitude of the output for a "0" that immediately follows a "1". The results obtained when using sinusoidal clocks are illustrated in Figs. 3 and 4. In Fig. 3, the upper trace is the output of CCD-5 for sinewave clocking at a frequency of 30 MHz. The lower trace of Fig. 3 is the $\phi - 1$ clock appropriately delayed so that the two traces are essentially 180° out of phase for the "zeros" of the CCD-5 output. In Fig. 4, the two traces of Fig. 3 have been added on a more sensitive voltage scale. Several advantages that result from the use of sinewave clocks are: clock feedthrough noise is significantly reduced; sinusoidal waveforms are simpler to generate and amplify; power required of the clock drivers can be reduced significantly by tuning the clock input circuits; the 180° phase difference between the phase clocks is not critical.

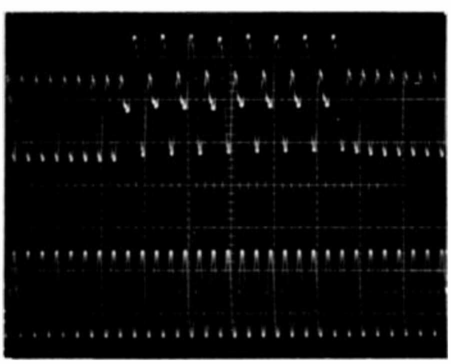
Fig. 3 — Output and delayed phase-1 clock. Upper trace: output of CCD-5 for sinewave clocks at 30 MHz (Input: sixty-four "0s", "1", "0", "1", "0", etc.) Lower trace: phase-1 clock with appropriate delay.

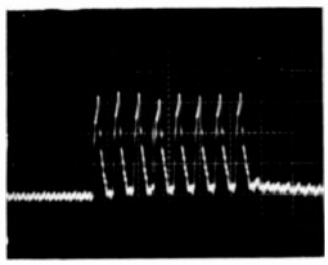
Fig. 4 — Traces of Fig. 3 added on more sensitive scale.

References

1. Kosonocky, W.F.; "Charge-coupled devices — an overview," Presented at 1974 WESCON, Technical Session No. 2, Los Angeles, CA (Sept. 10-13, 1974).
2. Carnes, J.E., and Kosonocky, W.F.; "Charge-coupled devices and applications", *RCA Engineer*, Vol. 18, No. 5, (Feb.-Mar., 1973).

Reprint RE-21-4-13| Final manuscript received June 16, 1975.

Glass passivation of semiconductor devices

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In the fabrication of semiconductor devices, the surfaces of the semiconductor bodies are commonly covered with various lead borosilicate glasses for the purpose of "passivating" the surfaces.

It has been found, however, that the presence of the lead in the passivating layer can give rise to certain problems. For example, for the purpose of nickel plating certain regions of the surfaces of the semiconductor bodies (for the purpose of applying layers of solder thereto), openings are etched through the glass passivating layer, and the semiconductor body is dipped in a solution containing, among others, hydrofluoric acid for the purpose of "sensitizing" the exposed surface portions to a subsequent electroless nickel plating process. The hydrofluoric acid component of the sensitizing solution, however, tends to interact with the lead in the passivating glass; lead ions first being leached from the glass and then being deposited on the workpiece surface, including the exposed body surface regions. The presence of lead on these exposed regions, it is found, tends to inhibit proper electroless plating of nickel on these regions.

A solution to this problem is to overcoat the first passivating layer of lead borosilicate glass with a second layer of an encapsulating glass containing no lead. For ease of fabrication, and compatibility with the first passivating layer, the second layer used is a borosilicate glass deposited pyrolitically by known techniques. The boron oxide (B_2O_3) content of the second layer is relatively critical to insure a proper match of thermal expansion of the two glass layers to prevent cracking of either, and to provide a glass having desirable etching characteristics. A preferred range of B_2O_3 is between 10 and 23 mol %, with a thickness of the second layer between 6000 and 20,000Å.

Reprint RE-21-4-13| Final manuscript received February 6, 1975.

Radiation shielding of electronic components

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Princeton, New Jersey

In the past, electronic components have been protected from radiation effects by shielding an entire "black box," which contained many radiation-sensitive devices. Even when aluminum is used, such shielding is heavy from the standpoint of spacecraft application, for which it is important to reduce the weight of payload packages to a minimum.

Encasing individual critical components in lead for localized shielding results in a substantial savings in weight, compared to shielding an entire black box. Such a configuration is described here, with the aid of Figs. 1 and 2.

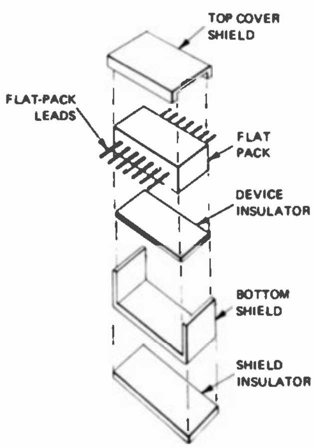

Fig. 1 — Shield — exploded view.

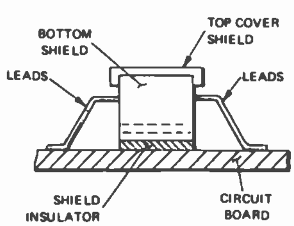

Fig. 2 — Shield assembly.

A lead cover shield, about 0.30 inch thick, is formed to wrap around the top of a flat pack, stopping just short of the connection leads (see Fig. 1).

The shield is bonded to the flat pack with a suitable adhesive, the assembly appearing as shown in Fig. 2.

A 4-mil thick glass-epoxy laminate is cemented to the bottom of the flat pack and this combination is cemented to a bottom lead shield, which wraps around the end of the flat pack. A second 4-mil thick glass-epoxy laminate, or other insulating material, insulates the assembly from the circuit board.

Except for the area surrounding the leads, the device is completely enclosed by the two sections of shielding. It was determined that, by employing the proper geometry, the greatest amount of the detrimental radiation is directed toward the top of the device, and a relatively small amount is directed toward the area of the leads.

An alternative to the use of formed lead shields is the use of lead-coated tape. This is wrapped around the device to cover the same areas covered by the formed shields. A polyimide tape, generally known as Kapton, with both sides coated with a pressure sensitive adhesive, may be substituted for the glass-epoxy laminate insulators and separately applied adhesive.

Reprint RE-21-4-13| Final manuscript received July 9, 1975
*Since this note was written Mr. Schenk has left RCA.

Video attenuator using a multiplier and FET

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The addition of a FET, and appropriate control circuitry, will increase the on-to-off ratio of a multiplier from about 40dB to more than 55dB without significantly degrading the inherent linearity of the original multiplier circuit. The additional circuitry is operated from the same input control, and the output signal has the same or similar voltage and impedance characteristics as the original multiplier circuit.

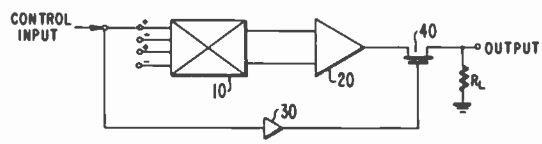

Fig. 1 — Video attenuator.

Fig. 1 shows a video attenuator which includes a four-quadrant multiplier and an output amplifier. The four inputs typically include a video signal, a variable dc control voltage, and two variable voltages for circuit offset adjustments.

The additional elements are the FET, with its circuit load (R_L) and the control amplifier. The amplifier receives the same control voltage as the multiplier. When this control voltage is typically positive for full *on*, the amplifier will produce a control voltage at the gate of the FET that will turn it full *on* — saturated — with a very low source-to-drain impedance. When the input control voltage is low or zero, for minimum multiplier gain, the amplifier will produce a voltage at the gate of the FET that will turn it *off*—a high source-to-drain impedance. This high source-to-drain impedance, working into the load (R_L), will give a signal attenuation in addition to that of the multiplier itself.

The gain of the amplifier will determine the point at which, as the control is increasing toward full-*on*, the FET saturates and thus gives little or no attenuation to the video signal. In a typical application, the gain of the amplifier was set so that, with only 10 to 15% of the total input control voltage, the FET was saturated and had no more effect on the circuit as the multiplier gain was further increased by the control voltage.

Reprint RE-21-4-13| Final manuscript received June 12, 1975.

Environmental control of TIPI DC/SR shelters

E.D. Veilleux

The Data Collection/Storage Retrieval (DC/SR) segment of the Tactical Information Processing and Interpretation (TIPI) system is a mobile, air, sea, and helicopter transportable, land-based system, designed to increase the accuracy of intelligence products by the application of automated assistance to combat intelligence forces. The DC/SR segment includes several shelters with a variable number of people working within each shelter. As a result, there is a requirement to provide a conditioned environment to each of these shelters from a common environmental control system.

THE INITIAL PHASE of the DC/SR segment development program consisted of a study whose objective was to determine the cooling and heating requirements for all shelters of the DC/SR segment and then to design the mechanical hardware to implement these requirements. The purpose of providing conditioned air was to assure an atmosphere in which occupants and equipment of the shelters can function effectively. Conditioned air not only provides a proper temperature, but also humidifies, dehumidifies, and filters the air, and assures that the proper quantity reaches the equipments and occupants as required. Under both hot and cold climatic conditions, this balance must be maintained between the operators and their environment and between the equipment and its environment. Fig. 1 portrays a typical shelter with its environmental control system ECS) in the deployed mode.

The DC/SR segment will be deployed at sites throughout the world and must operate satisfactorily under extreme climatic conditions. Operation in the Arctic Zone will subject the DC/SR segment shelters to temperatures of −65°F for long time periods with essentially dry air. This environment poses an extremely difficult heating and humidifying problem in trying to maintain a comfort level inside the shelters without moisture condensation on inner surfaces. Similarly, the DC/SR segment must be capable of efficient operation in a desert climate where temperatures may go to 125°F during daylight hours com-

Reprint RE-21-5-20
Final manuscript received March 17, 1975.

E.D. Veilleux, Engineering Scientist, Technical Staff, Government Communications and Automated Systems Division, Burlington, Massachusetts, received the BSME from the University of Massachusetts in 1955. In 1963 he was awarded the MS in Mechanical Engineering from Northeastern University. Since joining RCA in 1964, Mr. Veilleux has specialized in the field of heat transfer and has had the responsibility for thermal des gn of LM Rendezvous Radar and Transponder packages. He has also performed thermal analyses on several laser cavities and performed the thermal design of an advanced computer system. Mr. Veilleux has participated in the antenna hydraulic control design and thermal design of the Pulse Doppler Radar Systems and has also been responsible for the thermal design of microwave circuits applicable to airborne jamming systems. More recently, he has performed heating, cooling and ventilation analyses on a large shipboard radar system and a land-based shelter complex for extreme environments. Mr. Veilleux was employed by Sanders Associates, Inc., in the Mechanical Engineering Department where he performed theoretical analyses in the fields of structures, shock and vibration, and heat transfer. He was also responsible for the packaging of several major ECM systems. Prior to leaving Sanders, Mr. Veilleux was Project Mechanical Engineer for several electronic countermeasures systems and responsible for their mechanical design and development to meet military environments. He is a registered Engineer in the state of Massachusetts and a member of several professional societies.

Since this paper was written, Mr. Veilleux has left RCA.

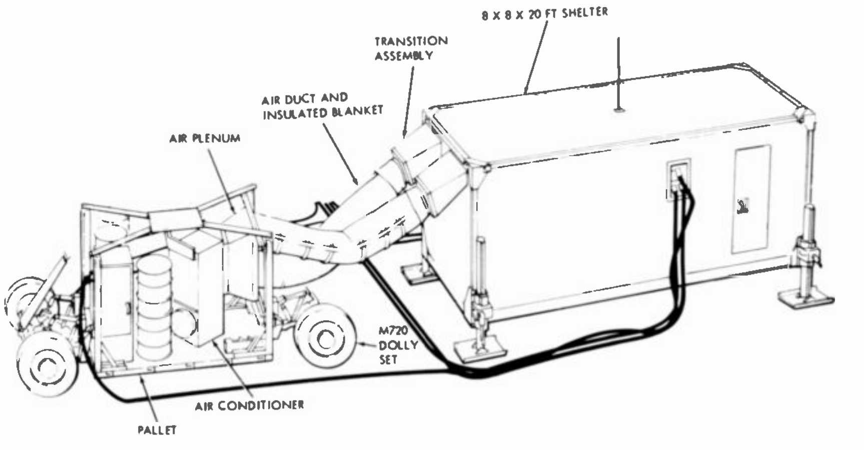

Fig. 1 — Typical TIPI DC/SR shelter-ECS combination in deployed position.

bined with a solar heat load that causes outside surface temperatures to reach 200°F. In addition there is the heat generated by the equipment and the relative dryness of the air. This presents a difficult cooling problem to maintain a comfort level inside each shelter. In the tropics where high temperatures are accompanied by persisting high humidity the air conditioning problem becomes one of cooling and dehumififying the atmosphere within the shelters.

System design criteria

System design criteria for the internal shelter environment, as taken from the system specification, is reflected in Fig. 2. The internal shelter environment that must be provided by the ECS must fall within the area generated by the solid black line and labeled "TIPI Internal Environment Requirement." Superimposed within this area, as well as below, is a dashed line area representing the combined winter and summer comfort zones for individuals within inhabited compartments as required by MIL-STD-1472A.

Based on these two requirements, a design goal was established to control temperature within shelters around a set point of 75°F with a ±5°F tolerance, and a relative humidity between 20% and 55% when the system is exposed to any of the worldwide extreme climatic conditions.

Fig. 2 also depicts the worldwide extreme climatic conditions to which the TIPI system may be subjected. These conditions are based on Army Regulation AR70-38. Also shown in conjunction with these extremes are the qualification test environment that the typical TIPI DC/SR shelter-ECS combination has been exposed to in order to assure that the ECS functions properly and meets its objectives.

Another design stipulation is that the above environmental control function must be performed with an ECS design that incorporates Government-furnished air conditioners as called out in specification MIL-A-38339.

In summary, the basic task in providing a satisfactory environment within the shelters of the TIPI DC/SR segment entailed proper design and development of thermal barriers within the shelter to minimize the environmental loads and the packaging of Government-supplied air conditioners into a viable environmental control system.

Design details

In considering the design details of the system, initial efforts centered on estimating overall environmental heating and cooling loads utilizing the overall shelter coefficient of heat transfer, U, in the following equation:

$$Q = UA\,(T_1 - T_2) \qquad (1)$$

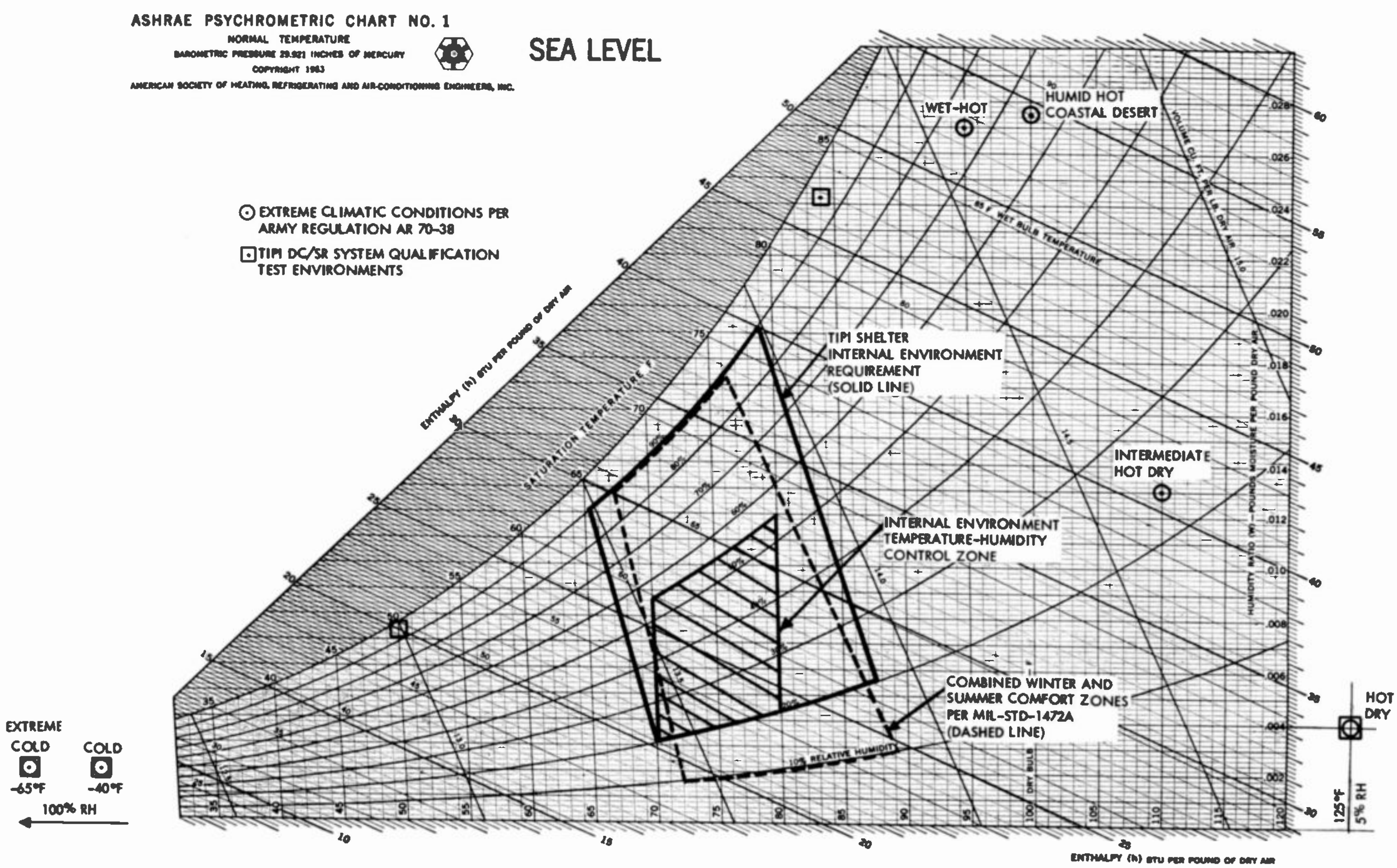

Fig. 2 — Internal and external TIPI DC/SR shelters-ECS environments.

where

Q = Heat loss from shelter or heat gain to shelter (Btu/h)
U = Overall coefficient of heat transfer (Btu/h ft^{2}°F)
A = Surface area across which heat is transferred (ft^{2})
T_1 = External ambient air temperature — hot or cold (°F)
T_2 = Internal shelter ambient air temperature (°F)

In reviewing the concept of estimating heat loss or gain across a barrier, as promulgated by the American Society of Heating, Refreigerating, and Air Conditioning Engineers, Inc., the assumption is made that there is a reasonably uniform heat loss or gain across the thermal barrier (shelter wall). A look at the structural details of a shelter wall reveals that the beam and foam construction technique does not allow for a reasonably uniform heat loss or gain across it. Calculations indicated that approximately 75% of heat loss or gain is across the beam section, and the remaining loss or gain is across the foam section. This occurs because the internal metal skin of the shelter wall acts as a fin collecting heat and conducting it to the wood-aluminum hat section structural member. Heat is then transmitted to the external skin that serves as another fin to dissipate heat to the external environment. Under these circumstances, heat loss or gain across the various sections is not uniform, and there is a non-uniform temperature distribution in the skin as well. Consequently, the sidewall structural sections and the corners of shelter would have localized surface temperatures that would be lower or higher than the aluminum skins adjacent to the foam sections midway between the structural members.

Thus, it becomes evident that there would be a severe condensation problem on the internal walls of the shelter at all the structural section locations under the extreme cold condition. As Fig. 2 shows, for a relative humidity of 20% and a dry bulb temperature of 75°F, the dew point approximates 31.5°F. Therefore, all surface temperatures within the shelter must be above this level if the shelter interior surfaces are to be free of condensation. Because of this condition, it was necessary to resolve the condensation problem prior to making reasonable estimates on the overall heating or cooling loads.

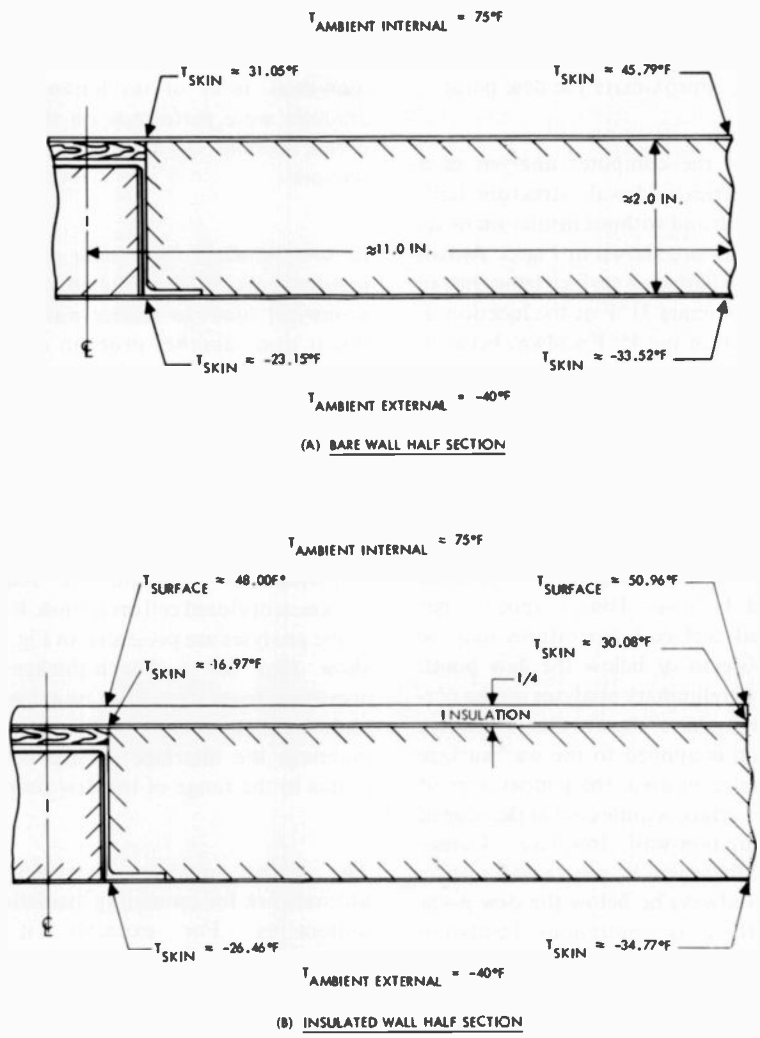

Fig. 3 — Typical shelter sidewall temperature distribution.

Condensation problem

The condensation problem results from the non-uniform heat transfer characteristics of the shelter wall and the inability to accurately and expeditiously estimate temperatures at various locations on the shelter wall surface. Thus, there was a need for a more realistic analysis technique to estimate surface temperatures and insulation thicknesses, when required. The approach utilized was to consider each critical structural member separately (wall sections, roof sections, corner sections, etc.) and establish detailed thermal circuits for analysis by computer.

The boundary conditions for this analysis with respect to the condensation problem are as follows:

a) *Internal shelter environment*

T_{int} = 75°F
Relative humidity = 20%
$T_{dew\ point}$ = 31.5°F

b) *External shelter environment*

T_{ext} = −40°F

Note that the external shelter environment of −40°F was selected as the steady-state design point rather than the climatic extreme of −65°F. This was done because MIL-STD-210A, p. 11, shows that the world-wide outdoor ground equilibrium temperature is −40°F while the −65°F temperature is likely to occur for a transient period of 72 hours.

Further, Army Regulation AR70-38 indicates that climatic extremes usually occur for no more than 1% of the time and that designs should be predicated on the more realistic equilibrium conditions. Coincidently, another reason for selecting −40°F was that the computer analyses shows that the surface temperature of the floor without insulation, and the corner structural sections of the shelter with a reasonable insulation thickness, approximate the dew point.

Results of the computer analysis of a typical vertical sidewall structure half-section with and without insulation on its bare surface are shown in Fig. 3. As can be seen the bare wall surface temperature will approximate 31°F at the location of the hat section and 45°F midway between structural sections. These temperatures are based on an air velocity wiping the interior walls at approximately 100 ft/min and the exterior walls at approximately 440 ft/min. Air spaces behind equipment cabinets will not have an air circulation with this air velocity. As a result, surface temperatures in these areas will be lower. Thus, it appears that bare wall surface temperatures may be quite close to or below the dew point. Further, preliminary analyses on the corner section have shown that whenever insulation is applied to the wall surface over a selected area, the temperature of the wall surface is quite cold at the edge of the insulation-wall interface. Consequently, there will be a bare wall section that will always be below the dew point unelss there is continuous insulation across the whole surface. For analysis, a 1/4-inch-thickness of insulation was selected because of the handling qualities of this material. The closed cell urethane insulation anticipated for use is rigid and fragile. It comes in large sheets that makes its installation difficult if it does not have a reasonable thickness. Reference to Fig. 3(b) shows that the insulation surface temperature will vary between 48°F and 51°F. So far, the above discussion considers a bare wall and a wall with a 1/4-inch-thick layer of insulation. Similar analyses were performed on the shelter corner sections, door sections, and floor sections.

In some shelters there were noise level requirements that required attachment of acoustical foam to shelter walls. When this is done another problem occurs in that acoustical foam is an open cell structure that allows moisture to penetrate its structure and condense whenever its temperature drops below the dew point. As a result, this foam cannot be attached directly to bare surfaces of the shelter. Several thermal analyses were performed to ascertain the required thickness of closed cell insulation. Results of the analyses are presented in Fig. 4 and show that for a 1-inch-thickness of acoustical foam there must be at least a 1-inch-thickness of closed cell insulation to maintain the interface surface between foams in the range of the dew point.

The above analyses provided the groundwork for estimating insulation requirements. For example, it was determined that roof panels of the shelter could accommodate 7/8-inch thickness of insulation and, therefore, dramatically reduce heat input due to solar load. It was also found that because the floor panel is quite close to ground level under the majority of deployment situations it did not require an insulation layer, but that there might be minor condensation near its edges at the vertical side-walls.

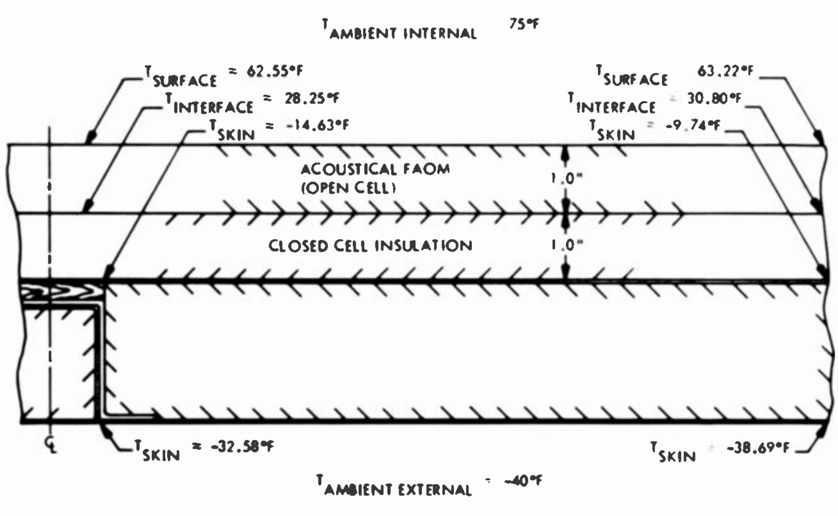

Fig. 4 — Insulated wall shelter temperature distribution with acoustical foam attached to closed cell insulation surface.

The above analysis provided basic guidelines in the solution to the condensation problem within the shelter. Internal shelter insulation requirements have been designed to maintain surface temperature above the dew point down to an external ambient of −40°F. Below this external ambient, condensation may occur at selected locations within the shelter. If it occurs, there are provisions to temporarily reduce the relative humidity to prevent further condensation.

In addition to the analysis performed on the shelter structural sections, it was also necessary to consider the effects of condensation on the air ducts of the system that interconnect the shelter with the ECS. Because of its method of fabrication the typical insulated air duct currently in use has a continuous surface section along its full length that is below the dew point. Further, the steel air duct fittings do not contain any insulation protection to keep their inner surfaces above the dew point. As a result the decision was made to eliminate the insulated air duct and use a conventional fabric duct and to wrap the exterior to it with an insulated blanket that would also cover the air duct fittings at both ends of the duct. The blanket was composed of a flexible urethane foam 1-inch-thick and fabric covered on its inner and outer surface. The transition assemblies that attach to the shelter and the ECS plenum that ties the air conditioners together had their inner surfaces coated with 1-inch-thick rigid urethane foam to minimize the condensation.

In summary, an effort was made to assure that all interior surfaces of the system that are in contact with the circulating air would always be above the dew point to eliminate condensation.

Environmental loads

Developing a computerized thermal model for the resolution of the condensation problem provided the necessary tools to quickly and easily estimate the heating and cooling loads on the system at the extreme environments. These loads are summarized in Table 1 along with other pertinent data. One significant factor that should not be overlooked is the reduction in environmental heat load that occurs because of the insulation used to resolve the condensation problem. For instance, the overall coefficient of heat transfer, U, for a typical shelter before the installation of insulation tested out to be approximately 0.3 Btu/h ft²°F. Calculations and qualification tests have verified that the U for an insulated shelter approximates 0.18 Btu/h ft²°F. This translates into an environmental load reduction of 40%. In a like manner the U for the conventional insulated air duct is quoted at 0.75 Btu/h ft²°F. For the insulated blanket configuration utilized on the TIPI the U approxiamtes 0.17 Btu/h ft²°F. Here the reduction approximates 77%. These reductions resulted in standardization on one size of air conditioner for use with all of the various types of shelters of the system. This would not have been possible if the insulation as discussed herein had not been used.

Table I — TIPI DC/SR shelter environmental data.

Extreme cold	*Extreme hot*
Environmental data	*Environmental data*
$T_{ambient} = -65°F$	$T_{ambient} = +125°F$
$T_{sky} = -80°F$	$T_{shelter\ surface} = +200°F$ (Two long sides due to solar heating)
$T_{shelter} = +75°F$ (Internal)	$T_{shelter} = +75°F$ (internal)
Wind = 5 mi/h	Wind = 7 mi/h
Relative humidity (external) = 100%	Relative humidity (external) = 5%
Heat loads	*Cooling loads*
Shelter heat loss = 176550 Btu/h	Shelter heat gain = 10 385 Btu/h
Air ducts, plenum = 1 485 Btu/h and transitions heat loss	Air ducts, plenum = 910 Btu/h and transitions heat gain
Ventilation heat loss = 4 540 Btu/h per person (30 ft³/min)	Ventilation heat gain = 1 525 Btu/h per person (30 ft³/min)
Electrical Equipment heat loads	
Maximum = 33 665 Btu/h (9.86 kW)	
Minimum = 2 184 Btu/h (0.64 kW)	
Overall shelter dimension	
8 × 8 × 20 ft	

Environmental control system design

The design of an ECS to provide a controlled environment to each TIPI DC/SR shelter was centered around the proper selection of Government Furnished Equipment air conditioners (ECU's). The initial design goal was to design a palletized system that would use two identical ECU's to provide environmental control to four types of TIPI shelters. Therefore, it was mandatory that only one type of ECU be selected for all the applications.

Three parameters were significant in determining the type of ECU utilized. These were heating and cooling load requirements and system air flow characteristics. The condensation analysis, previously discussed, provided the environmental load parameters, while a review of shelter layout drawings provided a basis for tentative analysis of the air flow characteristics of the system. Fig. 5 shows the air flow resistance diagram for a typical shelter-ECS system. An analysis of all air flow resistors shown in Fig. 5 indicated a system pressure drop of approximately 1.44 in. of water gage at an air flow rate of 1625 ft³/min. Coupling this parameter with the environmental loads and reviewing specifications on military air conditioners revealed that the AE32C-24 type ECU having a nominal cooling capacity of 36000 Btu/h would be satisfactory for the task. Since this cooling capacity is at free-flow conditions it was necessary to estimate actual air flow rate vs pressure load from Ref. 1. This data is shown on Fig. 6 along with the estimated shelter air flow resistor characteristics. For the initial design point of 1.44 in. in H_2O pressure drop and system air flow rate of 1625 ft³/min, the nominal cooling capacity of the ECS was estimated to be 49000 Btu/h. Comparing this cooling capacity with the overall cooling load requirements for the four basic types of TIPI DC/SR shelters (see Table II), it appears that two air conditioners are satisfactory to maintain internal shelter ambient at 75°F.

The environmental control system then designed and fabricated was a palletized air conditioning system consisting of two

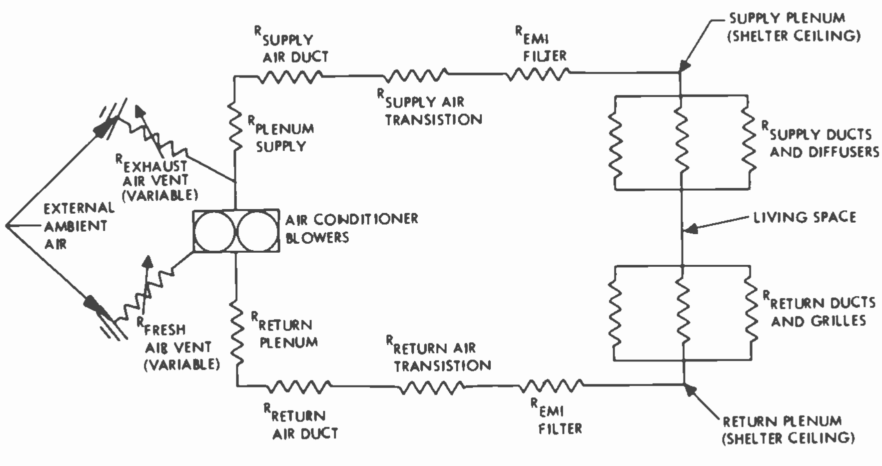

Fig. 5 — Typical air-flow resistance diagram for shelter-ECS system.

Table II — Shelter characteristics.

Shelter type	Air flow rate (ft^3/min)	Pressure drop (in. H_2O)	Cooling load requirement (Btu/h)
A	1540	1.80	46 938
B	1820	1.62	46 033
C	1540	1.80	30 227
G	1760	1.66	25 727

ECU's whose input and output are coupled to a plenum chamber. The plenum chamber attaches to the ECU front surfaces and serves as a blending chamber for supply air and a separation chamber for return air. The front end of the plenum chamber has provisions for attaching supply and return air. The front end of the plenum chamber has provisions for attaching supply and return air ducts and insulating blankets. On the pallet itself there are storage provisions for the air ducts and their insulating blankets, transition assemblies that attach to shelter end wall, a power cable reel, and miscellaneous equipments associated with transportation and deployment of a shelter-ECS combination. There is also a power distribution box that serves the purpose of accepting primary power and distributing it to the ECU's and control panel and also as a storage container for control cables. A control panel and sensor bracket assembly are located within the shelter interior for automatic control of the internal ambient.

Experimental results

Verification of the design of any major system usually occurs at the qualification test of the system and is preceded by a series of subsystem tests. Subsystem tests were performed to verify the air flow characteristics of the ECS as a separate entity as well as when it is attached to each of four types of shelters. Fig. 7 shows the air flow characterisitcs of the ECS. Also shown by the dashed line is the air flow characteristics of two ECU's in parallel as previously shown in Fig. 6. The variations in the two resulted from the removal of the filter elements from within each ECU and installing them in the return chamber of the plenum. The significance of this variation is the achievement of an increased air flow of approximately 12% for an equivalent pressure drop. This in turn provides increased cooling capacity for the same pressure drop. As an example, note from Fig. 6 that for a pressure drop of 1.3 in. of H_2O there is an air flow rate of 1860 ft^3/min and a cooling capacity of 51,200 Btu/h. For the same pressure drop the cooling capacity of the ECS with filter elements within the plenum the air flow is increased to 2080 ft^3/min (see Fig. 7) and the cooling capacity is also increased to 55,200 Btu/h resulting in an improvement of 8% (4,000 Btu/h) in cooling capacity.

Also shown by a dashed line is the estimated air flow characteristics of a shelter system as previously estimated and shown in Fig. 6. Table II lists the air

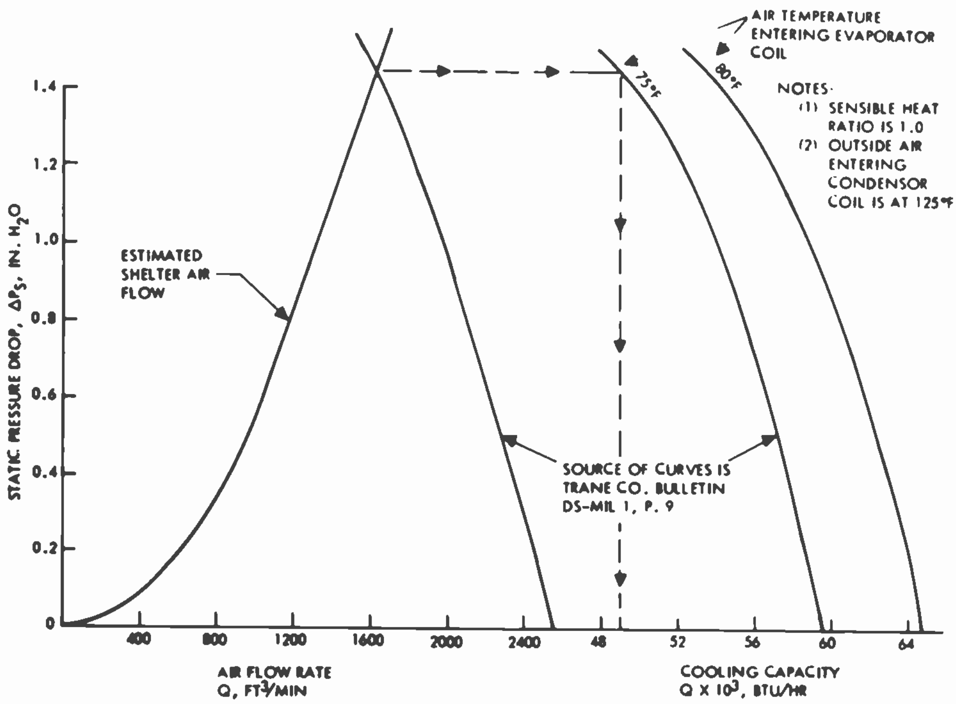

Fig. 6 — Cooling characteristics for two AE32C-24 air conditioners in parallel.

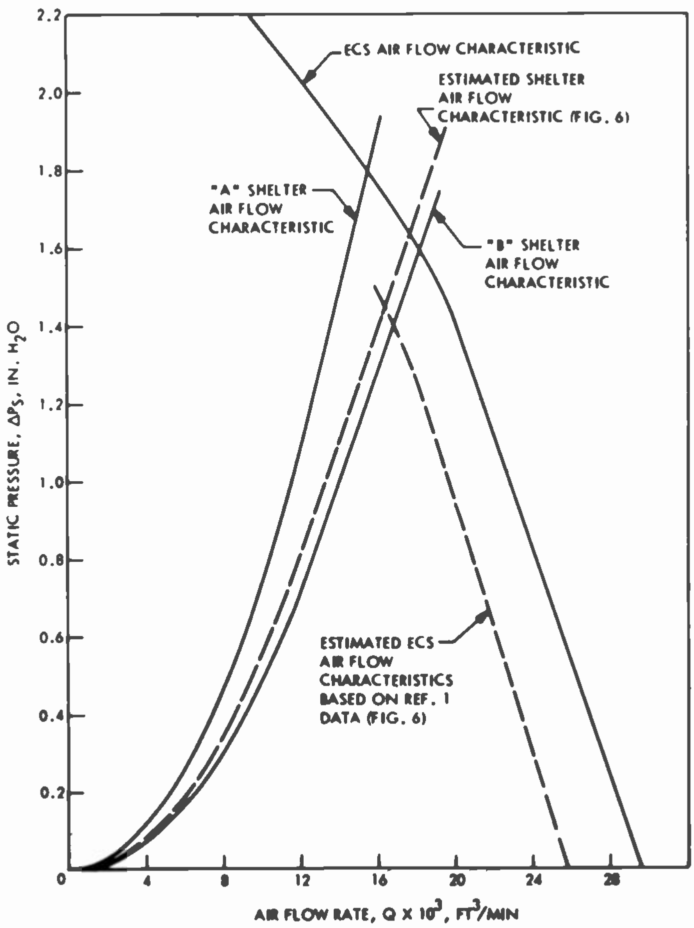

Fig. 7 — TIPI DC/SR shelter-ECS air flow characteristics.

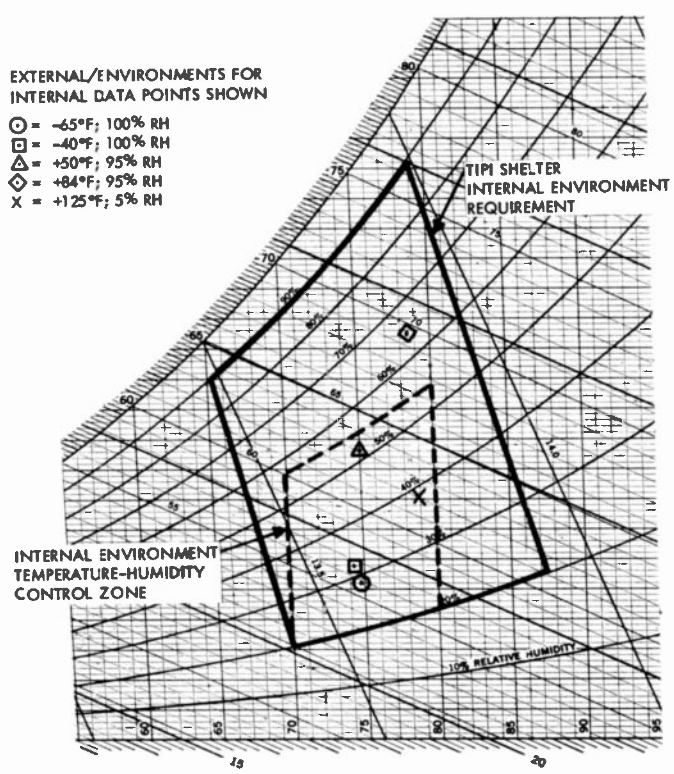

Fig. 8 — Temperature/humidity test data within shelter during qualification test.

flow design points for the various shelters as a result of subsystem tests. The air flow characteristics of the "A" and "B" shelters are also plotted on Fig. 7. As can be seen the original shelter air pressure drop estimates appear to be reasonably close to the "B" shelter pressure drop and somewhat lower than the "A" shelter pressure drop. However, the air flow rate of the "A" shelter is quite close to the original air flow rate estimate (1540 ft^3/min *vs* 1625 ft^3/min) and results in a similar cooling capacity for the ECS (47 200 Btu/hr *vs* 49 000 Btu/h). For the "B" shelter there is an increased cooling capacity because of increased air flow rate.

Finally the qualification test of the complete system provided assurance that the internal ambient of the shelter is maintained within the temperature profile specified in Fig. 2. Four shelters were exposed to the extreme environments shown in Fig. 2 and, the internal environment was maintained within the specified bands. Fig. 8 shows the average temperature within the "B" shelter for the five exterior environments shown in Fig. 2.

Conclusions

Environmental control of the TIPI DC/SR shelters, as described herein, has resulted in the development of insulating techniques that provide a "climatized" environment for shelter occupants and equipments regardless of exterior environmental extremes. Since the climatizing technique reduces environmental heating and cooling loads on conditioning equipment, it also allows for the use of more or higher heat dissipating electronic equipment when compared to techniques currently in use. It also brings computer equipment, formerly relegated to fixed temperature controlled installations, out into field utilization.

Finally, an automatic control system has been developed to remove the shelter occupants from the control loop and provides a controlled environment within the shelters with a minimum of adjustments.

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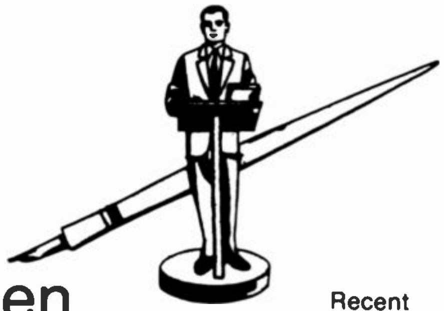

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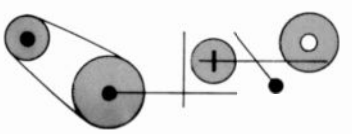

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Special Contract Inv.

Data signaling noise suppression system — C. D. Hughes, W.C. Painter, and C.A. Rypinski, U.S. Pat. 3909727, September 30, 1975.

Fault detection facilitating means for card reader of identification card reading system — F.F. Henriques, U.S. Pat. 3906448, September 16, 1975.

Information Systems

Check-out counter or similar article — T.C. Abrahamsen and J.D. Zaccai (IS, Marlboro) U.S. Pat. D236780, September 16, 1975.

Print actuator arrangement and encoder — P.R. Scott, Jr. (IS, Marlboro) U.S. Pat. 3901371, August 26, 1975.

Programmable test of read/write circuitry by varying clipping levels — W.H. Donovan (IS, CH) U.S. Pat. 3902190, August 26, 1975.

Commercial Communications Systems Division

Film projector apparatus — B.F. Floden (CCSD, Cam.) U.S. Pat. 3905691, September 16, 1975.

Avionics Systems

Electronic scoring system for bowling establishments — J. B. Fischer, R.A. Ito, W.L. Ross, M.R. Schmidt, and S.W. Stoddard (Av. Sys. Div., Van Nuys) U.S. Pat. 3907290, September 23, 1975.

RCA Limited

Multimode horn antenna — P. Foldes (RCA Ltd., Mont) U.S. Pat. 3906508, September 16, 1975.

Circuits exhibiting hysteresis using transistors of complementary conductivity type — R.T. Griffin and D.L. Hillman (RCA Ltd., England) U.S. Pat. 3904888, September 9, 1975.

Laboratories

Separate interdigital electrodes without using any special photolithographic techniques — R.J. Matarese (Labs, Pr.) U.S. Pat. 3908263, September 30, 1975.

Sheet wrapping and unwrapping apparatus — S. Naroff (Labs, Pr.) U.S. Pat. 3908981, September 30, 1975.

Controlled-angle viewing screens by interference techniques — D. Meyerhofer (Labs, Pr.) U.S. Pat. 3909111, September 30, 1975.

Indexing system for microfiche viewer — D. Meyerhofer (Labs, Pr.) U.S Pat. 3909123, September 30, 1975.

Disc records with groove bottom depth variations — J.K. Clemens (Labs, Pr.) U.S.Pat. 3909517, September 30, 1975.

Lumped element, broadband microwave apparatus using semiconductor diodes operating in the Trapatt mode — A.S. Clorfeine (Labs, Pr.) U.S. Pat. 3909740, September 30, 1975

Elastic light-scattering modulator device — D.H. Vilkomerson, R.S. Mezrich (Labs, Pr.) U.S. Pat. 3907407, September 23, 1975.

Liquid crystal devices of improved contrast — D. Meyerhofer (Labs, Pr.) U.S. Pat. 3905682, September 16, 1975.

Deformable mirror light valve for real-time operation — W.R. Roach, L. Darcy (Labs, Pr.) U.S. Pat. 3905683, September 16, 1975.

Electron tube having a semiconductor-coated metal anode electrode to prevent electron-bombardment-stimulated desorption of contaminants therefrom — H.E. Schade (Labs, Pr.) U.S. Pat. 3906277, September 16, 1975.

Frequency translator using gyromagnetic material — W.W Siekanowicz (Labs, Pr.) U.S. Pat. 3906408, September 16, 1975.

Apparatus for copying an electrostatic charge pattern in intensified form — H.G. Kiess (Labs, Zurich, Switzerland) U.S. Pat. 3906501, September 16, 1975.

A direct current electroluminescent panel using amorphous semiconductors for digitally addressing alpha-numeric displays — A.G. Fischer (Labs, Pr.) U.S. Pat. 3913090, October 14, 1975; Assigned to the U.S. Government.

Self-aligned drain and gate field effect transistor — L. S. Napoli and W.F. Reichert (Labs, Pr) U.S. Pat. 3898353, August 5, 1975.

True replication of soft substrates — R.W. Nosker, L.P. Fox (Labs, Pr.) U.S. Pat. 3904488, September 9, 1975.

Removal of dark current spikes from image sensor output signals — M.G. Kovac (Labs, Pr.) U.S. Pat. 3904818, September 9, 1975.

Combined amplifiers which consume substantially constant current — P.E. Haferl (Labs, Pr.) U.S. Pat. 3904973, September 9, 1975.

Gas laser tube — K.G. Hernqvist (Labs, Pr.) U.S. Pat. 3904986, September 9, 1975.

Metallized videodisc having a dielectric coating thereon — G. Kaganowicz (Labs, Pr.) U.S. Pat. 3901994, August 26, 1975.

Logarithmic attenuator — W.G. McGuffin (Labs, Pr.) U.S. Pat. 3568073, March 2, 1971.

Count comparison circuit — H. Borkan (SSTC, Som.) U.S. Pat. 3622987, November 23, 1971; Assigned to the U.S. Government.

Automated Systems Division

Cryogenic dewar — R.E. Rooney (ASD, Burl.) U.S. Pat. 3909225, September 30, 1975.

Exhaust-responsive engine speed and condition indicator — L.R. Hulls and S.C. Hadden (ASD, Burl.) U.S. Pat. 3908167, September 23, 1975.

Consumer Electronics

Signal switching apparatus for compensating record defects — A.L. Baker (CE, Indpls.) U.S. Pat. 3909518, September 30, 1975.

High voltage protection circuit — D.H. Willis (CE, Indpls.) U.S.Pat. 3906304, September 16, 1975.

Digital tuning of voltage control television tuners — W.W. Evans (CE, Indpls.) U.S. Pat. 3906351, September 16, 1975.

Grinding machine for generating a surface of revolution on a hollow workpiece — W.M. Binder (CE, Indpls.) U.S. Pat. 3903656, September 9, 1975.

Distributor and Special Products Division

Direction indicating display system — R.M. Wilson and W.J. Bachman (DSPD, Deptford) U.S. Pat. 3909691, September 30, 1975.

Electrical device with electrode connections — C.R. Wheeler and R.K. Reusch (DSPD, Hrsn.) U.S. Pat. 3902003, August 26, 1975.

Government Communications Systems

Digital message entry device — Z. Lieser (GCSD, W. Windsor, NJ) U.S. Pat. 3573473, April 6, 1971; Assigned to the U.S. Government.

Threshold logic using complementary MOS devices — D. Hampel, K.J. Prost and N.R. Scheinberg (GCSD, Som.) U.S. Pat. 3900742, August 19, 1975; Assigned to the U.S. Government.

Missile and Surface Radar Division

Universal digital filter and function generator — J.E. Courtney (MSRD, Mrstn.) U.S. Pat. 3543012, November 24, 1970; Assigned to the U.S. Government.

Multi-channel optic analyzer — H.M. Halpern and J.J. Rudnick (MSRD, Mrstn.) U.S. Pat. 3571583, March 23, 1971; Assigned to the U.S. Government.

Compact waveguide-coax transition — O.M. Woodward (MSRD, Mrstn.) U.S. Pat. 3725824, April 3, 1973; Assigned to the U.S. Government.

High speed microwave switching logic for ECCM — J.L. Christensen, T.B. Howard (MSRD, Mrstn.) U.S. Pat. 3887919, June 3, 1975; Assigned to the U.S. Government.

An improved signal processor system — H.C. Goodrich (MSRD, Mrstn.) U.S. Pat. 3906496, September 16, 1975; Assigned to the U.S. Government.

Solid State Division

Production of lead-monoxide-coated vidicon target — J.F. Heagy (SSD, Lanc.) U.S. Pat. 3909308, September 30, 1975.

High frequency semiconductor device having improved metallized patterns — I.E. Martin (SSD, Som.) U.S. Pat. 3908185, September 23, 1975.

Failure detecting and inhibiting circuit — D.A. Moe (SSD, Som.) U.S. Pat. 3906258, September 16, 1975.

Vacuum seal for envelope portions — M. B. Shrader (SSD, Lanc.) U.S. Pat. 3904065, September 9, 1975.

Voltage reduction circuit for deflection yoke — C.F. Wheatley, Jr. and O. Shevchenko (SSD, Som.) U.S. Pat. 3904927, September 9, 1975.

Overvoltage protection circuit — A. J. Leidich (SSD, Som.) U.S. Pat. 3904931, September 9, 1975.

Current amplifer — A.A. Ahmed (SSD, Som.) U.S. Pat. 3904976, September 9, 1975.

Electronic component assembly — R.K. Walter (SSD, Lanc.) U.S. Pat. 3905000, September 9, 1975.

High frequency transistor — D.S. Jacobson (SSD, Som.) U.S. Pat. 3902188, August 26, 1975.

Thermal flux transfer system — R.A. Freggens (SSD, Lanc.) U.S. Pat. 3759443, September 18, 1973; Assigned to the U.S. Government.

Multi-converter themionic energy module — R.W. Longsderff and R.S. Sheetz (SSD, Lanc.) U.S. Pat. 3702408, November 7, 1972; Assigned to the U.S. Government.

Frequency power transistors — R. Minton, C. Kamnitsis (SSD, Som.) U.S. Pat. 3714601, January 30, 1973; Assigned to the U.S. Government.

Dates and Deadlines

As an industry leader, RCA must be well represented in major professional conferences . . . to display its skills and abilities to both commercial and government interests.

How can you and your manager, leader, or chief-engineer do this for RCA?

Plan ahead! Watch these columns every issue for advance notices of upcoming meetings and "calls for papers". Formulate plans at staff meetings—and select pertinent topics to represent you and your group professionally. Every engineer and scientist is urged to scan these columns; call attention of important meetings to your Technical Publications Administrator (TPA) or your manager. Always work closely with your TPA who can help with scheduling and supplement contacts between engineers and professional societies. Inform your TPA whenever you present or publish a paper. These professional accomplishments will be cited in the "Pen and Podium" section of the *RCA Engineer*, as reported by your TPA.

Dates of upcoming meetings —plan ahead

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

FEB. 2-4, 1976 — **Digital Communications and Signal Processing Techniques** (Concordia Univ.) Montreal, Canada **Prog Info:** Dr. K. Feher, Electrical Engineering, Concordia University, (previously known as Sir George Williams University), 1455 de Maisoneuve West, Montreal, H3G 1M8, Canada. Telephone (514) 879-8049.

FEB. 18-20, 1976 — **Int'l. Solid State Circuits Conference** (SSC Council, Phila. Section, Univ. of Penna.) Marriott Hotel, Phila., PA **Prog Info:** J. H. Wuorinen, Bell Labs., Whippany, NJ 07981.

FEB. 18-20, 1976 — **Aerospace & Electronic Systems Winter Convention** (WINCON, AES) Sheraton-Universal Hotel, N. Hollywood, CA **Prog Info:** R.S. Carlson, ITT AECE Group, 500 Washington Ave., Nutley, NJ 07110.

FEB. 24-26, 1976 — **COMPCON SPRING** (C) Jack Tar Hotel, San Francisco, CA **Prog Info:** Sidney Fernbach, Computer Dept. L-61, Lawrence Livermore Lab., POB 808, Livermore, CA 94550.

MARCH 8-10, 1976 — **Industrial Electronics & Control Instrumentation** (IECI) Sheraton Hotel, Philadelphia, PA **Prog Info:** S.J. Vahaviolos, Engrg. Res. Ctr., Western Elec. Co., POB 900, Princeton, NJ 08540.

MARCH 11, 1976 — **Int'l. Zurich Seminar on Digital Communications** (Switzerland Section, ASSP, COMM, C, CAS) Fed. Inst. of Tech., Zurich, Switzerland **Prog Info:** Albert Kundig, PTT Res Lab., TZV 907, CH-3000, Bern 29, Switzerland.

MARCH 10-12, 1976 — **Region V Control of Power Systems Conference** (Region V, Oklahoma City Sec.) Holiday Inn, N.W. Oklahoma City, OK **Prog Info:** M. E. Council, Sch. of EE, Univ. of Oklahoma, 202 W. Boyd, Norman, OK 73069.

MARCH 16-18, 1976 — **1976 Power Tube Specialist Conference**, Naval Post Graduate School, Monterey, CA **Prog Info:** Dr. J. V. Leacqz, Technical Program Chairman, Stanford Linear Accelerator Center, 2575 Sand Hill Road, Menlo Park, CA 94025.

MARCH 17-19, 1976 — **Simulation Symposium** (C et al) Tampa, FL **Prog Info:** L. E. Gess, Green Giant Co., Hazeltine Gates, Chaska, MN 55555.

MARCH 24-26, 1976 — **Vehicular Technology**, (VT) Washington, DC **Prog Info:** Sam McConoughey, Fed. Comm. Commission, 1919 M St., N.W., Rm. 8308, Washington, DC 20554.

MARCH 30 - APRIL 1, 1976 — **Small Electrical Machines** (IEE, IEEE UKRI Section) Savoy Place, London, England **Prog Info:** IEE, Savoy Place, London WC2R OBL England.

MARCH 30-31, APRIL 1, 1976 — **The Personal Communications Two-Way Radio Show** (EIA) Las Vegas Hilton, Las Vegas VN **Prog info:** Mr. Robert Black, The Show Company International, 1605 Cahuenga Blvd., Los Angeles, CA 90028.

APRIL 1976 — **Carnahan Conference on Electronic Crime Countermeasures** (AES, Univ. of Kentucky) **Prog info:** Office of Continuing Education Engrg., Rm. 779, Anderson Hall, Univ. of Ky., Lexington, KY 40506.

MAY 1-6, 1976 — **78th Annual Meeting & Exposition** (Nuclear Div. - American Ceramic Society) Convention Center, Cincinnati, OH **Prog info:** P. L. Farnsworth, Program Chairman, Nuclear Division, Exxon Nuclear Company, 2101 Horn Rapids Road, Richland, WA 99352.

APRIL 5-7, 1976 — **SOUTHEASTCON** (Region 3, S.C. Affiliation of Sections) Clemson Univ., Clemson SC **Prog info:** J. W. Lathrop, E&CE Dept., Clemson Univ., Clemson, SC 29631.

APRIL 6-8, 1976 — **Applications of Electronics in Medicine** (IERE, IEEE UKRI Section et al) Southampton, England **Prog info:** Conference Dept., IERE, 8-9 Bedford Square, London WC1B, 3RG, England.

APRIL 7-9, 1976 — **Region 6 Conference** (Region 6 — Fort Huachuca & Tucson Sections) Braniff Place Hotel, Tucson, AZ **Prog info:** Lloyd Perper, 3725 Ironwood Hill Dr., Tucson, AZ 85705.

APRIL 12-14, 1976 — **Acoustics, Speech & Signal Processing Int'l. Conference** (ASSP, Phila. Section) Marriott Hotel, Philadephia, PA **Prog info:** Thos. Martin, Threshold Tech. Inc., Rte. 130, Union Landing Rd., Cinnaminson, NJ 08077.

APRIL 14-16, 1976 — **Region V Annual Conference (Region V) Univ. of Texas, Austin, TX Prog info:** A. B. Buckman, EE Dept., Univ. of Texas at Austin, Austin, TX 78712.

APRIL 20-22, 1976 — **Computer Software Engrg. Reliability, Management Design** (C, R, Polytechnic Inst. of N.Y. et al) **Prog info:** M. L. Shooman, Polytechnic Inst. of N.Y., 333 Jay St., Brooklyn, NY 11201.

APRIL 20-22, 1976 — **Reliability Physics Int'l. Symposium** (ED, R) Caesars Palace, Las Vegas, NV **Prog info:** J. H. Martin, SS Draper Lab., 75 Cambridge Parkway, Cambridge, MA 02142.

APRIL 26-28, 1976 — **Electronic Components Conference** (PHP, EIA) Jack Tar Hotel, San Francisco, CA **Prog info:** J. H. Powers, Jr., IBM-System Pdts. Div., Dept. ID4, Bldg. 414-700 Hopewell Junction, NY 12533.

APRIL 27-29, 1976 — **Circuits and Systems Int'l. Symposium** (CAS, VDE NTG) Technical Univ., Munich, Germany **Prog info:** Alfred Fettweis, Lehrstuhl fur Nachrichtentechnik, Univ. of Bochum, PO 2148, D-4630 Bochum, F. R. Germany.

MAY 16-18, 1976 — **1976 ASME Joint Conference** (Gen. Engrg. Dept.) St. Louis, MO **Prog info:** Marvin Birken, Program Chairman, Airesearch Industrial Division, 3201 Lomita Blvd., Torrance, CA 90505.

MAY 25-27, 1976 — **IEEE/OSA Conference on Laser and Electro-Optical Systems** San Diego, CA **Prog info:** Ms. Leslie Hill, Hughes Aircraft Company, Electron Dynamics Division, 3100 West Lomita Boulevard, Torrance, CA 90509.

Calls for papers —be sure deadlines are met

Ed. Note: Calls are listed chronologically by meeting date. Listed after the meeting title (in bold type) are the sponsor(s), the location, and deadline information for submittals.

MAY 25-27, 1976 — **Laser & Electro-Optical Systems** (QE Council, OSA) Town & Country, San Diego, Calif. **Deadline info: (A&S)** 1/23/76 to M.E. Rabedeau, IBM-F 55/015, San Jose, CA 95193.

JUNE 7-10, 1976 — **National Computer Conference** (C, AFIPS) New York, N.Y. **Deadline info: (ms)** 1/5/76 to Stanley Winkler, IBM Corp., 18100 Frederick Pike, Gaithersburg, MD 20760.

JUNE 14-16, 1976 — **Int'l. Conference on Communications** (COMM) Marriott Motor Hotel, Philadelphia, Penna. **Deadline info: (paper)** 2/1/76 to Ralph Wyndrum, Bell Labs., Whippany Rd., 1B306, Whippany, NJ 07981.

JUNE 14-16, 1976 — **International Microwave Symposium** (MTT) Cherry Hill, NJ **Deadline info: (abst)** 1/2/76 to Martin Caulton, RCA, Princeton, NJ 08540.

JUNE 28-JULY 1, 1976 — **Conference on Precision Electromagnetic Measurements** (IM, NBS, URSI) National Bureau of Standards, Boulder, Colo. **Deadline info: (sum)** 1/15/76 to R. A. Kamper, Electromagnetics Div., NBS, Boulder CO 80302.

JULY 18-23, 1976 — **Power Engineering Society Summer Meeting** (PE) Portland Hilton Hotel, Portland, Oregon **Deadline info: (paper)** 2/1/76 to W.S. Greer, Westinghouse Elec. Corp., 1414 N.E. Grand Ave., Portland, OR 97212 (request *Power Author's Kit* from IEEE, Technical Conference Services Office, 345 East 47th St., New York, NY 10017).

AUG. 30 - SEPT. 1, 1976 — **Petroleum & Chemical Ind. Tech. Conference** (IA) Marriott Hotel, Philadelphia, PA **Deadline info: (ms)** 3/1/76 to J. A. Stewart, FMC Corp., 633 Third Ave., New York, NY 10017.

SEPT. 12-17, 1976 — **Intersociety Energy Conversion Engrg. Conference** (ED, AES et al) Sahara Tahoe, Nevada **Deadline info: (abst)** 1/1/76 to W. R. Martini, D. W. Douglas Labs., 2955 George Washington Way, Richland, WA 99352.

SEPT. 19-23, 1976 — **Jt. Power Generation Technical Conference** (PE, ASME, ASCE) Buffalo Hilton Hotel, Buffalo, New York **Deadline info: (abst)** 1/29/76 to E. F. Chelotti, Gibbs & Hill, 393 Seventh Ave., New York, NY 10001.

SEPT. 29 - OCT. 1, 1976 — **Ultrasonics Symposium** (SU) Annapolis Hilton Hotel, Annapolis, MD **Deadline info: (ms)** 7/1/76 to P. H. Carr, AFCRL, L.G. Hanscom Field, Bedford, MA 01730.

OCT. 10-15, 1976 — **Int'l. IEEE/AP Symp. & USNC/URSI Meeting** (AP, USNC/URSI) Univ. of Massachusetts, Amherst, Mass. **Deadline info: (paper)** 7/76 to C. J. Sletten & R Fante, AF Cambridge Res. Ctr., Bedford, Mass. 01730.

OCT. 25-27, 1976 — **Frontiers in Education** (IEEE and the Ed. Res. & Methods Div. of the ASEE, College of Engrg. Univ. of Ariz.) Ramada Inn, Tucson, Ariz. **Deadline info: (syn)** 1/15/76 **(final drafts)** 6/15/76 to Dr. E. R. Owen, Program Coordinator, FIE '76, Electrical and Electronic Engineering, California Polytechnic State University, San Luis Obispo, CA 93401.

NOV. 9-12, 1976 — **Millimetric Waveguide Systems** (IEE, IEEE UKRI Section et al) IEE, London, England **Deadline info: (syn)** 1/9/76 to IEE, Savoy Place, London WC2R OBL England.

DEC. 1-3, 1976 — **Decision and Control-Adaptive Processes** (CS, SIAM) Sheraton Sand Key, Clearwater Beach, Florida **Deadline info: (abst or ms)** 4/1/76 to Earl Barnes, IBM Thos. J. Watson Res. Ctr., POB 218, Yorktown Heights, NY 10598.

DEC. 6-10, 1976 — **Submillimeter Waves & Their Applications** (MTT, OSA ICO) San Juan, Puerto Rico **Deadline info: (ms)** 8/1/76 to K. J. Button, MIT, National Magnet Lab., Cambridge, MA 02139.

Clip out and mail to Editor, *RCA Engineer*, 204-2, Cherry Hill, N.J.

RCA Engineer

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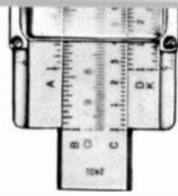
Engineering  News and Highlights

Sarnoff resigns — Conrad named President and Chief Executive Officer

On November 5, **Robert W. Sarnoff** submitted to the RCA Board of Directors his resignation, effective December 31, 1975, as Chairman and a member of the Board of Directors of RCA Corporation.

In accepting Mr. Sarnoff's resignation, the board designated **Anthony L. Conrad,** President and Chief Operating Officer of RCA, as President and Chief Executive Officer.

Mr. Sarnoff will complete at the end of this year a full decade as President and as Chairman of RCA. For the prior 18 years he served the National Broadcasting Company, a wholly-owned subsidiary, in a succession of executive posts, rising to Chairman and Chief Executive Officer. Mr. Sarnoff, who is 57 years old, indicated that he intended to pursue other interests of a personal nature.

Mr. Conrad became President of RCA on August 1, 1971, following a career of a quarter of a century with the Corporation. He is the eighth President in the history of RCA.

Previously, Mr. Conrad had been Executive Vice President, Services, since April 1969. He was elected to the RCA Board of Directors at the company's 1970 annual meeting.

He is a member of the Board of Directors of The Hertz Corporation, Random House, Inc., RCA Global Communications, Inc., Banquet Foods Corporation, Coronet Industries, Inc., and Cushman & Wakefield, Inc., all subsidiaries of RCA. Mr. Conrad also is a member of the Board of Directors of ICI Americas, Chesebrough-Pond's Inc. and National Merit Scholarship Corporation.

Mr. Conrad served as President of the RCA Service Company for eight years prior to his appointment as Vice President, Education Systems, on Corporate Staff, in August, 1968. He joined the RCA Service Company in 1946 following his discharge from the U.S. Army Signal Corps. He then held various managerial and engineering assignments with that RCA subsidiary.

A native of Walpole, Mass., Mr. Conrad was graduated from Lafayette College in 1943, and was commissioned a Second Lieutenant in the U.S. Army Signal Corps shortly thereafter. During his military career, he was Commanding Officer, 220th Signal Radar Maintenance Unit and also served in various Signal Schools.

Mr. Conrad is a member of the Board of Trustees of Lafayette College. He has previously served as Vice Chairman of the college's Board of Trustees and was formerly President of its Alumni Association.

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to: *RCA Engineer*, Bldg. 204-2, RCA, Cherry Hill, N.J. New listings (and corrections or changes to previous listings) will be published in each issue.

Government Communications Systems Division

R.D. Houck, Camden, N.J.; 22536, New Jersey.

Commercial Communications Systems Division

James R. Neidlinger, Meadow Lands, Pa.; E-40301, Ohio.

Missile and Surface Radar Division

Martin A. Karch, Moorestown, N.J.; 21862, New Jersey.

Solid State Division

L.R. Campbell, Somerville, N.J.; 12958, New Jersey.

Advanced Technology Laboratories

Henry J. Zadell, Camden, N.J.; 22374, New Jersey.

Staff announcements

President and Chief Executive Officer

Anthony L. Conrad, RCA President and Chief Executive Officer, has announced the organization of the RCA Corporation as follows: **Edgar H. Griffith,** President, RCA Electronics and Diversified Businesses; and **Howard R. Hawkins,** President, RCA Communications. (Messrs. Griffiths and Hawkins are also Executive Vice Presidents, RCA Corporation.) Also, **Kenneth W. Bilby,** Executive Vice President, Corporate Affairs; **Charles R. Denny,** Executive Vice President, Washington; **Charles C. Ellis,** Senior Vice President, Finance; **George C. Evanoff,** Vice President, Corporate Development; **George A. Fadler,** Vice President; **George H. Fuchs,** Executive Vice President, Industrial Relations; **James Hillier,** Executive Vice President, Research and Engineering; **Eugene A. Sekulow,** Vice President, International; and **Robert L. Werner,** Executive Vice President and General Counsel.

In addition, the National Broadcasting Company, Inc., will report to the RCA President and Chief Executive Officer.

Consumer Electronics

Jay J. Brandinger, Division Vice President, Television Engineering, has announced the organization of Television Engineering as follows: **Jay J. Brandinger,** Acting Manager, Product Development Engineering; **Clyde W. Hoyt,** Manager, Product Safety and Reliability Center; **Eugene Lemke,** Manager, Display Systems; **Robert J. Lewis,** Chief International Television Engineer; and **John M. Wright,** Chief Product Design Engineer.

J. Peter Bingham, Manager, Product Development Support, has announced the organization of Product Development Support as follows: **Robert D. Flood,** Manager, Testing Methods; and **Eugene E. Janson,** Manager, Product Evaluation and Analysis.

R. Kennon Lockhart, Manager, Signal Systems, has announced the Signal Systems organization as follows: **Donald H. Willis,** Manager, Signal Processing Engineering; and **Willard M. Workman,** Manager, I.F. and Tuner Engineering.

Harry Anderson, Division Vice President, Manufacturing Operations has appointed **David D. Eden** as Plant Manager, Monticello Plant.

Solid State Division

Bernard V. Vonderschmitt, Vice President & General Manager, Solid State Division, has announced the newly created activity of Solid State Management Systems & Services as follows: **Edward M. Troy,** Division Vice President, Solid State Management Systems & Services; **Thomas L. Cambria,** Director, Management, Information Systems; **Edward M. Troy,** Acting Manager, Technical Services; **Parker T. Valentine,** Manager, Solid State Services; **John D. Watkins,** Manager, Solid State Materials; and **Gilbert Wolfe,** Administrator, Solid State Operations Planning & Administration.

Edward M. Troy, Division Vice President, Solid State Management Systems & Services has made the following organization announcements. The Manufacturing Systems activity and the Management Information Systems activity are transferred to the staff of the Director, Management Information Systems; and the Industrial Engineering activity is transferred to the staff of the Manager, Solid State Services. **Thomas L. Cambria,** Director, Management Information Systems and **Parker T. Valentine,** Manager, Solid State Services, will report to the Division Vice President, Solid State Management Systems & Services.

Mr. Troy also announced the organization of Technical Services as follows: **Fred G. Block,** Manager, Technical Services; **James A. Amick,** Manager, Materials & Process Development; **Anthony J. Bianculli,** Manager, Engineering Standards; **W. Robert Guerin,** Leader, Wafer Fabrication Equipment—Power; and **Raymond A. McFarlane,** Manager, Equipment Technology—IC.

Richard A. Santilli, Division Vice President, Solid State Bipolar Integrated Circuits & Special Products, has announced that the Offshore Manufacturing activities are transferred to the staff of the Division Vice President, Solid State Bipolar Integrated Circuits & Special Products. **Harry B. Gould** is General Manager, RCA Senderian, Berhad (Malaysia). **Raymond C. Reutter** will continue in his capacity as Manager, Solid State — RCA Taiwan, Ltd. Messrs. Gould and Reutter will report administratively to the appropriate subsidiary company management and functionally to the Division Vice President, Solid State Bipolar Integrated Circuits & Special Products, from who they will receive product and business guidance.

Julius Litus, Jr., Manager, Design Engineering — COS/MOS, has appointed **Richard P. Fillmore,** Leader, Custom Circuit Design; and **Robert C. Heuner,** Leader, Standard Circuit Design.

Terry G. Athanas, Manager, Circuit Design and Technology—Memories, has announced that the Test Technology activity in the Solid State MOS Integrated Circuits organization is transferred to the staff of the Manager, Circuit Design and Technology—Memories. **Edward C. Crossley** continues as Leader, Test Technology.

Ben A. Jacoby, Division Vice President, Solid State Marketing, has announced the appointment of **Joseph M. Cleary** as Director, National Sales.

Anthony J. Froio, Manager, Advertising & Sales Promotion, has announced the newly created activity of Advertising, Sales Promotion, & Publications—EOD as follows: **John F. Chattin,** Manager, Advertising, Sales Promotion & Publications—EOD; and **Arthur P. Sweet, Jr.,** Administrator, Engineering Publications—EOD.

George W. Ianson, Manager, Power Operations Support, has announced the organization as follows: **John A. Adolfson,** Manager, Industrial Engineering & Facilities; **Charles M. Cianciarulo,** Manager, Product Control — Production Control & Customer Scheduling; **Thomas P. Helvig,** Manager, Purchasing; **Thomas J. Lally,** Administrator, Power Manufacturing Systems; **Charles J. McCarthy,** Manager, Material Control; and **Daniel J. Smith,** Manager, Offshore Operations Support.

Henry C. Waltke, Manager, Operations Services has announced the following appointments: **Michael A. Caravaggio** as Manager, Technical Support and **Thomas E. Nash,** Manager, Plant Engineering.

Charles M. Cianciarulo, Manager, Product Control—Power, has announced the appointment of **Glen P. Daniels** as Administrator, Product Control—High Reliability/RF/Hybrids.

Philip R. Thomas, Division Vice President, Solid State MOS Integrated Circuits, has announced the following appointments along with the Organization of the MOS Manufacturing Operations activity:

Robert O. Winder is appointed Director, Microprocessor Products and **Richard J. Hall** is appointed Director, MOS Manufacturing Operations.

The organization of MOS Manufacturing Operations is as follows: **Philip R. Thomas,** Acting Director, MOS Manufacturing Operations; **Frank J. DiGesualdo,** Manager, Palm Beach Gardens—Solid State Operations; **Robert A. Donnelly,** Manager, Findlay Operations Support; **Robert P. Jones,** Manager, Manufacturing—COS/MOS; **Michael Zanakos,** Manager, Operations Control & Planning—MOS; and **Evan P. Zlock,** Manager, Photomask Operations.

Robert O. Winder, Director, Microprocessor Products has announced the appointment of **Alexander W. Young** as Manager, Design Engineering—Microprocessors.

Robert P. Jones, Manager, Manufacturing—COS/MOS has announced the appointment of **Stuart N. Levy** as Manager, Assembly & Test—COS/MOS.

John P. McCarthy, Director, MOS High Reliability Products has announced the appointment of **George A. Riley** as Administrator, Product & Operations Planning—MOS High Reliability.

Norman C. Turner, Director, COS/MOS Integrated Circuits, has appointed **Peter J. Jones** as Manager, Product Marketing, COS/MOS Integrated Circuits.

David S. Jacobson, Manager, Process Engineering and Cost Reduction—COS/MOS has announced the organization as follows: **Martin A. Blumenfeld,** Leader, Process Development and Cost Reduction; and **David S. Jacobson,** Acting Leader, Process and Package Development.

Offshore Manufacturing support activities will report into the appropriate staff organizations in Solid State Bipolar Integrated Circuits & Special Products, from whom they will receive product and business guidance. Offshore Manufacturing support activities will report into the appropriate staff organizations in Solid State Bipolar Integrated Circuits & Special Products.

Carl R. Turner, Division Vice President, Solid State Power Devices, has announced the organization of the newly created Operations Planning and Equipment Engineering as follows: **Melvin Bondy,** Manager, Operations Planning & Equipment Engineering; **Robert J. Satriano,** Manager, Equipment Engineering; **Vincent J. Grobe,** Manager, Systems Engineering; **Stanley Kolenda,** Supervisor, Mechanical Equipment Shop;

Keith E. Loofborrow, Leader, Test Equipment Engineering; **Edward T. Schmitt,** Leader, Assembly Equipment Engineering; **Luis H. Urdang,** Leader, Equipment Engineering; and **Francis J. Yannotti,** Administrator, Operations Planning.

John E. Mainzer, Director, Power Manufacturing Operations, has announced the organization as follows: **Edward A. Czeck,** Manager, Wafer Fabrication; **George W. Ianson,** Manager Power Manufacturing Operations Support; **Frank P. Jacobelli,** Manager, Industrial Relations—Mountaintop; **Henry A. Kellar,** Manager, Device Fabrication; **Vicent J. Lukach,** Manager, Quality & Reliability Assurance; **Richard M. Marshall,** Manager, Financial Operations; **Juan C. J. Suarez,** Manager, Solid State Manufacturing, Belo Horizonte (Brazil); and **Henry C. Waltke,** Manager, Operations Services.

SelectaVision

Levon M. Berberian, Staff Vice President, "SelectaVision" Marketing and Programming has announced the appointment of **Robert L. Weinberg** as Director, Marketing Planning and Research.

Donald S. McCoy, Staff Vice President, "SelectaVision" Engineering and Manufacturing has announced the organization as follows: **Lawrence J. Chiponis,** Manager, "SelectaVision" Technical Services; **Roland N. Rhodes,** Manager, "SelectaVision" VideoDisc Player Design and Development; **H. Robert Snow,** Manager, "SelectaVision" VideoDisc Operations; and **W. Eugene Winston,** Manager, "SelectaVision" VideoDisc Player Manufacturing.

Picture Tube Division

J.H. Colgrove, Division Vice President and General Manager, Picture Tube Division, has announced the appointment of **Wellesley J. Dodds** as Director, Quality, Product Safety, and Reliability.

D. J. Donahue, Division Vice President, Engineering, has announced the Organization of Engineering as follows: **Robert L. Barbin,** Manager, Applications, Reliability & Safety; **D. Joseph Donahue,** Acting, Project Management and Administration; **Leonard F. Hopen,** Manager, Process & Materials Development (In this capacity, Mr. Hopen is responsible for all process work including process development and production support.); **Clifford E. Shedd,** Manager, Equipment Development; and **David D. VanOrmer,** Manager, Product Development (In this capacity, Mr. VanOrmer is responsible for all design activity, including new products, pilot production and design support of manufacturing.)

Wellesley J. Dodds, Director, Quality, Product Safety and Reliability has announced the organization as follows: **Sherman L. Babcock,** Administrator, Quality Control and Product Safety; **Rex E. McNickle,** Administrator, Quality and Reliability Assurance Systems; and **Robert D. Reichert,** Administrator, Reliability Engineering.

John S. Ignar, Plant Manager, Scranton Plant, has announced the organization of the Scranton Plant as follows: **John J. Bross,** Manager, Materials and Industrial Engineering; **Thomas R. Conway,** Manager, Plant Engineering; **J. Edward Fagan,** Manager, Quality and Reliability Assurance; **Joseph J. McHugh,** Manager, Manufacturing; **Jack I. Nubani,** Manager, Process and Production Engineering; **Raymond C. Reneker,** Manager, Financial Operations; and **Allan R. Zoss,** Manager, Industrial Relations.

Government and Commercial Systems

David Shore, Division Vice President, Advanced Programs Development, has announced the appointment of **Dr. Irving Maron** as Manager, Advanced Tactical Programs.

Government Communications Systems Division

James Vollmer, Division Vice President and General Manager, Government Communications Systems Division, has announced the organization as follows: **Tony L. Genetta,** Manager, Telecommunications Systems; **Joseph B. Howe,** Chief Engineer, Engineering; **F. Donald Kell,** Manager, Information Processing and Recording Systems; **Robert S. Miller,** Manager, Contracts Management; **Donald J. Parker,** Manager, Digital Communications Systems; **William A. Parkinson,** Manager, Operations Control; **John D. Rittenhouse,** Manager, Maroon Shield Programs; **John C. Shannon,** Manager, Radio and Transmission Systems; **Francis H. Stelter, Jr.,** Director, Marketing; **Edmund J. Westcott,** Manager, Product Effectiveness; and **George P. Williams,** Manager, Business Planning.

Donald J. Parker, Manager, Digital Communications Systems, has announced the organization as follows: **Joseph B. Christopher,** Manager, ComSec Manufacturing; **John V. Holt,** Manager, Switching Programs; **Donald J. Parker,** Acting, VINSON Program; **Donald J. Parker,** Acting, Purchasing Administration; **Charles A. Schmidt,** Manager, TENLEY Program; and **Joe Terry Swaim,** Manager, Switching Programs.

Tony L. Genetta, Manager, Telecommunications Systems has announced the organization as follows: **Peter H. Bennett,** Manager, EPABBX Equipment and Systems; **Tony L. Genetta,** Manager, Acting, Telex Eqiupment and Systems; and **Raymond J. Kowalski,** Manager, Site Operations.

Joseph B. Howe, Chief Engineer, Engineering has announced the Engineering organization as follows: **John N. Breen,** Manager, Engineering Technical Support; **James V. Fayer,** Manager, Digital Communications Equipment Engineering; **Daniel Hampel,** Manager, Advanced Communications Laboratory; **Irving Joffe,** Manager, Communications Equipment Engineering; **Robert S. Lawton,** Manager, Transmission Equipment Engineering; **Anthony Liquori,** Staff Engineer; **Alfred Mack,** Staff Engineer; **Donald L. Miller,** Manager, Engineering Administration and Services; and **John L. Santoro,** Manager, Communications Systems.

James V. Fayer, Manager, Digital Communications Equipment Engineering has announced the organization as follows: **Robert H. G. Chan,** Manager, Digital Equipment Technology; **George Dardarian,** Manager, Telephone Systems Engineering; **Marvin I. Stricker,** Manager, Telex Implementation; **Daniel A. Tannenbaum,** Manager, Engineering Administration Controls, **Robert D. Torrey,** Staff Engineer; and **Donald B. Wolfe,** Staff Engineer.

Mobile Communications

Donald O. Reinert, Director, Marketing has announced the appointment of **Jerry J. Donahue** as Manager, Market Planning and Development.

RCA Avionics Systems

John P. Mollema, Director, Marketing, has announced the appointment of **Gordon H. Borth** as Manager, Government Sales.

RCA Laboratories

William M. Webster, Vice President, RCA Laboratories, has announced that the Manufacturing Systems and Technology activity is transferred to the RCA Laboratories. **James L. Miller** continues as Director, Manufacturing Systems and Technology, and reports to **Thomas O. Stanley,** Staff Vice President, Research Programs.

Richard E. Quinn, Director, Finance and Technical Services, has announced the appointment of **Emil V. Fitzke** as Manager, Technological Services at the Laboratories.

James J. Tietijen, Director, Materials Research Laboratory, has announced the organization as follows: **Roger W. Cohen,** Head, Physics and Chemistry of Solids Research; **Benjamin Abeles,** Fellow, Technical Staff; **Ralph W. Klopfenstein,** Fellow, Technical Staff; **Henry Kressel,** Head, Semiconductor Device Research; **Richard Denning,** Manager, Advanced Power Engineering (SSD); **Jacques I. Pankove,** Fellow, Technical Staff; **Harold B. Law,** Staff Advisor; **David Richman,** Head, Semiconductor Materials Research; **Joseph J. Hanak,** Fellow, Technical Staff; **John A. VanRaalte,** Head, Displays and Device Concepts Research; **Kern K. N. Chang,** Fellow, Technical Staff; **P. Niel Yocom,** Head, Luminescent and Electro-Optic Materials Research; and **Simon Larach,** Fellow, Technical Staff

Nathan L. Gordon, Director, Systems Research Laboratory, has announced the organization as follows: **Jack Avins,** Staff Engineer; **Allen A. Barco,** Staff Advisor; **Istvan Gorog,** Head, Physical Electronics Research; **Karl G. Hernqvist,** Fellow, Technical Staff; **Thornley C. Jobe,** Staff Engineer; **Bernard J. Lechner,** Head, Color Television Research; **Dalton H. Pritchard,** Fellow, Technical Staff; **Robert D. Lohman,** Head, Television Circuits Research; and **Alfred H. Teger,** Head, Advanced Systems Reserach.

Awards

RCA Laboratories

Dr. Jacques I. Pankove, Fellow, Materials Research Laboratory, received the 1975 IEEE J.J. Ebers Award at the annual International Electron Devices meeting Dr. Pankove was cited "for outstanding technical contributions to electron devices including alloy bipolar transistors, photoelectric devices, early demonstration of efficient light emitting diodes, room temperature and visible light lasers, and for the concept and study of radiative tunneling."

Award winners (left to right, seated) Jay Hoover, Dave Sapp, Dick Orr, Al Foster, and Jim Devlin with Leader Ollie Bessette (standing) who is holding a 164-channel magnetic tape head.

Government Communications Systems Division

The team of **Jim Devlin, Al Foster, Jay Hoover, Dick Orr,** and **Dave Sapp** of Recording Systems has received a Technical Excellence Award for outstanding work in the development of the High Density Multitrack Recorder (HDMR). Their efforts have resulted in a recent sole source contract from NASA for an Engineering Model of a 240 Mb/s spacecraft recorder for the EOS Program.

The team of **Fred Bartholomew, Ed Donald, Ken Funk, Mike Kleidermacher, Bernie McNelis, Al Michel** and **Rich Reindl** received a Technical Excellence Award for outstanding work in the development of a family of CMOS LSI arrays for the Tenley Program. The use of these arrays resulted in improved performance and reduced size and pwoer consumption as compared with previous systems configurations.

Award winners (standing, left to right) Ken Funk, Rich Reindl, Bernie McNelis, Fred Bartholomew, Ed Donald, Al Michel, and Mike Kleidermacher. Seated (left to right) are E. (Chip) McGrogan, Leader; Charley Schmidt, Manager; and Bob Torrey, Staff Engineer.

Kirkwood receives Consumer Electronics Award

Loren R. Kirkwood, a pioneer in consumer electronics engineering for 45 years, has received the 1975 Consumer Electronics Award of the IEEE, Consumer Electronics Group.

Mr. Kirkwood, who is chief technical consultant to RCA Consumer Electronics, has been active since 1930 in the design and development of radios, phonographs, black-and-white and color television, and home video players. A graduate of Kansas State University with a BSEE degree, Mr. Kirkwood rose to the position of Division Vice President, Television Engineering and Strategic Planning, RCA Consumer Electronics in 1974.

Promotions

Astro-Electronics Division

R.C. Shultz from Engr. to Mgr., (Specialty) Engrg. (G. Barna, Hightstown)

C.A. Berard from Engrg. to Mgr. (Specialty) Engrg. (A. Aukstikalnis, Hightstown)

Missile and Surface Radar Division

J.V. Amatrudi from Tech. Opns. Anal. to Admr. Logistics (T. Stecki, Moorestown)

P.G. Anderson from Sr. Mbr. Engrg. Staff to Princ. Mbr. Engrg. Staff (J. Stringer, Moorestown)

D.C. Drumheller from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (T. Burke, Moorestown)

F. Kurtz from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (T. Stecki, Moorestown)

M. Lee from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (W. Perecinic, Moorestown).

A.J. Mastrogiovanni from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (R. Kolc, Moorestown)

F. Ogle from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (E. Fox, Moorestown)

E.J. Smith from Engrg. Support Anal. to Mbr. Engrg. Staff (F. Stewart, Moorestown)

N. Synderman from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (B. Matulis, Moorestown)

R. Wood from Sr. Mbr. Engrg. Staff to Ldr., Eng. Sys. Proj. (H. Boardman, Moorestown

W. Armstead from Sr. Mbr. Engrg. Staff to Ldr. Des. & Dev. Engrs. (W. Patton, Antenna & Micro Systems, Mrstn.).

W. Atwood from Ldr. Engrg. Sys. Proj. to Mgr., Projects (R. Howery, WCS/FCS Project and ORTS C/P, Mrstn.).

P. Bronecke from Assoc. Mbr. Engrg. Staff to Mbr. Engrg. Staff (J. Bauer, Adv. Cir. Dev. & Tech. Labs., Mrstn.).

T. Clark from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (E. Schwartz, AN/TPQ-27 Program, Mrstn.).

M. Fink from Sr. Mbr. Engrg. Staff to Mbr. Proj. Mgmt. Staff (E.W. Petrillo, TPQ-27 Program, Mrstn.).

F. Freiman from Mgr. Sys. Economics to Dir. PRICE Sys. (D. Shore, PRICE Program, Mrstn.).

D. Fuerle from Sr. Mbr. Engrg. Staff to Ldr., Engrg. Sys. Proj. (J. W. Haake, Weapon System Software Development, Mrstn.).

R. Jones from Mbr. Engrg. Staff to Sr. Mbr. Engrg. Staff (P. Beadle, WCS&C&C Equipment, Mrstn.).

M. Levinson from Sr. Mbr. Engrg. Staff to Principal Mbr. Engrg. (R. Lieber, Sys. Design Analysis, Mrstn.).

I. Maron from Ldr., SEER from Mgr. Adv. Tactical Prog. (D. Shore, Advanced Programs).

L. Stander from Ldr. Engrg. Sys. Proj. to Mbr. Proj. Mgmt. Staff (E. W. Petrillo, TPQ-27 Program, Mrstn.).

RCA Service Company

T.H. Brown from Sys. Sv. Engr. to Ldr., Sys. Sv. Engr. (B. Schell, Johnsville, PA).

W.C. Johnson from Ships Sys. Engr. to Mgr., Ships Instrumentation (D.E. Price, U.S.N.S. Vandenberg, Patrick AF Base, FL)

R.N. Krumenacker from Engr. to Ldr., Engrs. (R.D. Clubb, Hyattsville, MD)

C.M. Leech from Sys. Sv. Engr. to Ldr., Engrs. (R.F. Schneider, Atlantic Underseas Test & Evaluation Center Project — FL)

Picture Tube Division

T. R. Conway from Mgr., Engineering Svcs. to Mgr., Plant Engineering (J.S. Ignar, Manager, Scranton Plant).

G. J. McCauley from Engrg. Tech. Elec./Mech. to Mgr., Engrg. Stds., Color (A. Morrell, Mgr., Design Lab. & Engrg. Stds., Lanc.).

N. R. Thornton from Engrg. Prod. Dev. to Mgr. Eng. Projects Equip. Design and Development (C.E. Shedd, Mgr., Equipment Design & Development, Lanc.).

T. E. Swander from Mgr., Plant Engineering, Harrison and Woodbridge to Mgr., Plant Engineering (J. Fanale, Circleville)

Solid State Division

R.Jarl from Mbr. Tech. Staff to Ldr. Tech. Staff, Applications Engineering, High Reliability & RF Dept. (M. Geller, Somerville)

M. Rosenfield from Mbr. Tech. Staff to Ldr., Tech. Staff, Assembly Technology of Bipolar IC Engineering Dept. (L.A. Jacobus, Somerville)

Commercial Communications Systems Division

D. Hall from Member, Engrg. Staff to Mgr., Mobile Quality Assurance & Inspect (C. Lowe, Meadow Lands)

C. G. Rauchfuss, Jr. from Sr. Member of the Engineering Staff to Leader, Engineering Staff (R.E. Jansen, Recording and Television Equipment Camden).

RCA Alaska Communications, Inc.

D.E. Brendgard from Sr. Engrg. Assoc. to Supervisor, Field Installation (A.F. Perkins, Anchorage, AK)

L.D. Herlocker from Engr. A to Mgr., Interim Pipeline System (G.P. Roberts, Anchorage, AK)

A.J. Mack from Sr. Engrg. Assoc. to Supervisor, Field Installation (F.E. Tinch, Anchorage, AK)

September RCA Review dedicated to Albert Rose

Albert Rose, a Fellow of the Technical Staff at RCA Laboratories, retired recently after almost forty years with RCA. The September 1975 issue of the *RCA Review* is a collection of articles by several of his colleagues dedicated to Dr. Rose's work over those forty years.

Quoting from the introduction written by **Dr. Richard Williams:**

"Those who have worked in this field [electronic vision] have felt the profound influence of Albert Rose and of his research in vision, electronics, and solid-state physics...This collection of articles, by some of the many people who have worked with him over the years, attests to the continuing activity in the field."

RCA Review, September, 1975
Volume 36, Number 3

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An Approximate Model of the Beam-Blocking Contact in a PbO Vidicon .... Alvin M. Goodman
Semiconductor Heterojunction Vidicons .... C.R. Wronski
Simplicity in Theory: An Anecdotal Account of Current Injection in Solids—In Tribute to Albert Rose .... Murray A. Lampert
Photoconductivity in Amorphous Semiconductors .... Richard H. Bube
Speed of Response of Photocurrents in CdSe .... H. Kiess and B. Binggeli
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Oxygen Chemisorption and Photodesorption Processes on ZnO Surfaces .... D. Eger, Y. Goldstein, and A. Many
A. Criterion for the Onset of Hot Electron Transport . Richard S. Crandall
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Solar-Cell Capacitance .... A.R. Moore
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Tunneling Conductivity in Granular Metal Films ... B. Abeles
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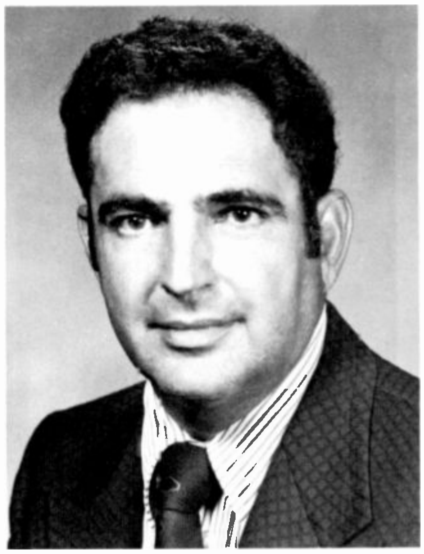
An X-Ray-Sensitive Fiber-Optic Intensifier Screen for Topography .... R.W. Smith

New Editorial Representatives

Editorial Representatives are responsible for planning and processing articles for the *RCA Engineer* and for working with the Technical Publications Administrators in their Divisions to support the corporate-wide technical papers and reports program. A complete listing of Technical Publications Administrators and Editorial Representatives is provided on the inside back cover of each *RCA Engineer* issue.



Meena named Ed Rep for Circleville

John Fanale, Director of Glass Operations, Circleville, Ohio, has announced the appointment of **Nicholas Meena** as *RCA Engineer* Editorial Representative for the Circleville Glass Plant.

After receiving the BSME in 1951 from the University of Pennsylvania, Mr. Meena joined RCA in Camden as a specialized trainee and was assigned to the Picture Tube Plant at Marion, Indiana, as a Methods Engineer. He transferred to Production Engineering in 1953 and was promoted to Manager within that activity in 1959. In September 1969, he was named Manager of Production Engineering. He transferred to Circleville in 1974 as Manager of Production Engineering, responsible for process engineering, mold design, mold fabrication, and computer applications.

Smith is Ed Rep for Burlington

Ken Palm, Technical Publications Administrator, Automated Systems Division, has appointed **Larry B. Smith** as Editorial Representative for Automated Systems Division at Burlington, Mass.

Mr. Smith has attended the University of New Hampshire and Boston University where he specialized in the fields of accounting and economics. He joined RCA's Financial Operations in Waltham, Mass in 1956. His responsibilities during the years included contract and overhead control budgets, scheduling, manpower planning, cost estimating, project plans and space and facilities. Larry was promoted to Administrator, Manpower and Budgets, in 1969 and currently holds that position on the Chief Engineer's Staff.

Professional activities

Record Division

Devendra Mishra, Manager, Engineering Services, RCA Records, Indianapolis, is Editor of *AIEE News* a quarterly bulletin of the Planning and Production Control Division, American Institute of Industrial Engineers. Mr. Mishra is Director-Elect of the division and will assume the directorship in April, 1976.

W. Rex Isom, retired Chief Engineer of RCA Records, is President-Elect of the Audio Engineering Society to become President in the fall of 1976.

Astro-Electronics Division

C. Robert Hume was a member of an international panel that discussed a proposed new satellite system to aid transoceanic air traffic control and communcations at the sixth US-European Conference on the Aeronautical Satellite (Aerosat). Mr. Hume is manager of Space Communications Systems.

(Professional activities continued)

Missile and Surface Radar Division

R.J. Rader participated in a recent three-day workshop on Management of Large Software Projects at New Jersey Institute of Technology. **P.G. Anderson** was Program Coordinator of the workshop.

Automated Systems Division

Dick Cahoon, Burt Clay, and **Bob Bosselaers** were recognized by Northeastern University for their achievement in Continuing Education. Each man was awarded a Certificate of Achievement for completing twenty credits of continuing education courses at Northeastern.

Government Communications Systems Division

Boris H. Rosen, Leader, Electron Devices Group, Parts Applications in GCSD's Central Engineering activity has been nominated and elected for his sixth consecutive term as chairman of the Electronic Industries Association's G-12 Committee on Solid State Devices.

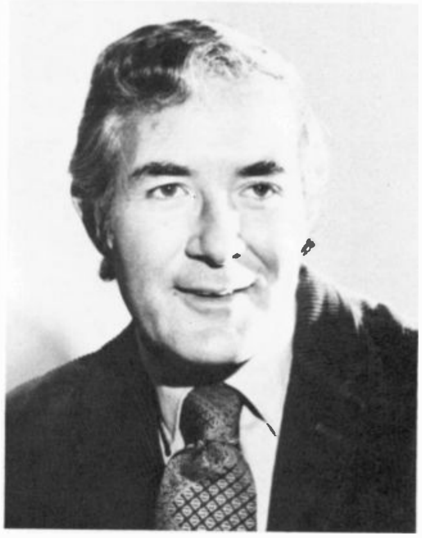
Errata

Otto Schade, Jr., (left) accepts SID award on his father's behalf. Philip Damon (right) is SID awards/honors chairman and Joseph Bryden (center) from Raytheon is also an award winner.

Otto Schade, Sr., recently received an award from the Society of Information Display "for the pioneering applications of frequency response concepts to the analysis and optimization of electro-optic systems." Our last issue (p.95) contained a picture of the award ceremonies which was incorrectly cropped and labeled. The photo is shown correctly here. Actually, Mr. Schade was unable to the attend the ceremonies and his son, Otto Schade, Jr., accepted on his behalf.

In "Chemical conservation in the Solid State Division" by Epifano, Zuber, and Amick (p.55, last issue), the pictures of Messrs. Epifano and Zuber were interchanged.

Schoen is TPA for Solid State



Eleanor McElwee, Manager, Engineering Publications, has announced the appointment of **John E. Schoen** as Technical Publications Administrator for Solid State Division.

Mr. Schoen received the BS in Physics from the Polytechnic Institute of New York and the MA in English Literature (*magna cum laude*) from Fairleigh Dickinson University. Prior to joining RCA in 1966, he was employed in a number of writing and editing positions, including that of Department Editor with the System Development Corporation and Senior Associate Technical Writer with IBM. His responsibilities with the Solid State Division have included participation in planning, writing, editing, and production of all forms of printed communication originated within the Division.

Obituaries

Matt Hollander

Matthias Hollander, Manager of Engineering Information Services for the Astro-Electronics Division in Hightstown, N.J., died on October 3. He was 59. Mr. Hollander received the AB in English from Harvard University in 1938 and certificates of education in Electronics Engineering from the University of Maine in 1943. He was with RCA for 18 years — 15 of those years at AED. He was also a Documentation Specialist for 3 years with the Philco Corporation and for 3 years with the U.S. Naval Air Development Center. He spent 3 years with the USAF Watson Laboratories performing industrial liaison with Government contractors. Additionally, Mr. Hollander taught Technical Writing at Penn State University. He was a member of the Society of Technical Writers and Publishers, Mensa Society, IEEE, American Documentation Institute, and AIAA.

Hans Burri

Hans U. Burri, a Senior Engineering Scientist at Automated Systems Division in Burlington, Mass. died on July 1; he was 53. He received the diploma in Mechanical Engineering from the Swiss Federal Institute of Technology in Zurich Switzerland in 1946. Joining RCA in 1961, his original assignments were almost exclusively concerned with astrodynamics and navigation and guidance of spacecrafts. He participated in studies of automatic rendezvous and docking operations and was a member of the RCA-LM team since its formation. During 1966 he headed a team of RCA engineers who performed a study of integrated electronics for an advanced space vehicle. Next, he was technical director for the RCA in-house space shuttle avionics effort. His most recent work involved studies of non-electronic test engineering.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

Government and Commercial Systems

Astro-Electronics Division	**I.M. SEIDEMAN*** Engineering, Princeton, N.J.
Automated Systems Division	**K.E. PALM*** Engineering, Burlington, Mass. **A.J. SKAVICUS** Engineering , Burlington, Mass. **L.B. SMITH** Engineering, Burlington, Mass.
Commercial Communications Systems Division	
Broadcast Systems	**W.S. SEPICH*** Broadcast Systems Engineering Camden, N.J. **R.E. WINN** Broadcast Systems Antenna Equip. Eng., Gibbsboro, N.J. **A.C. BILLIE** Broadcast Engineering, Meadowlands, Pa.
Mobile Communications Systems	**F.A. BARTON*** Advanced Development, Meadow Lands, Pa.
Avionics Systems	**C.S. METCHETTE*** Engineering, Van Nuys, Calif. **J. McDONOUGH** Equipment Engineering, Van Nuys, Calif.
Government Communications Systems Division	**A. LIGUORI*** Engineering, Camden, N.J. **H.R. KETCHAM** Engineering, Camden, N.J.
Government Engineering	**M.G. PIETZ*** Advanced Technology Laboratories, Camden, N.J.
Missile and Surface Radar Division	**D.R. HIGGS*** Engineering, Moorestown, N.J.

Research and Engineering

Laboratories	**C.W. SALL*** Research, Princeton, N.J.

Solid State Division

J.E. SCHOEN* Engineerig Publications, Somerville, N.J.
H.R. RONAN Power Devices, Mountaintop, Pa.
S. SILVERSTEIN Power Transistors, Somerville, N.J.
A.J. BIANCULLI Integrated Circuits and Special Devices, Somerville, N.J.
J.D. YOUNG Manufacturing, Findlay, Ohio
R.W. ENGSTROM Electro-Optics and Devices, Lancaster, Pa.

Consumer Electronics

C.W. HOYT* Engineering, Indianapolis, Ind.
R.J. BUTH Engineering, Indianapolis, Ind.
P.E. CROOKSHANKS Television Engineering, Indianapolis, Ind.
F.R. HOLT Advanced Products, Indianapolis, Ind
J.S. OLIVER Manufacturing Operations, Indianapolis, Ind.

RCA Service Company

J.E. STEOGER, Consumer Services Engineering, Cherry Hill, N.J.
R. MacWILLIAMS, Marketing Services, Government Services Division, Cherry Hill, N.J.
R.M. DOMBROSKY Technical Support, Cherry Hill, N.J.

Distributor and Special Products Division

C.C. REARICK* Product Development Engineering, Deptford, N.J.
J.N. KOFF Receiving Tube Operations, Harrison, N.J.

Picture Tube Division

C.A. MEYER* Commercial Engineering, Harrison, N.J.
J.H. LIPSCOMBE Television Picture Tube Operations, Marion, Ind.
E.K. MADENFORD Engineering, Lancaster, Pa.
N. MEENA Glass Operations, Circleville, Oh.
J. NUBANI Television Picture Tube Operations, Scranton, Pa.

RCA Global Communications, Inc.

W.S. LEIS* RCA Global Communications, Inc.,New York, N.Y.
P. WEST* RCA Alaska Communications, Inc., Anchorage, Alaska

NBC, Inc.

W.A. HOWARD* Staff Eng., Technical Development, New York, N.Y.

RCA Records

J.F. WELLS* Record Eng., Indianapolis, Ind.

RCA Ltd

W.A. CHISHOLM* Research & Eng. Montreal, Canada

Patent Operations

J.S. TRIPOLI Patent Plans and Services, Princeton, N.J.

Electronic Industrial Engineering

J. OVNICK* Engineering, N. Hollywood, Calif.

*Technical Publications Administrators (asterisked * above) are responsible for review and approval of papers and presentations

RCA Engineer
A TECHNICAL JOURNAL PUBLISHED BY CORPORATE TECHNICAL COMMUNICATIONS
"BY AND FOR THE RCA ENGINEER"

Printed in U.S.A.

Form No. RE-21-4