RCA Engineer

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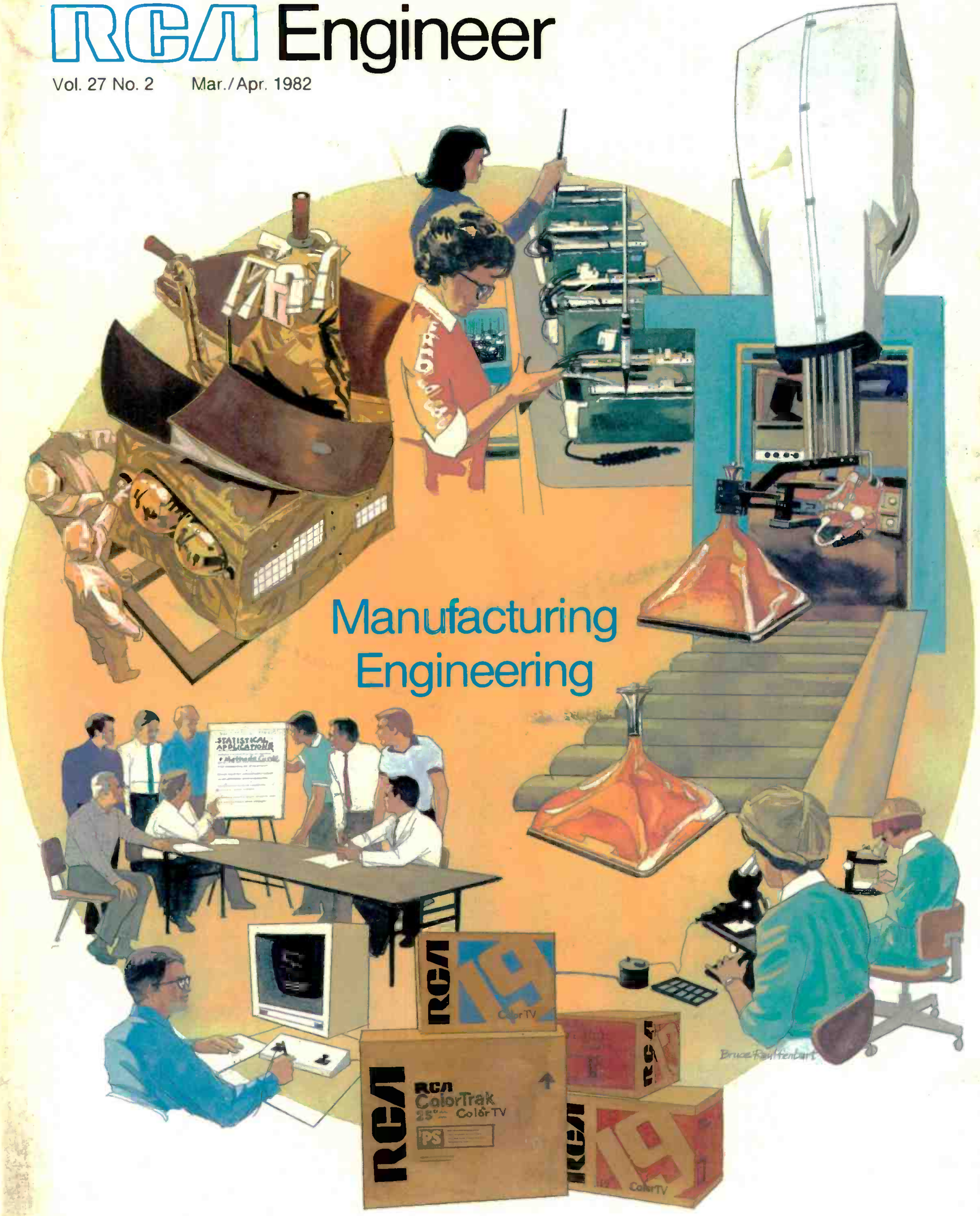

Manufacturing Engineering

Cover design by Louise Carr
Cover illustration by Bruce Rauffenbart
Illustrations on pages 22-23, 39-40 by Gerald Kolpan

Our cover shows some of the wide-ranging concerns of manufacturing engineers. Included are scenes, counterclockwise from the top, of quantity and custom manufacturing, quality circles dealing with statistical methods, computerized methods, packaging, testing, and robotics. Authors in this issue examine these subjects and others.

The following government reports on the state of manufacturing engineering may interest you and supplement the contents of this issue.

- Computer-Aided Manufacturing: An International Comparison;
- Improving Managerial Evaluations of Computer-Aided Manufacturing;
- Innovation and Transfer of U.S. Air Force Manufacturing Technology;
- Portability and Integration of CAD/CAM Modules: Definition and Measurement;
- Strategic Issues in the Investment Process Involving New Technologies;
- Technical Review of the ICAM Program, June 25-27, 1980;
- Technical Review of the ICAM Program, February 1981; and
- Committee on Computer-Aided Manufacturing: Report on Activities.

In addition, a report on the problems of manufacturing engineering education from the perspective of industry is included in the "Report on Activities." You must include postage and handling fees to receive the reports.
They are available from:

Committee on Computer-Aided Manufacturing (COCAM)
National Academy of Sciences
2101 Constitution Avenue, N.W.
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—MRS

RCA Engineer

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

B.L. Borman

Manufacturing programs at Consumer Electronics

In the 70s, the U.S. consumer electronics industry witnessed a tremendous influx of Japanese-made products that were highly competitive from both a quality and cost point of view. The signal to U.S. producers was clear—improvements must be made to remain competitive. We, at RCA Consumer Electronics, made an all-out effort to improve the compatibility of design with manufacture, significantly increased investments in mechanization and automation, and highlighted productivity and quality as our first order of business.

Due to the very large volume of production, the necessary transition in manufacturing had to be evolutionary rather than revolutionary, dramatically improving chassis cost reduction and quality and still leaving much to be done in components, tuning systems, and instrumentation. An integration of new manufacturing technology and existing methodology has been achieved in many areas. Extensive use of computer-oriented test systems and board insertion equipment marked the largest inroads in automation.

Manufacturing Engineering was strengthened at the Division Home Office and at each of the manufacturing locations, with programs that include automatic component insertion, automatic test and alignment, manufacturing control systems, semiautomatic instrument set-up, computer-based winding techniques, and a commitment to upgrade component and ferrite production facilities.

Complementing Consumer Electronics efforts is the Manufacturing Technology Center (MTC), a satellite laboratory of the RCA Laboratories, which has been established for the purpose of evaluating and developing new manufacturing methods. Areas being developed include robotic applications such as spray painting and odd-form-factor parts insertion. Hard automation programs being developed include automatic keyboard assembly and conveyorized automatic packaging and delivery for plastic cabinets. Factory information systems include FACTS (Factory Analysis and Control Tracking System). FACTS collects data, analyzes the data through statistical techniques and provides production control using feedback of real-time production information.

Today, manufacturing at CE, including television receiver and video disc player manufacture, relies on a balanced proportion of technical resources, investment, facilitation, and product design that is directed to improved productivity, product yields, and reliability. The goal is to make RCA products competitive with the best in the world.

B L Borman

Bennie L. Borman
Director, Manufacturing Engineering
and Technology
Consumer Electronics Division

RCA Engineer

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manufacturing engineering: contemporary themes

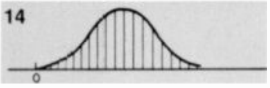
manufacturing engineering: applications

on the job/off the job

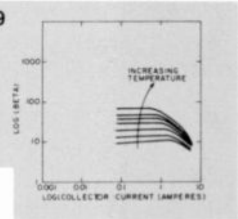
departments

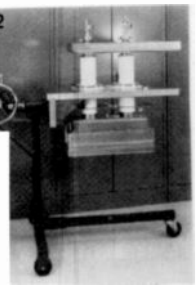
in this issue ...
manufacturing engineering

- **D'Arcy/Miller:** *"As indicated in the preceding paragraphs, significant evidence shows that a 'cross-over' of technology already exists between custom manufacturing and mass production."*
- **Gunter/Rayl:** *"But we feel that the lessons of the past few years—particularly in the electronics industry—have demonstrated the vital importance of bringing statistical methodology into our traditional manufacturing environments."*
- **Mishra:** *"To achieve the objectives of the PTC, it was imperative that the interface between Player Engineering and Manufacturing Engineering be established at the outset ...."*
- **Mecca:** *"We are committed to maintaining and improving our competitive position. We are committed to Quality Circles."*
- **Blumenfeld/Shambelan:** *"In order to coordinate the decision-making process for new equipment procedures, RCA has established technology committees that meet periodically."*
- **Young:** *"NC is an excellent example of how computers can be effectively used in manufacturing."*



- **Chen:** *"This program simulates the actual forming processes and accurately predicts the forming loads, the metal flows, the stress and strain distributions, and the shapes and dimensions of the final products."*
- **Haggerty:** *"Packaging is essential to the manufacture of the product."*
- **Philip:** *"The parylene-coating process involves heating a parylene dimer, which splits to form a monomer that polymerizes on the surface of the equipment to be coated."*
- **Lynch/Reed:** *"The success of this government-funded, joint laboratory/electronics-industry venture has been interpreted in some quarters as justification for seeking industry involvement earlier in the design of such large-scale projects."*
- **Snowden/Amantea:** *"The automated test system is an excellent engineering tool, providing accurate measurements and rapid graphical presentation of the data."*





- **Schneider:** *"As noted previously, I began my hobby by learning how to make a telescope mirror."*

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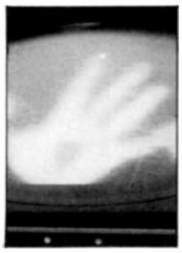
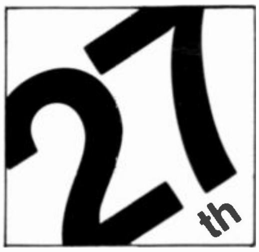
in future issues ...
electro-optics
anniversary issue
microwave technology
modelling, simulation, and analysis

J.A. D'Arcy | R. Miller

Custom and Quantity Manufacturing: An Engineering Comparison

While one flawless satellite is being put together, over a half million quality VideoDisc players could leave the assembly line. Differences and similarities in these two styles of production tell us a lot about manufacturing engineering.

Generally, in a custom manufacturing operation, a few (perhaps one to more than a hundred) of each of many unique products are manufactured. At RCA Astro-Electronics (Princeton) many different types of satellite systems and subassemblies have been and are being designed, but only a relatively few of each have been manufactured. These include the TIROS weather satellite, different versions of a synchronous communications satellite, and the space shuttle television system. In contrast, a mass production operation manufactures many (perhaps greater than 100,000) copies of each of a few unique products. In RCA Consumer Electronics (Indianapolis), examples of the product lines include the VideoDisc player, a variety of color television models, and so on. Both operations pursue the same major goals: realize technical requirements; minimize cost; maximize quality and reliability; and provide customer satisfaction. But, the methods of manufacturing and testing each unit can be quite different.

At RCA Astro-Electronics, the manufacturing engineer (see box page 6) must develop manufacturing processes that apply to a variety of products, while allowing efficient manufacturing of each product. Here, automation is used to the extent feasible. For example, numerically controlled machines are used for circuit board welded-wiring, for milling-machine operation and for drilling control. Automation is also used for testing where feasible. The Manufacturing Automated Test System (MATS), which is computer-based, is used for testing circuit boards and electronic boxes. MATS is flexible enough to test (with some programming changes) a variety of different boards or boxes.

Abstract: *RCA manufactures a wide range of products, from the custom-built synchronous communications satellite at Astro-Electronics to the mass-produced VideoDisc player at Consumer Electronics. The major goals for each product are the same: realize technical requirements; maximize quality and reliability; minimize cost; and provide customer satisfaction. But the methods used for designing, manufacturing, and testing a custom-built product can be quite different from those used for a mass-assembled product. This paper describes each approach and compares the manufacturing engineering required, in each case, to translate the design into the desired product.*

The Manufacturing Engineer: Custom

In a custom-manufacturing operation, the manufacturing engineer designs, develops, and implements the required manufacturing and test methods and processes. He must plan the work flow, and arrange the layout of the production areas and equipment, for the most efficient and productive operation.

The manufacturing engineer must become involved with the product early in the design phase, to ensure that the design of the product and the available processes and methods are compatible. The manufacturing engineer must develop and use the most cost-effective method of producing a small quantity of many different items. The engineer must remain involved during the production to rapidly solve problems that arise and to improve the process where possible.

In the case of spacecraft manufacturing, the responsibilities of the manufacturing engineer include: the development of processes to machine and assemble parts using aerospace materials; the design and development of special tooling and handling fixtures for assemblies ranging from miniature circuits to very large spacecraft; and the design, development and application of automated test equipment.

Many of the tests on each of the Landsat satellite television (return-beam vidicon) cameras were performed using an HP 2114 computer system. This computer processed and analyzed such data as shading and geometric distortion, so that many repeatable tests could be performed rapidly on each camera. Such techniques as welded wiring of circuit boards permit design-changes (for example, customer modifications) to be made throughout the testing and evaluation of the few units being produced.

At Consumer Electronics, the manufacturing engineer (see box, page 10) must develop a unique manufacturing process for producing many units of a product line at a minimum cost per unit. Automation and mechanization are used wherever possible, because the equipment can be liquidated over a large number of manufactured units and because the number of units produced per hour of manpower becomes a vital measure of productivity. In this instance, computer-based testing, where possible, minimizes the time per test and provides repeatable testing over many units. Printed circuit boards are used where possible, because they can be duplicated in great quantities very rapidly, all containing the copper traces as well as imprinted circuit functions and part legends. The design must be proven through substantial evaluation, before production starts, to avoid modidification to existing equipment. Subsequently, if design improvements are made, they can be "cut-in" to production at an appropriate point.

facturing and mass-production manufacturing, showing the involvement of the corresponding manufacturing engineer. In conclusion, we will list features of each form of manufacturing that have beneficially "crossed over."

Custom manufacturing

RCA Astro-Electronics is one of the major producers of spacecraft for the U.S. Government and fixed-service communications industry. The early spacecraft—such as the first RCA TIROS weather satellite launched April 1, 1960—were designed, built, and tested under laboratory conditions. Over the past two decades the production of the various types of spacecraft has progressed from the laboratory to become a manufacturing operation. Although the component parts such as semiconductor devices, resistors, capacitors, solar cells, connectors, and fasteners are produced in quantity, the spacecraft itself and its subassemblies are custom manufactured in relatively small quantities.

Each spacecraft is a unique assembly of mechanical parts, electromechanical devices, and electronic units to perform a particular mission—such as meteorologic observation, scientific measurement, navigation, or communication. The spacecraft must perform this mission without maintenance or repair in space for up to ten years. Extensive testing is performed at the component, circuit board, unit, subsystem and spacecraft level to assure that performance standards throughout mission life will be met.

The state-of-the-art of the spacecraft payloads is constantly advancing, resulting in continuous design changes. With very few exceptions, the maximum number of spacecraft with an identical configuration is three. Electromechanical devices such as solar-array drives and momentum wheels, and electronic units such as central processor units and solid-state radio-frequency (rf) amplifiers are used in identical configurations on many spacecraft, so that the number of such units built can be between ten and a few hundred.

The result is that spacecraft production is a custom-manufacturing operation bounded by low volume, high reliability, intensive test, and frequent changes. The challenge to both the design and the manufacturing engineer is to design the spacecraft and the processes for production within these boundaries and at the lowest possible cost to remain competitive and to maintain profit. The use of computer-aided design, numerically controlled machining, numerically controlled wiring, and automated testing has enabled RCA to meet this challenge.

Design

The space environment and the absolute necessity to reduce size and weight, while maintaining reliability by use of qualified component parts, constrain the design engineer in some respects. But the design

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must be geared to the most efficient manufacturing processes within the boundaries cited above. An example is the use of welded wire for interconnection of integrated circuit components on the circuit boards for the central processor unit and the command interface units of the weather satellites (Fig. 1).

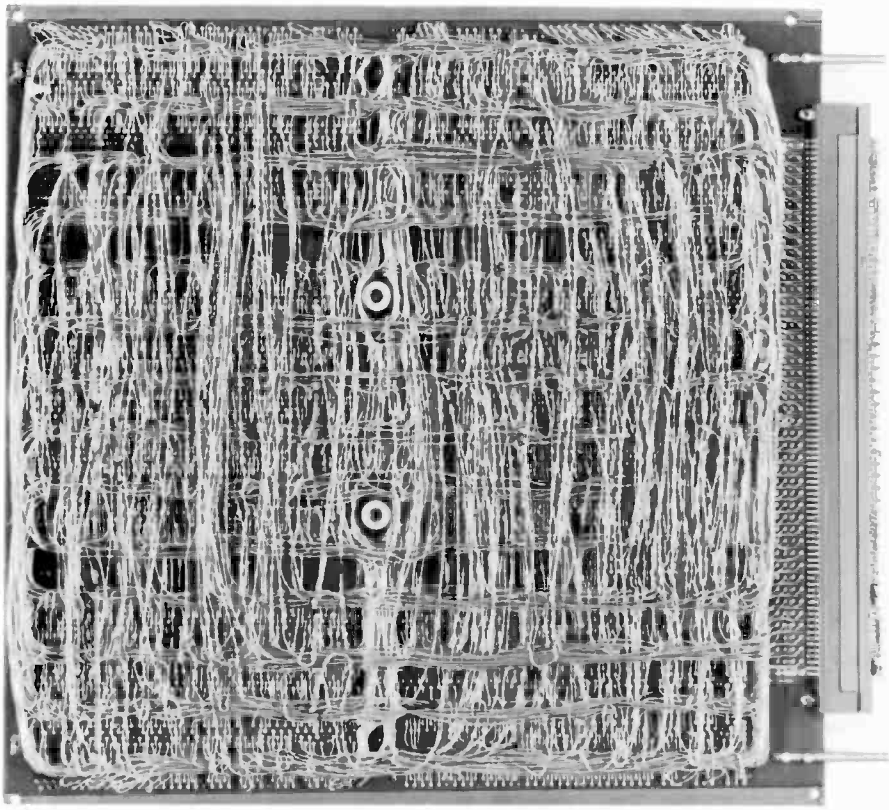
Fig. 1. Welded-wire circuit board. Interconnections between the integrated circuit components are made on the backplane of the circuit board using small-gauge wire welded to pins.

The welded-wire interconnect construction offers cost advantages in this application by:

- Using CAD to obtain the logic diagrams, integrated circuit locations, key pin lists, drill tapes, welded-wire net lists and weld tapes;
- Using automated and semiautomated manufacturing techniques for circuit-board drilling and wiring; and
- Enabling changes to be incorporated in asssembled boards without scrapping high-value components—this is significant in custom-built units, where mission changes directed by the customer affect the in-process hardware.

A second example of how the design affects the manufacturing process is the solid-state rf power amplifier (Fig. 2). In this case, strip-line modular circuit boards were selected to enable automated testing of subassemblies and the completed amplifier, and yet allow manual tuning and component select-at-test for optimal amplifier operation.

Manufacture

The processes used in the production of a custom-manufactured product must be cost effective and controllable to produce small quantities of many different items with a scrap rate approaching zero. The small quantities of high-cost items used in a spacecraft prohibit the use of prototype units or pilot runs. It is now accepted practice in the space industry to fly the first unit built.

Production is structured on the progressive assembly of thoroughly inspected and tested parts, components, assemblies, and units. A flow-process record is established for each assembly, from the lowest identifiable assembly level to the final spacecraft. These records denote all assembly operations, tests, and inspections to be performed on a given assembly and become the historical record for that item when completed.

Productivity has been improved by automation where applicable in the machining, assembly, and test operations. Numerically controlled machining is used for very complex items such as the TIROS instrument mounting platforms.[1]

In constructing circuit boards, the welded-wire interconnections are made using a semiautomatic tape-controlled weld station (Fig. 3). Component insertion and attachment to the circuit board remains a manual operation because of the small quantities and the many different board configurations.

Testing

The Manufacturing Automatic Test System (MATS) is used at RCA Astro-Electronics to perform the automated functional testing of analog and digital circuit boards and boxes before integration in the spacecraft (Fig. 4). The station uses a Perkin Elmer 1610 CPU and Wang 10-megabyte disc with the appropriate mea-

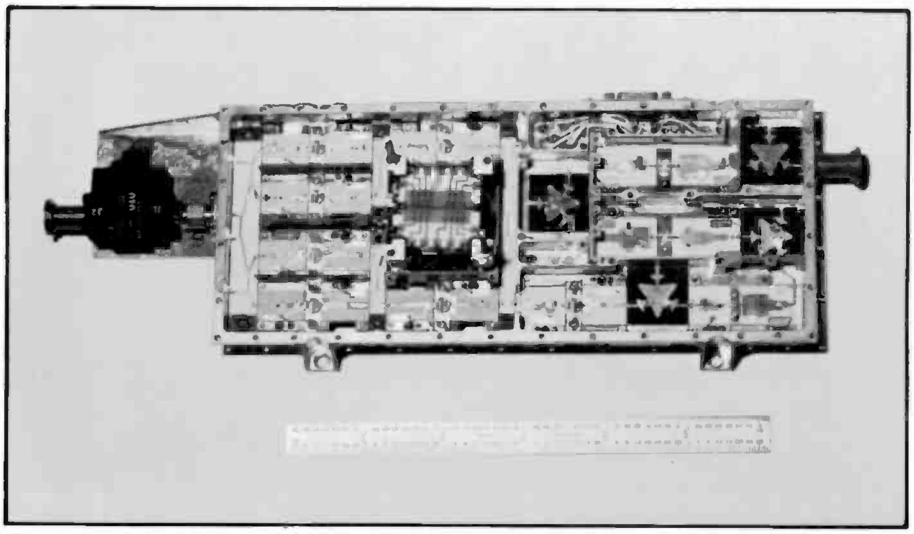
Fig. 2. Solid-state power amplifier (SSPA). Strip-line modules enhance reproducibility and automated testing and enable manual timing for optimal amplifier operation.

Fig. 3. Tape-controlled backplane-wire-welding station. Integrated circuit interconnection wire networks are welded using a tape-controlled weld station.

surement devices, power supplies, clocks, and switching as described by Parikh[2] to stimulate and measure the response of the unit under test.

The test software for the MATS is generated, for each unit to be tested, in a companion Software Development Station (SDA) using a Perkin Elmer 7132 CII CPU and Microsim simulator also described by Parikh.[2] MATS has reduced the test time of a typical circuit board from 10 hours to less than 1 hour, and that of a complex digital box such as the command interface unit from 16 hours to 4 hours.

The functional testing of a typical unit is performed seven times using the MATS (before and after vibration exposure, twice at a high temperature extreme, twice at a low temperature extreme and at a final ambient temperature level). Therefore, use of automated testing reduces the test time of a command interface unit by 84 hours.

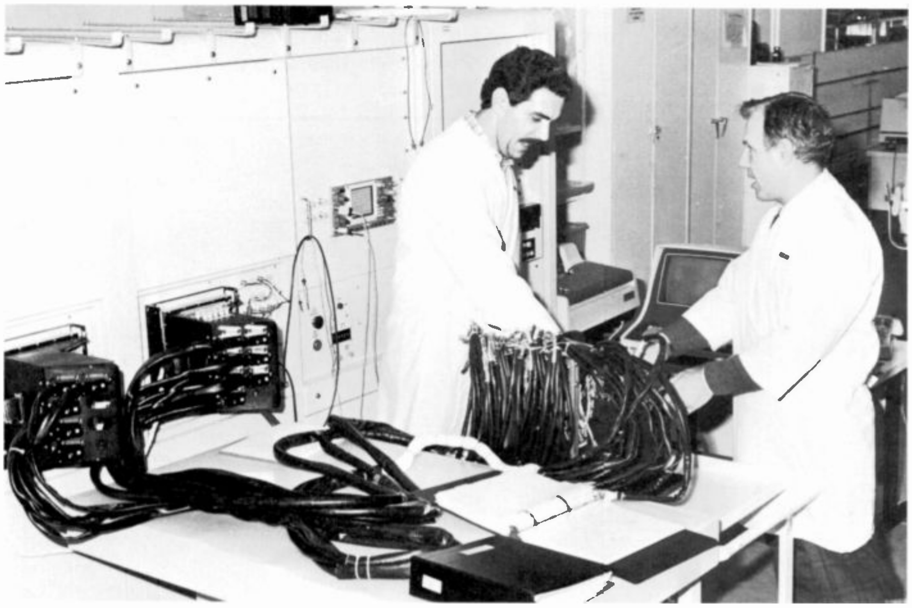

Fig. 4. Manufacturing Automatic Test System (MATS). This test system is used to functionally test a variety of analog and digital circuit boards and boxes. The system provides power and test stimuli, while measuring the response of the unit under test.

Another example of automated testing is the solid-state power-amplifier test system (Fig. 5), which uses an HP 1000 to control four test stations. Each station can perform a variety of rf measurements, display the results in graphical or tabular form on a CRT, and provide a hardcopy record of the results. The stations are used for subassembly and unit-level testing.

After successfully passing their functional tests and a visual inspection, the units are assembled into the spacecraft. An initial test is made to assure that the interface between each unit and the spacecraft is correct. A complete functional test of the spacecraft is then performed to establish the baseline performance of the spacecraft (for the record), and to detect any malfunction or out-of-specification performance. This test is repeated several times while subjecting the spacecraft to a thermal-vacuum environment simulating orbital conditions, before and after exposure of the spacecraft to vibration and acoustic environments, and again at the launch site.

In the case of the TIROS weather spacecraft, the functional test has been automated using the TIROS-N Aerospace Ground Equipment (NAGE). Using the NAGE, we can perform a functional test of the complete spacecraft, including the payload sensors, in seventy-two hours. The data is recorded for future reference and significant performance information presented in printed form for review by Quality Control, Engineering, and the customer (Fig. 6). The NAGE will also compare the recorded data from the several functional tests performed on a given spacecraft and then present trends for selected performance parameters. This trend data is evaluated to detect changes indicative of potential failure, so that corrective action can be taken before launch of the spacecraft.

Salient features

In summary, the salient features of custom manufacturing are: the volume is low with one to a few hundred units being typical; the reliability must be high; the testing is intensive from the component part to the final product; the machining assembly and the test processes must accommodate a small number of many different articles; and all operations must be

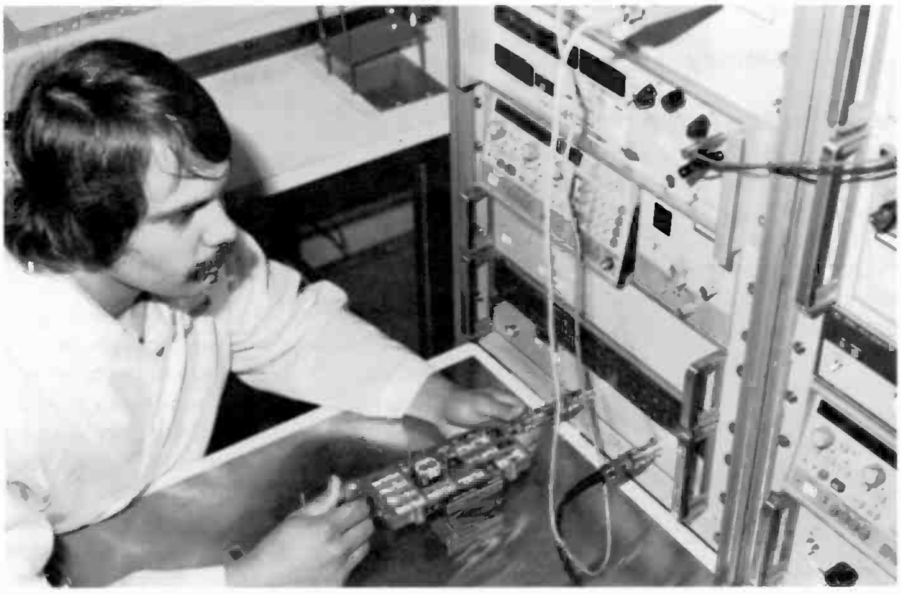

Fig. 5. SSPA test system. The solid-state power-amplifier test system, using an HP 1000, controls four test stations for subassembly and unit radio frequency testing.

accomplished efficiently to remain competitive and to protect the profit.

Mass production

RCA is well known for its manufacture of consumer electronics products, for example, color television receivers.[3] Its most recent entry into the consumer market is the VideoDisc player.[4] This player, together with the color TV receivers, can now be seen in the show rooms of the thousands of RCA dealers across the United States. Moreover, RCA also mass produces a wide variety of components used in these consumer products—for example, color picture tubes, circuit boards, ferrites, and television cabinets. Other products mass produced by RCA include transistors, integrated circuits, audio records, and VideoDiscs.

In each of these areas, whether it be an existing product line or the start-up of a new product line, three of the primary goals for manufacturing and engineering are:

- To reduce costs so that the profit and competitive positions are maintained (in mass production, a key ingredient is to maximize the number of units produced per hour of manpower);
- To maximize product safety; and
- To improve quality and reliability, thus increasing customer satisfaction.

To accomplish these goals for a new product, manufacturing engineering must become intimately involved in the design phase at least a year before production begins, as Orman and Tinsley indicate.[5] Early involvement gives manufacturing engineers the opportunity to review the design. Engineers can then begin to determine the most efficient method of manufacturing the product and begin to develop the production process with step-by-step procedures for manufacturing, assembling, and testing the product. Above all, the manufacturing engineer must develop a cost-effective process with a procedure for building a quality product in the required quantities. During the coordination effort between design and manufacturing engineering, areas suitable for mechanization and automation will be determined. If the production system is complex enough, a system of production monitoring and analysis will be developed.

Manufacturing process

A process is a step-by-step "recipe" for manufacturing on an assembly line, and it includes the labor requirements, space requirements, assembly rates, assembly machines and tools, test equipment, and other production facilities.[5] Development of the process is evolutionary, beginning with the first meeting between manufacturing engineering and design engineering and continuing, through factory-pilot and preproduction runs, to the start of production. A recent example of process development is that of the VideoDisc player, a complex electromechanical product unlike the television receiver, which is primarily electronic.

For the VideoDisc player, both the process and the production facility were developed concurrently. To quickly provide a production facility, part of plant 1 of RCA Bloomington was renovated and new assembly lines and test equipment

Fig. 6. TIROS-N Aerospace Ground Equipment (NAGE). Three Data General Eclipse computers are used in the automated test equipment to functionally test the entire TIROS weather satellite in 72 hours.

The Manufacturing Engineer: Mass-Assembly

In a mass-production environment, the manufacturing engineer plans and formulates manufacturing and testing processes, procedures, rates and assembly sequences in accordance with production schedules. The engineer must specify the machines, equipment, tools and labor classifications used in assembly or test operations. This specifying may require the analysis of existing methods, equipment and tools.

It is essential that the manufacturing engineer become involved with the product early in the design phase, to determine the most efficient method of manufacturing the product and to begin to develop the production process that is the step-by-step procedure for manufacturing, assembling and testing the product. Essentially, the manufacturing engineer is responsible for developing the most cost-effective method of producing many copies of a quality product rapidly. In addition, the manufacturing engineer must remain involved in this production process to solve production problems rapidly and to improve the process where possible.

In the case of the VideoDisc player, the responsibilities of the manufacturing engineer have included: developing the assembly and test processes; specifying and purchasing the assembly lines and other manufacturing equipment; specifying and operating the computer-based Manufacturing Analysis System (MACS),[10] specifying and operating the signal generation system; and proper operation of the assembly equipment and automatic test equipment (ATE).[8] Because the player is a new electromechanical product, the manufacturing engineer needed to develop many novel assembly and test processes. Continued involvement in the production process for current players merges with the preparation and specification of processes and equipment for future models.

were installed. Through a review of the design, it was determined that the manufacture and test of the player would include the manufacture and test of many subassemblies as well. Six "board" lines are provided for the several circuit boards in the player; three "arm" lines are provided for the arm in the player; and also several "instrument" lines (Fig. 7) are provided for final assembly and test. An additional area is devoted to mechanical subassemblies, for example, the turntable, servo drive, and turntable motor. As a result, the VideoDisc player manufacturing procedure is in reality a compilation of many processes.

Fig. 7. Assembly line for the VideoDisc player. As a player progresses along this assembly line, it is gradually assembled by the many operators stationed along the line. Each operator, in turn, assembles one or more components (for example, the turntable) or subassemblies (for example, control-board assembly). At the end of the assembly operation, the test operation begins. Finally, before the player is transported to packing, the quality evaluation is performed.

In developing a manufacturing process, there are several important considerations, particularly for a long assembly line. First, the sequence of operations for assembly and test are divided into the smallest complete work elements. Since the required production rate is known, the number of the work elements required to assemble and test the product, together with the time required for each work element, must be combined to determine the required number of line operators. A system called "work factor," a predetermined motion/time system, is generally used to determine the time required to perform each work element. Second, the line must be balanced. The line should be running for about two weeks before it is balanced.[5] Then the time-study group will review each operation under actual conditions. With the actual times known, portions of work can be moved from one operator to another for better work balance among operators. Thereafter, for the duration of production, the manufacturing engineer will be improving the process continually so that the cost per unit, and the quality of the product, can be further improved.

Automation

Properly used, automation can reduce costs and improve quality. For VideoDisc player production, automation is used primarily for component insertion and testing. Because many players are being produced daily, the design must be "solid" before production begins, otherwise a large amount of waste will result.

The printed circuit boards are fabricated at RCA Consumer Electronics (Indianapolis) using the automated system described by Arvin.[6] When the boards are delivered to VideoDisc player manufacturing in Bloomington, many of the components (resistors, capacitors, and diodes) are automatically formed, inserted, clipped, and clenched using variable-center-distance (VCD), automated-component-insertion (ACI) equipment such as the unit shown in Fig. 8. As Barrio[7] indicates, the rate for VCD-ACI equipment varies with the number of components inserted; for example, components can be inserted into 50-component boards at the rate of about 200

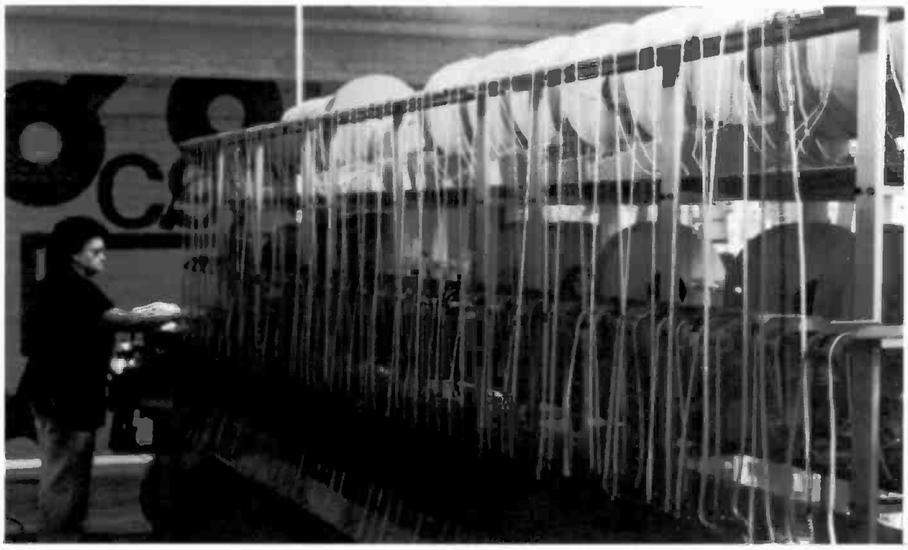

Fig. 8. Automatic component insertion (ACI). This variable-center computer-driven equipment automatically removes components from the reels, bends the leads to the proper dimensions, inserts the circuit components into the lead holes at the correct location on the boards, then crimps and cuts the leads. This equipment can insert components into 50-component boards at the rate of 200 boards per hour.

Fig. 10 Automatic test equipment (ATE). This computer-based tester is one of several that align and test the signal boards of the VideoDisc player. This unit uses computer-controlled motor-driven alignment tools to align the signal-board circuits. It also contains a built-in signal system to provide the test signals used during alignment and test.

boards per hour. To provide the components in the proper sequence for the ACI equipment, an automatic sequencer automatically places the components onto reels in the proper sequence (Fig. 9).

After the automatic insertion of the first group of components, operators who sit in front of in-line conveyor bins insert the remaining components, for example, transistors and integrated circuits. The board moves from one operator to another by means of a conveyor. Thereafter, the boards are moved by conveyor through a solder pot, and after inspection, the boards are moved to the test stations.

Automatic test equipment (ATE) systems, similar to those described by Borman[8], are used to align and test the two most complex circuit boards (control and signal) in the VideoDisc player (Fig. 10). Computer-based ATE systems are particularly useful for improving productivity; they can be used to align and test the circuit boards very rapidly and with very uniform results. The VideoDisc signal board, for example, requires many alignments and tests. To do these manually—using a spectrum analyzer, frequency counter and so on—would take about 30 minutes per board. But the computer-based ATE can perform this function in less than 2 minutes. In the case of the VideoDisc player, the remaining boards are manually tested. Thereafter, the good boards are placed in "mills" ready for the next higher assembly. The automatic test equipment systems used for VideoDisc player production were designed and built by the Test Technology Department of Consumer Electronics (Indianapolis).

Automation is one of the keys to improving productivity, quality, and reliability. Significant use of automation within RCA is a desirable goal where the quantity of product required is large and labor cost and/or availability are limiting. The use of intelligent robots versus dedicated mechanized assembly, pick and place equipment is dependent on cost and the need to make rapid changes in product as well as the volume of product to be produced. These trade-offs are evaluated by manufacturing engineers.

For VideoDisc player production, the several forms of automation include: the conveyor systems, automatic insertion and automatic testing, the turntable-assembly system, the cartridge assembly line, and the stylus micromachining lines.

Quality control and reliability

In any comparison of mass production and custom manufacturing, the philoso-

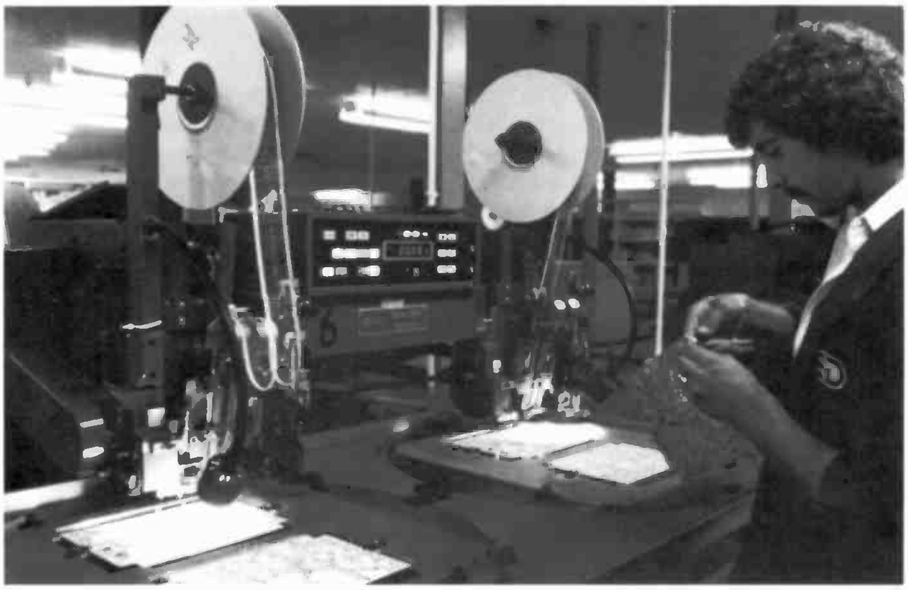

Fig. 9. Automatic sequences. This computer-driven equipment places circuit components (resistors, diodes, and capacitors) in the proper sequence onto reels for use on the Automatic Component Insertion (ACI) equipment. The sequencer measures one or two parameters of each component before placing it on the reel.

Some Folklore

"Folklore has it in America that quality and production are incompatible: that you cannot have both. It is either or. Insist on quality and you will fall behind in production. Push production and find that quality has suffered.

The fact is that quality is achieved by improvement of the process. Improvement of the process increases uniformity of output of product, reduces mistakes and reduces waste of manpower, machine-time, and materials.

Reduction of waste transfers man hours and machine-hours from the manufacture of defectives into the manufacture of additional good product. In effect the capacity of a production-line is increased. The benefits of better quality through improvement of the process are thus not just better quality, and the long-range improvement of market-position that goes with it, but greater productivity and much better profit as well."

—W.E. Deming, Dec. 1981

phies and procedures pertaining to quality control and product reliability must be discussed. Improving quality and reliability leads to greater customer satisfaction and good will, to fewer product returns, (or on-site repairs), and potentially to more sales. Thus, all manufacturing engineers must give as much attention to improving quality and reliability as they do to reducing costs.

The quality control (QC) system used for VideoDisc player production is not unlike that for television production. The quality-control organization tests each player at the end of the assembly and test cycle before sending it to the packing department. Thereafter, samples of packed players are taken to a Customer Acceptance Lab (CAL),[9] where they are subjected to lengthy functional tests and some are selected for life testing.

As Scearce[9] describes, additional effort is made to evaluate player reliability in the customer environment through information gained from field-service sources. Environmental testing is also performed on the player, as it is on other consumer products, to ensure that adverse transportation (drop-and-shake test), storage (thermal shock tests), and usage (user error-and-abuse tests, electrical transient tests, and so on) will not affect product reliability.

Monitoring and analysis

If the mass production system is complex enough, a system of production monitoring and analysis can be developed. In the case of the VideoDisc player production, a computer-based system called Manufacturing Analysis and Control System (MACS) was developed.[10] MACS is used for manufacturing analysis of VideoDisc player production, for the timely detection of assembly line anomalies and trends. To accomplish this a minicomputer automatically collects production test data and serialization information from a large number of test stations, processes the data, and generates a variety of reports on yields, failure patterns, and other information of interest to manufacturing management.

Conclusions

As indicated in the preceding paragraphs, significant evidence shows that a "crossover" of technology already exists between custom manufacturing and mass production. In the case of custom manufacturing, automation (for example, numerical control of machining) is being implemented extensively, and an effort is being made to use mass-produced components (for example, the solid-state power amplifier) where possible. In the case of mass production, high technology has been injected into the manufacturing process in a significant way with computer-based testing and the use of computer-based manufacturing analysis.

This trend of technology crossover is continuing. Astro-Electronics is looking at the feasibility of using robotics for some operations. The assembly of solar arrays, for example, contains thousands of repetitive operations that make the use of robotics ideal. More large scale integration (LSI) is being used in spacecraft electronics, for example, the CPU. Moreover, the use of automatic testing continues to increase at Astro-Electronics. On the other hand, the state-of-the-art technology being developed by aerospace manufacturers, primarily for custom applications, will continue to migrate toward the consumer

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Bob Miller joined RCA Astro-Electronics in 1964 and worked on tape recorder, vidicon camera, power, and communications equipment projects. He was manager of the NIMBUS, Atmospheric Explorer, RCA SATCOM, ANIK-B, and TIROS spacecraft programs prior to his present assignment as Manager, Satellite Programs.

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market: some examples include: the further miniaturization of consumer products, and the increased use of space age materials.

One method used by RCA to promote manufacturing technology transfer is a manufacturing symposium held each year for the past several years. The theme of the most recent symposium, held in December 1981 at the David Sarnoff Research Center (Princeton), was "Computers in Manufacturing." This paper directly resulted from our opportunities for conversations and planning at this meeting. Perhaps, the next Symposium should be an overview of the techniques used in the diverse manufacturing operations throughout RCA.

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The Manufacturing Technology Center

A market as competitive as consumer electronics demands efficient manufacturing methods. It is necessary to be aware of the latest manufacturing techniques and methods used throughout the world. The latest technology must be translated into practical manufacturing processes that are capable of high yields and low cost.

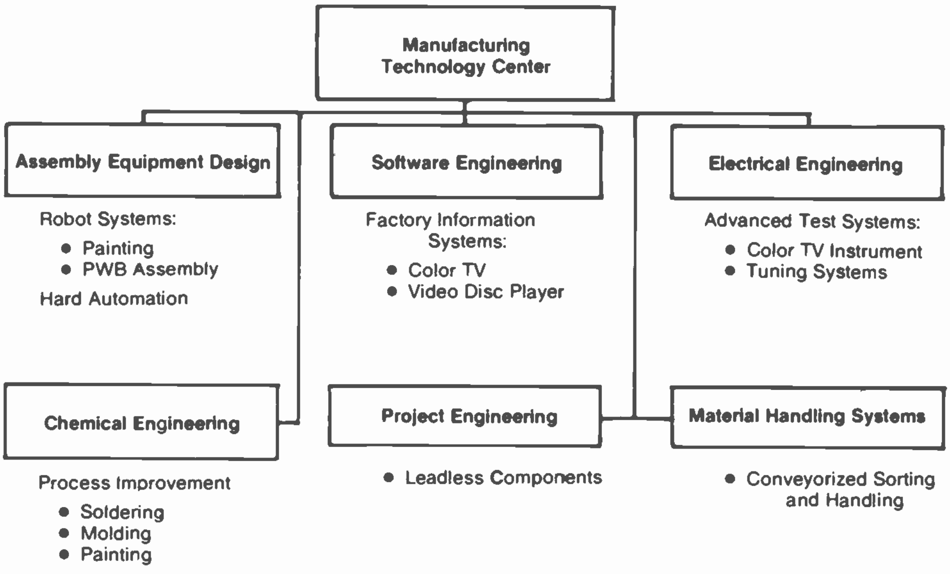
The Manufacturing Technology Center (MTC) is responsible for developing advanced manufacturing techniques and equipment for the Consumer Electronics Division. The MTC, a satellite of the RCA Labs, is located at Consumer Electronics Division Home Office in Indianapolis.

The MTC is an advanced manufacturing effort that connects long-range Princeton development and the daily needs of the factory. It translates up-to-date technology into practical manufacturing methods and systems.

The emphasis in MTC during 1982 will be placed on yield improvement programs, programs to automate the final alignment of color TV sets, the development of a factory information and tracking system for chassis production, a robot system for painting plastic cabinets, a robot system for assembling components to printed wiring boards, a conveyorized product sorting and delivery system, and the introduction of leadless components.

To accomplish these challenging projects, the MTC is organized into skill centers (see chart). Prime responsibility for a project is given to the skill center that is most involved. Thus, robot systems are assigned to the Assembly Equipment Design group, factory information systems are assigned to the Software Engineering group, and advanced test systems are assigned to the Electrical Engineering group. With the full range of skills available in the MTC, engineers will be able to use mature technologies and new technologies in a timely manner to provide practical and efficient manufacturing systems for the Consumer Electronics Division.

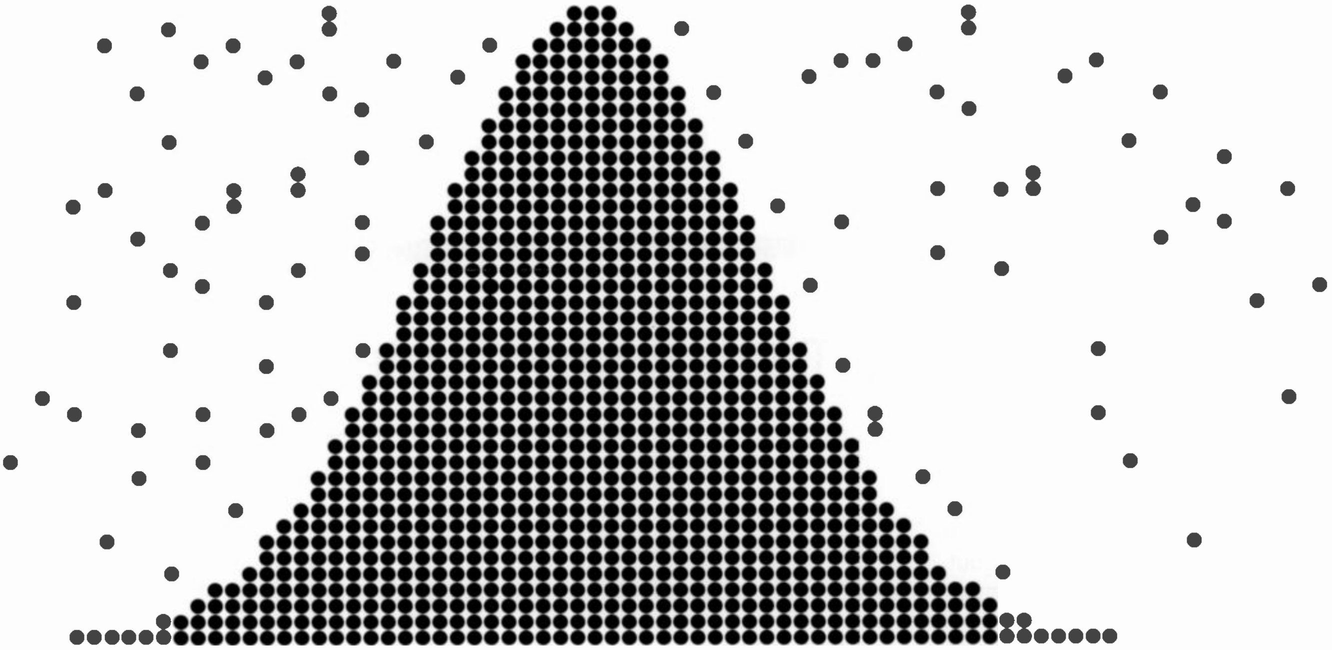
—*C. Limberg*



B.H. Gunter | M. Rayl

Applications of statistics to manufacturing

Simple and effective statistical techniques should yield big gains in productivity and quality.



Abstract: *The history of applied statistics in American industry is briefly summarized. Several areas of possible application are described—statistical process control, incoming materials control, measurement control, statistical experimental design and large database analysis—with discussions of the expected benefits.*

"Make maximum use of statistical knowledge and talent in your company."

—W.E. Deming

The application of statistical techniques to help control and improve manufacturing has been widespread in American industry since the Second World War. Stemming from the statistical process-control methodology originated by Shewhart and others at Western Electric and Bell Laboratories,[1, 2] statistical quality-control procedures were extensively developed and applied to the task of producing high-volume, high-quality, high-uniformity war materials.[3] By the end of the war, these techniques were incorporated into the military procurement system—the famous MIL standards.

After 1945, industry in this country returned to the production of consumer goods, and the application of statistical control methodology to manufacturing gradually declined. However, starting in 1950, Dr. W. Edwards Deming, an American statistician, visited Japan at the invitation of the Japanese Union of Scientists and Engineers (JUSE) to teach them how to use statistical techniques to improve quality and reliability—and hence productivity—in their manufacturing.

At this time, of course, the Japanese economy had been shattered by the war, and Japan had a worldwide reputation for the production of shoddy manufactured goods. This small country, dependent on a competitiveness in world markets for economic prosperity, enthusiastically received Deming's message that the key to success was the efficient production of high-quality consumer goods. The statistical techniques he taught were widely adopted by the Japanese consumer manufacturing industry. Workers on the line and in top management—as well as the engineers—were trained in their use, so that by 1960 Japan's commitment to quality had already resulted in economic resur-

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gence and successful penetration into many key world markets. Today, Japan is considered to be among the world's most productive and advanced manufacturing powers. It is a formidable competitor in a broad range of consumer technologies.

Although this is certainly not exclusively due to the statistical methodology that Deming taught (Japanese investment in technological improvement and commitment to long-term business objectives are well known, for example), the Japanese have long recognized the critical importance of these contributions to their success and have established the Deming Award to honor their teacher. This highly coveted medal, awarded annually to the Japanese corporation with the most outstanding achievements in quality control, is often prominently featured in the advertisements of its winners and bears the following inscription by Deming: "The right quality and uniformity are foundations of commerce, prosperity and peace...."

While the Japanese were adapting Deming's teachings to direct their quality revolution, American statisticians were developing novel and highly successful approaches to difficult industrial problems of control and optimization, particularly in the chemical and other "process"-oriented industries. This work had a very interesting source: agricultural experimentation—in particular the work of R.A. Fisher* at the British agricultural experiment station in Rothamstead, England. There, Fisher, one of the giants of twentieth-century science, founded modern mathematical genetics, and originated many of the techniques on which modern statistics is based—among them analysis of variance (ANOVA), statistical experimental design, and the concept of "sufficiency" and "information" in statistical estimation procedures. In his work, he developed and applied statistical theory to complex problems in the improvement of agricultural hybrids, animal husbandry, and crop-culture practices. In the 1930s, some of his students and colleagues established a similar department at Iowa State University in Ames, Iowa.

By the 1950s, graduates of this and other American and English departments of statistics were beginning to apply these techniques to the improvement and optimization of industrial practices and processes. Among them was George Box, a Fisher disciple (and his son-in-law), who became one of the leaders in this new field of application. He developed multivariable experimental design approaches that enabled scientists and engineers to gain more and better information from their work at a fraction of the cost of the traditional experimental approaches, which varied only one variable at a time. These multivariable techniques, generally described under the heading of statistical design and response-surface methodology, saw fruitful application in the chemical industry, where the cost of experimentation in manufacturing processes was high.

Box then extended this work to the day-to-day improvement of manufacturing processes, and the method of Evolutionary Operation was born. This technique, again widely applied in the chemical industry, is a method for constant gradual improvement in an industrial process through the evaluation of small, carefully structured changes in normal operations—changes too small to cause problems but whose effects can nonetheless be statistically characterized.

For the past two decades, statistical applications in industry have been closely associated with the same key technology that has dominated all of modern science and engineering—the computer. As in other fields, the availability of fast, cheap computational power has freed statisticians from the bounds of simply computable "nice procedures" to permit development of complex models that more realistically describe nature's own complexities. The explosion of data that the computer ignited has also led to radical developments in statistical approaches to the analysis of data. A typical factory, for example, can generate literally tens of thousands of numbers every day. The availability of computers now enables us to hold this data in a form accessible to examination.

But how does one make sense of such large quantities of data? Usual tabular approaches have difficulty conveying information from such a complex mass of numbers. So, to extract useful information from this kind of data "explosion," whole new fields of statistics—exploratory data analysis, cluster analysis, multivariate graphing procedures—have been and continue to be developed. Although the field is new, it has led unquestionably to promising new approaches, revolutionizing the way we think about the analysis of large databases. But there is still a long way to go, particularly in developing algorithms to ensure data quality and to thus avoid the GIGO (garbage-in-garbage-out) syndrome. Nevertheless, statistical approaches will be essential in extracting valuable information from the data storehouses that sophisticated computer technology can now build.

This article will outline some of the approaches we are taking now and in the future to apply statistics in RCA's manufacturing environment. At the RCA Laboratories in Princeton, the demand for statistical assistance in the efficient design of experimentation and in the interpretation of complex databases is growing rapidly, and we expect the fallout of much of this work to heavily impact our products and processes in the future. But we feel that the lessons of the past few years—particularly in the electronics industry—have demonstrated the vital importance of bringing statistical methodology into our traditional manufacturing environments. We wish to focus on this challenge and the work we are doing to meet it.

Statistical process control

Two fundamental ideas underlie the statistical control philosphy that Deming taught the JUSE.† First, the key to producing a consistent, high-quality product is control of the manufacturing process. Second, the key to successful process control is to make the distinction between random statistical variations inherent in the process (global causes) and the structural variations (special causes) that are not.

The manufacturer who knows how to distinguish these sources of variability has an enormous edge in producing a high-quality product at minimal cost. Let us examine these principles more closely to see why this is so.

Controlling the process

A major distinction between these principles and traditional views of quality control is that traditional views emphasize methods of product screening—separating good from bad quality at the end of the production line—while Deming's approach

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* His daughter, Joan Fisher Box, has recently published a widely acclaimed biography of her father entitled *R.A. Fisher, The Life of a Scientist.*

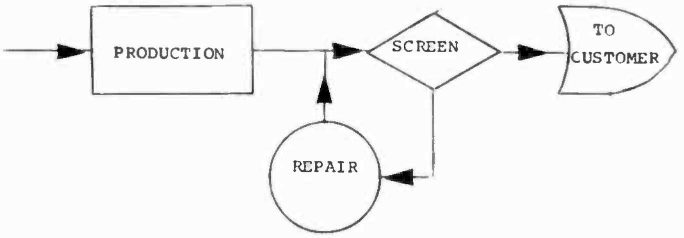
† Deming still teaches. At age 82, he is an active lecturer and world traveler.

Appendix A:

How error rates affect screening

The following model was used to generate the curves in Fig. 1.

Assume that the product is made and screened with any product failing to pass the screen being cycled to a repair process that "fixes" the product and returns it to the screen.



Assume further that both the screening process and the repair process are subject to error as follows:

α = probability of calling a good part bad at screening.
β = probability of calling a bad part good at screening.
r = probability of properly repairing a bad part.
s = probability of damaging a good part in repair.

Finally, let p equal the actual percentage of good parts manufactured. This model has actually been applied to RCA TV manufacturing. See reference 16 for details.

An easy way to write down the equations for the model is to consider, for example, the fate of a day's production. Both good and bad parts can theoretically go through many cycles of screening and repair before all the parts are eventually shipped. In practice, of course, two or three repair cycles is about the most that would occur.

Let p_j equal the fraction of good parts (of the original production) entering the screening process at cycle j with $p_o = p$. Let q_j equal the fraction of bad parts at cycle j. Clearly, $p_o + q_o = 1$. Now note:

$$p_{j+1} + q_j + 1 = \underset{\substack{\downarrow\\ \text{good}\\ \text{parts}\\ \text{rejected}}}{\alpha p_j} + \underset{\substack{\downarrow\\ \text{bad}\\ \text{parts}\\ \text{rejected}}}{(1-\beta)\, q_j}$$

Further:

$$p_{j+1} = \underset{\substack{\downarrow\\ \text{good}\\ \text{parts}\\ \text{repaired}}}{\alpha(1-s)\, p_j} + \underset{\substack{\downarrow\\ \text{bad}\\ \text{parts}\\ \text{repaired}}}{(1-\beta)\, rq_j}$$

So:

$$\begin{aligned} q_{j+1} &= \alpha p_j + (1-\beta) q_j - p_{j+1} \\ &= \alpha s\, p_j + (1-\beta)(1-r)\, q_j \end{aligned}$$

Hence, the fraction (of original day's production) of bad parts passed at cycle j is equal to βq_j.

From these equations, it is not hard to derive the relationship between the fraction of good parts made and the actual fraction deemed good in the screened parts. Model the above as a four-state Markov chain and solve simultaneous equations for the absorption probabilities. The result is that the fraction of good parts in screened output, when the fraction of good parts made is p, is $f(p)$, and

$$f(p) = \frac{(1-\beta)r}{\lambda} + \frac{\beta}{\lambda}\, p$$

where

$$\lambda = r + \beta\left(1 - r - \frac{\alpha s}{1-\alpha}\right)$$

This is the form $f(p) = a + bp$.

The fraction of bad parts in the screened parts is obviously $1 - f(p)$. For example, for $\alpha = 0.1$, $\beta = 0.2$, $r = 0.8$; and $s = 0.1$, $1 - f(p) = 0.24 - 0.24\, p$.

This is the result graphed in Fig. 1.

is to ensure that the process is controlled to produce a good product in the first place. As a result:

- Waste and inefficiency due to scrap and rework are minimized. This results in higher productivity since little productive effort is spent in producing goods that cannot be sold or that require work.
- Manufacturing and engineering problems are more easily identified and attacked. Because the process performs consistently (within random statistical variation), special problems such as a bad lot of material or a machine that needs adjustment can be quickly located and responded to, while global problems—for example, a process that consistently fails to meet the dimensional tolerances required—can be analyzed and solved against a stable and predictable background of process behavior. Anyone who has ever tried to evaluate data from an unstable manufacturing process will appreciate how important this can be.
- Higher quality and reliability of the final product result.

There are two reasons for this. First, emphasis on running a consistent, well-controlled manufacturing operation inevitably results in increased technological understanding and hence direct quality improvement. Second, *no* screening process is ever 100-percent efficient at screening "good" from "bad" product. Failure to recognize and control the statistical nature of the measuring process itself (what is good? what is bad? how do we measure it reliably and repeatably?) may result in a significant error rate in screening. Indeed, it is easy to show (Appendix A) that any screening procedure that is less than perfect in discriminating between a good and a bad product leaves the final quality shipped to the customer dependent on the quality produced. Figure 1 plots such a typical relationship.* In the plot, "TOTBAD" is the fraction of product, passing the screen, that is bad. "GOOD%" is the fraction of original production that is good. Note that bad product

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* This model assumes an operation that repairs parts that fail screening.

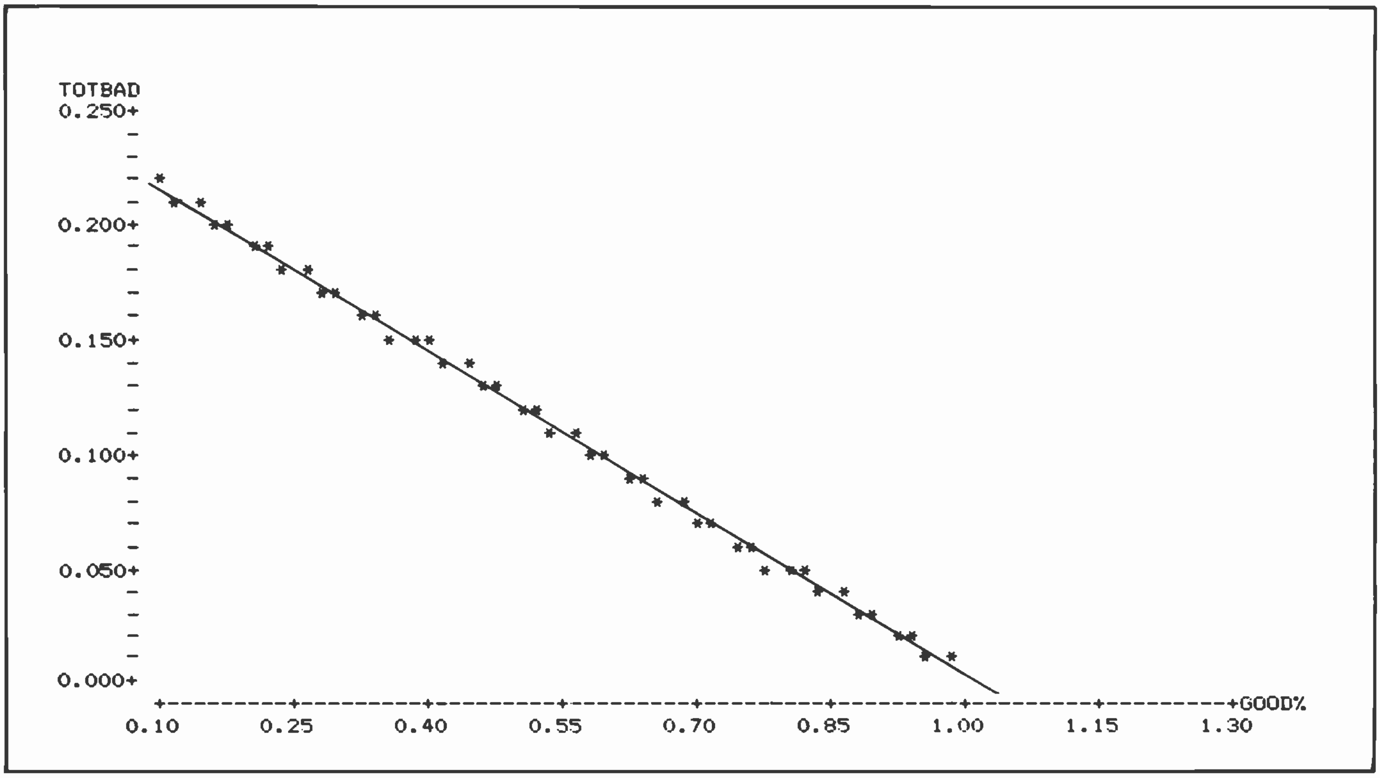


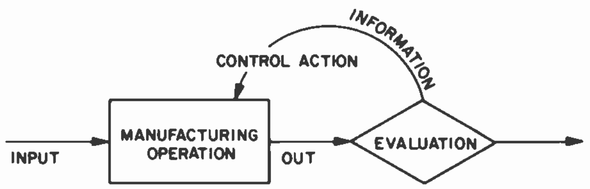
Fig. 1. Fraction of bad product escaping inspection screening versus fraction of good product produced.

which escapes the screen decreases linearly as production defects decrease.

Basic principles

Statistical control methodology is based on the following basic principles:

- Any factory can be viewed as a series of control loops.



- A process in control exhibits characterizable statistical behavior on which control decisions can be based.

These principles are quite general. They apply equally well to the complex automated process of manufacturing PC boards and to the simple process of hand insertion of components into a chassis. As we shall see later, they even apply to inspection and measurement procedures.

"Closing the loop" can involve computer-controlled valve systems or a supervisor telling an operator to clean the excess oil from the gears, but the principle is the same: an evaluation determines whether there has been a statistically significant change in the process that requires compensatory control action. If and only if this is the case, action is taken. In this way, the extremes of unnecessary destabilizing changes and inaction when change is required are avoided, and consistency in the process and product is maintained.

The key to the use of statistical control techniques in this loop is understanding the variability observed in the output. There exist two distinct origins of process variability: assignable causes and inherent process variation. Assignable causes include whatever variables are susceptible to control in the manufacturing operation, for example, machine settings, substandard incoming parts, contamination of raw materials, improperly calibrated measurements, and so on. These are the changes one wishes either to react to or to anticipate.

The inherent process variation—the process capability—is the random statistical noise due to the existence of a large number of factors over which there is no direct control. Examples might include differences between actual and desired settings of a machine due to minor variations in internal spring tension, minor (or within-specification) differences in incoming materials, electrical noise in a measurement process, slight quantities of materials contamination, and so forth. Such variation is observed even when the process is stable and consistent. Hence, reacting to such changes is fruitless—in many cases it can be shown actually to increase the variability and thus decrease product consistency.

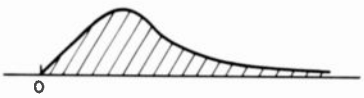
The "signature" of a process in a state of statistical control is the random distribution of the data used for evaluation. Although there are many different kinds of "random" distributions, for a variety of reasons it turns out that a single one, the bell-shaped *Gaussian distribution*, is all that one needs in the overwhelming majority of practical manufacturing situations (Appendix B). That is, most of the time, data from a process in a state of statistical control can be well approximated by a normal distribution with mean μ and variance σ^2 for some μ

Appendix B:

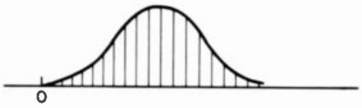
The Normal distribution

Why is the normal distribution so successfully used to approximate collections of data? There are two reasons. The first is theoretical: Various versions of the Central Limit Theorem of probability theory give a mathematical set of conditions quite often approximated by reality so that the conclusion of normality nearly holds, especially for averages. The second is practical: Even if data are not normally distributed, a simple transformation can yield approximate normality.

Here is an example of the second situation. Suppose a histogram of data is skewed decidedly to the right as could happen, for example, if we were measuring copper contamination for solder. Such contamination is always greater than or equal to 0, so that histogram of data might well look like:

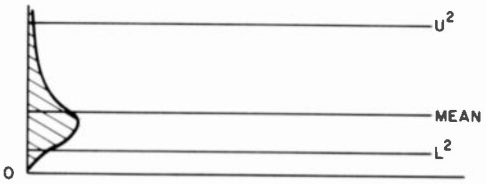


Since this is decidedly skew, it would not be well approximated by a normal distribution. However, if we transformed our data by taking the square root of each value, the histogram of the square roots would then look more like:



(If a square root doesn't do it, log transformation could.)

Since this does appear reasonably "normal," we could then apply the usual theory to obtain upper and lower control limits U and L for the *square root data.* Of course, if $0 \leq L \leq \sqrt{\text{data}} \leq U$, then $L^2 \leq \text{data} \leq U^2$. Thus, we now have control limits L^2 and U^2 for the original data. These limits would look like:



The limits would not be symmetric about the mean. But since the data in its original form is not symmetrically distributed, this is quite sensible.

Another commonly used example is that of controlling the size of a plane figure. If the distribution of the perimeters of the figures is symmetric, that of the areas cannot be. The square roots of the area data would, of course, yield symmetry and approximate normality. The techniques and the utility of data transformations are discussed in references 7, 9, and 14.

and σ. All that is necessary is to study the process carefully—do a so-called process capability study—to determine the particular values of μ and σ that characterize the process when it is in control. Thereafter, probable changes in the process's statistical signature can easily be identified by the use of statistical control charts.

Figures 2 and 3 give examples of $\bar{x}$ and R charts. The data are artificial, but illustrate some of the techniques involved. The $\bar{x}$ chart plots averages of successive groups of five samples; the R charts plot the range of the five, equal to the maximum minus the minimum. Thus, the $\bar{x}$ chart measures the level of the process at a given time, while R measures its short-term variability. The control limits—UCL (upper-control limit) and LCL (lower-control limit)—would be obtained from a previous process-capability study and, as discussed above, reflect the statistical signature the process gives when it is in control.

Examples of what a chart for solder contamination level could reveal are:

A. The R chart indicates excessive short-term variability in copper contamination. Possible cause: a problem with reagents used in measurement.

B. The $\bar{x}$ chart indicates excessive copper contamination; The R chart indicates somewhat high variability, also. Possible cause: a contaminated lot of solder.

C. The process is in control. Both $\bar{x}$ and R charts are OK.

D. The $\bar{x}$ chart shows excessive "spikiness." This is usually an indication of some kind of operator overadjustment. The cause: In our case, a new night-shift QC person was sampling for contamination using wrong procedures, thus contaminating his samples. The day-shift person was using correct procedures.

E. The R chart indicates excessive variability. The $\bar{x}$ chart is OK. Cause: A new laboratory calibration procedure was not being uniformly followed.

References 1, 2, 4, and 5 give further examples.

These techniques are both simple and effective, and as they receive wider application in RCA manufacturing activities, they should yield significant gains in productivity and quality.

Measurement control

Although not usually identified as such, making measurements can also be viewed as a "production" process. In this case, the input is something to be measured and the output is numbers. As in a production process, a measurement process is subject to assignable and inherent variation that must be maintained in statistical control to be of maximum value. Examples of assignable causes include failure to maintain proper calibration, interference caused by other equipment or unwelcome environments, and contamination of reagents. Inherent variability might include sensitivity to humidity or electrical line noise.

The effect of an uncontrolled measurement system on manufacturing accuracy and/or yields can vary. If the sensitivity (or precision) of the device far exceeds the variability of the material to be measured, the lack of tight measurement control may have little practical effect. If this is not the case, due, for exam-

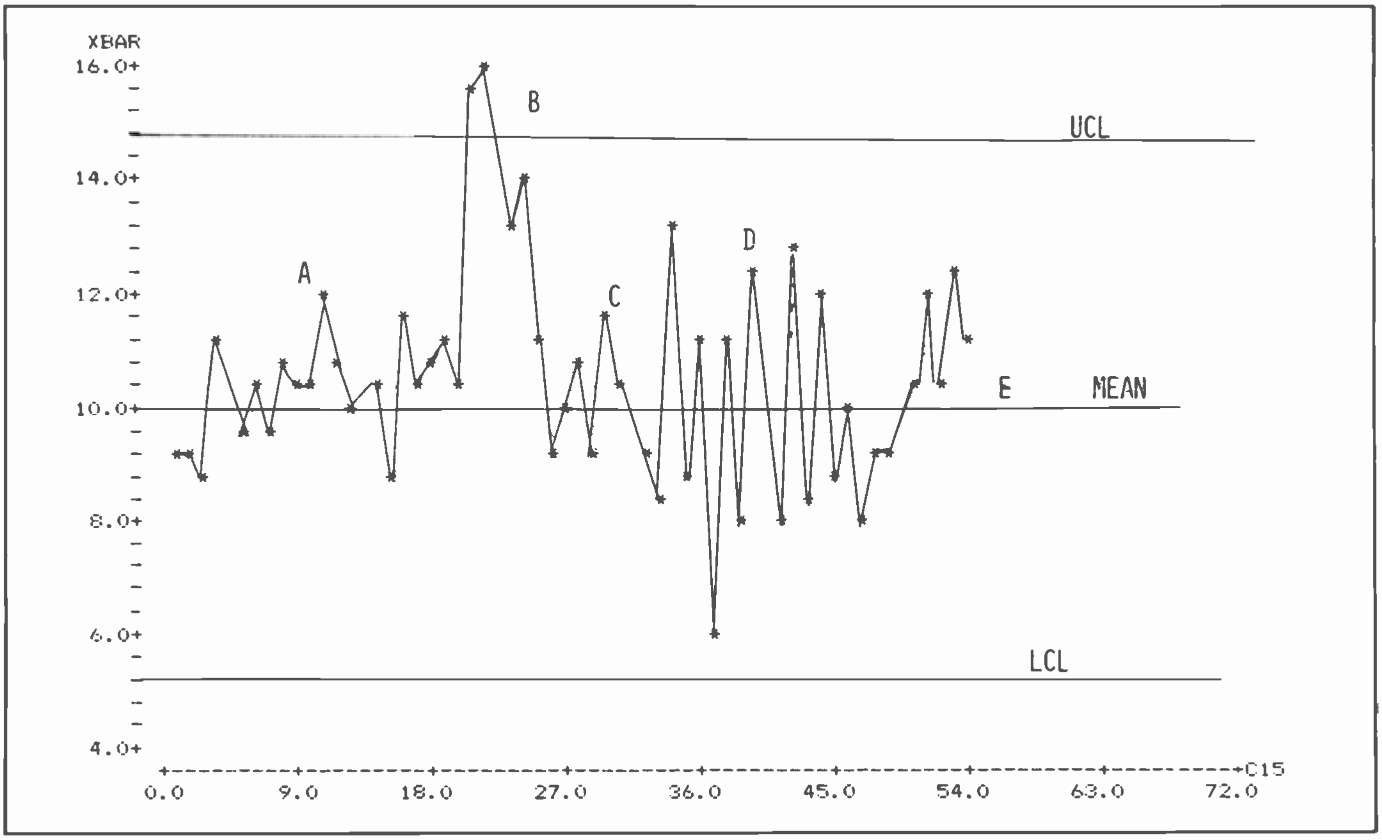


Fig. 2. A simulated $\bar{x}$ chart.

ple, to the increased cost associated with high precision, the decrease in precision due to lack of control could be sufficiently large to invalidate the measurement process entirely. When this happens, the reliable feedback necessary to keep track of the process and help control product quality is lost. In the extreme, this could be manifested by the inability to tell "good" from "bad" (a product could pass at one time or at one tester, and fail at another), or the difficulty in maintaining stable opera-

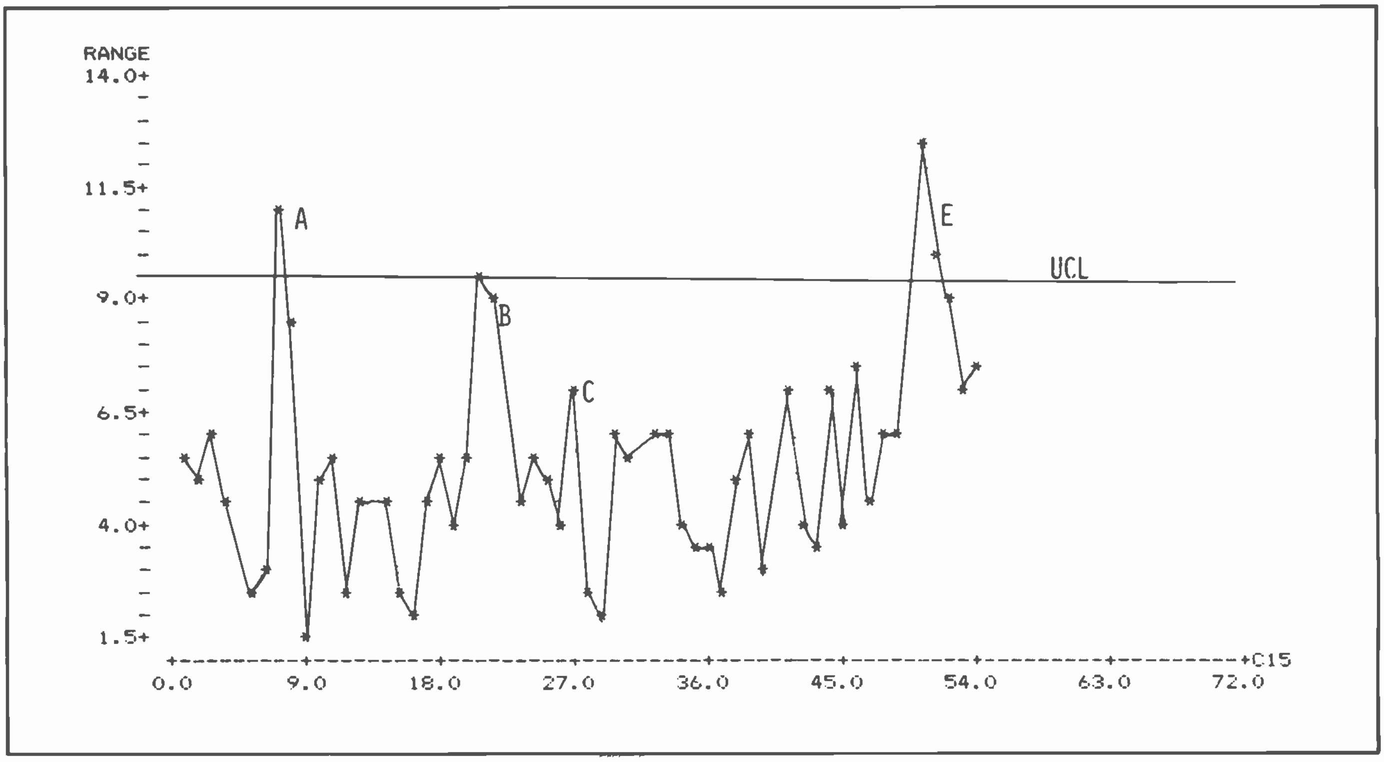


Fig. 3. A simulated R chart.

tions (for example, the temperature needs to be known within ±5° but can be measured only within ±15°).

One also sees the effects of lack of measurement control in the "correlation" problem—the perceived lack of agreement among different measurements (at different labs, different factories, or different mesurement machines within a factory) on the same input. This is particularly exacerbated as the complexity of the measurement systems increases. Moreover, these issues become more crucial as the level of automation in both production and inspection increases, since accurate and precise measurement systems must provide the information needed by the automated equipment to perform effectively.

The principles and practices of statistical production control can be adapted with little modification to statistical measurement control. For example, several measurement devices that are supposed to produce identical measurement products (numbers) can be control charted exactly like several production lines producing the same manufactured product. By the use of repeated testing of fixed standards (so-called "round-robin" testing), device-to-device and within-device variation can be compared and controlled. As in production situations, the information generated by such a program can lead to the identification of measurement shortcomings that were previously unsuspected. The increased measurement sensitivity that results can, in turn, help identify and solve problems in the material or process being measured.

Statistical control of incoming materials

One of the particularly successful applications of statistical control methodology is to the control of incoming materials quality. Good quality in incoming parts is, of course, critical to the efficient manufacturing of a complex final product. For example, if each part used in a 500-component TV set has only a 0.001 chance of being defective, then 40 percent of the sets made will have a defective part in them; if the rate is 0.005, more than 90 percent of the sets will have at least one defective part. Because the costs of defects explode as they move from incoming raw material to finished consumer product—cents on the loading dock, dollars in a plant repair, tens of dollars on a warranty, perhaps thousands of dollars in lost business due to a reputation for poor quality—it is obvious that maintaining high-quality incoming material is a cost-efficient way to increase productivity. But W.E. Deming has shown what is not so obvious: The only cost-effective way to do this in most real situations is to either have a nearly perfect 100-percent incoming-material inspection or not to inspect at all. More specifically, Deming shows (see reference 5, chapter 8) that with the low defect rate required in incoming materials, standard sampling procedures cannot screen out enough bad material to justify their cost. The exception to this is a lot-screening inspection that can eliminate sporadic severely defective lots. However, to achieve incoming material-defect rates at a parts-per-million level required for high-quality production, either 100-percent screening must be used or that level must be present already in the received material.

Deming goes farther still: Since perfect inspection, that can perfectly screen "good" from "bad" is unlikely, the only way left is to ensure that the vendor supplies the high quality required. The way to do this? Ensure that the vendor's process is maintained in a state of statistical control by requiring his use and documentation of the procedures described previously. This is the only way the manufacturer can assure himself of consistent, high-quality supplies. Deming says it this way: "Price (or incoming materials) has no meaning without evidence of quality. Demand and expect suppliers to use statistical process control, and to furnish evidence thereof" (*Business Week*, July 20, 1981). This will, no doubt, be difficult to achieve, but the increase in productivity and quality to be gained by minimizing losses due to defective incoming supplies appears worth the effort.

Statistically designed experiments

One of the foremost contributions of statistics to the scientific method has been the development of a body of techniques—statistical experimental design—that permit the precise and accurate evaluation of a large number of experimental factors with much higher efficiency than standard techniques. By varying several factors at a time in carefully specified patterns, rather than one factor at a time as is usually done, a large reduction can be made in the time and effort required for obtaining experimental information. The information obtained is also usually more comprehensive and reliable. Because of these benefits, statistically designed experiments can be performed in manufacturing environments where economy of effort is vital.

Because the specific environment of the factory is rarely amenable to accurate duplication in the laboratory, critical information that can be generated only by factory experimentation can be obtained with minimal disturbance to production. As an example, suppose there are six key parameters which, alone or in combination, are believed to affect the electrical properties of a plastic insulating compound. Inadequate manufacturing experience and the inability to approximate the large-scale, high-volume manufacturing conditions in laboratory experiments have resulted in a process that is not consistently meeting specifications. These six factors and their interactions can be studied in detail by using as few as sixteen different combinations of experimental settings in one type of statistical design (a so-called 2^{6-2} fractional factorial design; see reference 6 for details). Traditional approaches might require the same number of combinations, but no information would be gained on possible interactions among the parameters.

Statistically designed experiments can be applied to improving yield, evaluation of alternative sources of supply, choosing the best among different manufacturing techniques—to nearly any situation where good data can be of value to objective decision making (see references 6, 7, and 8 for many examples). In "process"-oriented operations (for example, injection molding, wave soldering, and so on) these techniques can be adapted to provide continuous, ongoing information for the optimization of quality and efficiency without interfering with production. As mentioned above, this evolutionary operations approach, EVOP, has been applied very successfully in the chemical industry.[15] Statistically designed experiments provide an efficient means for gaining crucial information to improve manufacturing performance and product quality. When used in combination with the control techniques outlined above, they can act as a precisely aimed arrow to target the assignable causes and then determine the appropriate corrective actions.

Manufacturing database design and analysis

The ready availability of cheap and powerful computing power has enabled modern society to organize and analyze massive amounts of data that used to be discarded or ignored. Sociological research and huge cancer studies are some well-known examples.

Manufacturing facilities also generate enormous amounts of data that used to be discarded. These data can now be retained and examined. The question is, how? Clearly, there is potential for enormous value. But it is also becoming clear that considerable thought and effort must be extended to devising ways to change the data into information; and care must be taken in drawing conclusions from the data due to the number of apparently "rare" events that can happen purely by chance in a massive amount of complex data.

Statistics plays a key role in both areas. Graphical displays based on statistical ideas are clearly one key to the data-into-information problem. Good graphics is much easier to interpret than tabular displays.[9, 10, 12] Sophisticated multivariate comparisons, trend analyses, and so forth, will be involved in the second.[11, 12, 13] Issues of data validity, "robust" analyses (analysis immune to a percentage of bad data), and the design of the database structure to facilitate analyses all have an important component of statistics in them. For these reasons, it is safe to predict that the development of large-scale manufacturing databases will benefit from concurrent statistical work to help optimize their yield of valuable information to control and improve manufacturing.

Summary

As this overview indicates, the application of statistical methodology to RCA manufacturing offers much promise. Great opportunities exist for increased productivity, higher quality and reliability, and better evaluation of engineering innnovations in both product design and manufacture. As these approaches are tried, appropriately adapted, and integrated into the framework of the manufacturing operation, we expect even greater demand and more opportunities for statistical applications.

Do you have an operation that might be improved by applications of statistical methods? The authors will answer your questions and explore the possibilities.

Authors Martin Rayl (left), and Bert Gunter.

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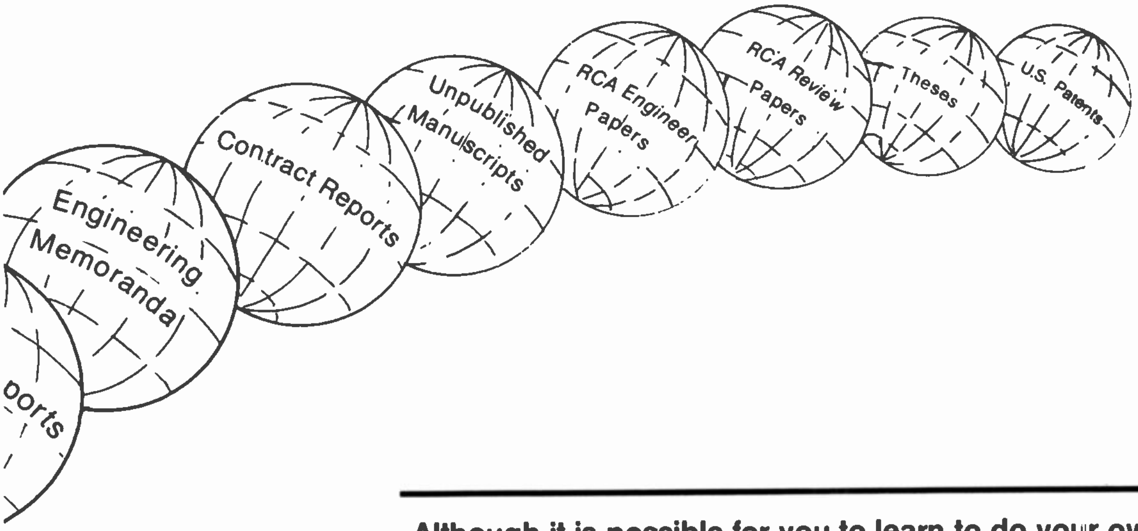

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Table I. TAD subject categories. Shown are a sampling of the 44 different categories used in *RCA Technical Abstracts,* and included in TAD. The number of references for each of these subjects is listed.

Subject	*Number of entries*
Materials	3378
Devices	3979
Circuits	3620
Systems	7575
Electro-optics	1618
Displays	1101
Recording	1022
Television	2233
Communications	1616
Radar	1227
Computer Equipment	1201
Computer Programming	1400
Manufacturing	1875
Management and Business	530

The best way to learn about what TAD can do for you is to go see your librarian with your topic of interest and go through a search with her. It may open a new world to you!

D. Mishra

The Player Technology Center: Key to innovation

For the introduction of the VideoDisc player, the Player Technology Center was conceived as a development laboratory for player and manufacturing engineering.

Abstract: *The Player Technology Center has proved to be a useful laboratory for VideoDisc player engineers and manufacturing engineers in their quest for a manufacturable VideoDisc player design. Considerable experience has been gained in the evolution of an effective interface between design engineering and manufacturing engineering and in the development of a systematic approach to enhance the manufacturability of the player design. In addition, an integrated Player Quality, Reliability, and Manufacturability Program was effectively set up for the new product development.*

A large investment was made in the manpower and facilities of the Player Technology Center to achieve well-defined objectives.

Primary objectives

- Build players for Player Engineering product development.
- Ensure manufacturability of player design.
- Design the necessary manufacturing system.
- Develop a Computerized Manufacturing Control System.

Secondary Objectives

- Mechanize manufacturing operations where economically justifiable.
- Provide a training ground for manufacturing personnel.
- Provide an insight into the necessary manufacturing technology, for the existing and prospective player-manufacturing licensees.

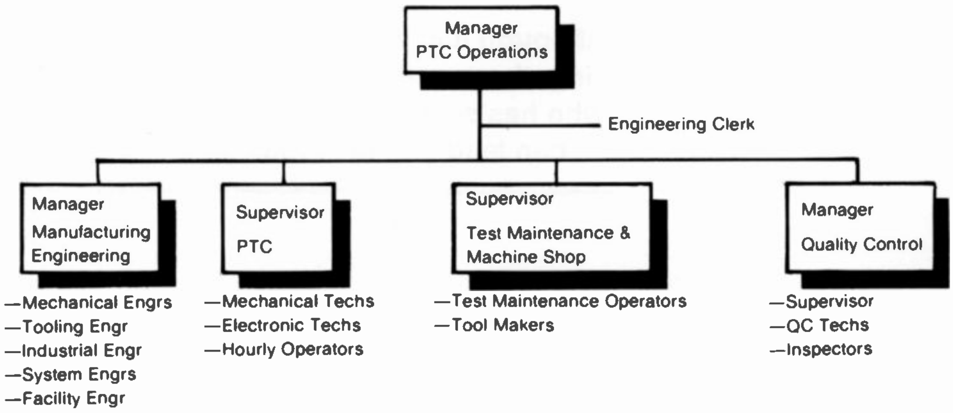

Fig. 1. Organization of the PTC Operation.

Organization

Organization of the PTC Operations, as displayed in Fig. 1, consisted of the Player Technology Center, Manufacturing Engineering, Electronic Test Maintenance and Machine Shop, and Quality Control. The Player Technology Center was manned with electronic and mechanical engineering technicians, with hourly employees contributing to large pilot runs of the player. The Manufacturing Engineering disciplines consisted of mechanical equipment design, tooling, industrial, electronic systems and facility engineering. The Test Maintenance and Machine Shop, which primarily supported the other manufacturing operations, provided support for test-equipment maintenance and construction of assembly fixtures. A skeleton quality-control group supported the Purchased Material Inspection (PMI) and product-build requirements.

Facilities

The Player Technology Center was equipped to build limited engineering and pilot models; consequently, several types of production and test equipment were provided. Figure 2 shows a bird's-eye view of the facility.

In the printed-circuit (PC) board area, automatic sequencing and insertion of axial lead components was accomplished with a Universal Instruments 60-component sequencer that can sequence 18,000 parts per hour and a Universal Instruments variable center distance inserter that can insert 16,000 parts per hour. Manual insertion of PC boards was performed by using the Universal Man-U-Sert™ assembly machines or by manually stuffing on an Isles push-along conveyor system. Board soldering was done with a Hollis bidirectional wave-soldering system with a perchloroethylene brush-cleaning system. Figure 3 illustrates some of the varied equipment described above.

Simplicity and versatility were the deciding factors in mechanical subassembly setups. Air presses, press takers, and single and

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Fig. 2. A bird's-eye view of the Player Technology Center.

multi-head rivet machines, tooled for easy changeover, minimized space requirements and maximized equipment usage. Ultrasonic degreasing stations were provided for parts cleaning.

A palletized conveyor system, displayed in Fig. 4a, was developed to assemble the pickup arm. Four operators, seated on the "oval" conveyor system, built arm assemblies. Subsequently, the arm was aligned and tested off line. This conveyor system was a miniature replica of the assembly line to be installed at Bloomington.

Mechanism/instrument assembly was completed on another push-along rail conveyor system as exhibited in Fig. 4b. The majority of assembly operations performed on this line used air screwdrivers suspended over the work area along with specially designed parts hoppers.

Sections of a PC-board conveyor, palletless as well as palletized, were installed in the PTC for developmental purposes.

These pieces of conveyor enabled engineers to simulate the conveyors currently used in the manufacturing facility at Bloomington, thereby providing ground for new ideas in material handling, work-place layout and labor reductions.

A master automatic test system for PC boards, developed by Consumer Electronics, and the computerized Manufacturing Analysis and Control System served as powerful systems for testing and quality control. Figure 5 presents these important testing tools.

Player engineering—manufacturing engineering interface

To achieve the objectives of PTC, it was imperative that the interface between Player Engineering and Manufacturing Engineering be established at the outset, and made very effective. In view of the different interests and backgrounds of the two engineering groups, this was to be a formidable challenge. Consequently, a two-pronged strategy was formulated. It consisted of upgrading the technical competence of the Manufacturing Engineering department, and encouraging members to contribute significantly and vis-

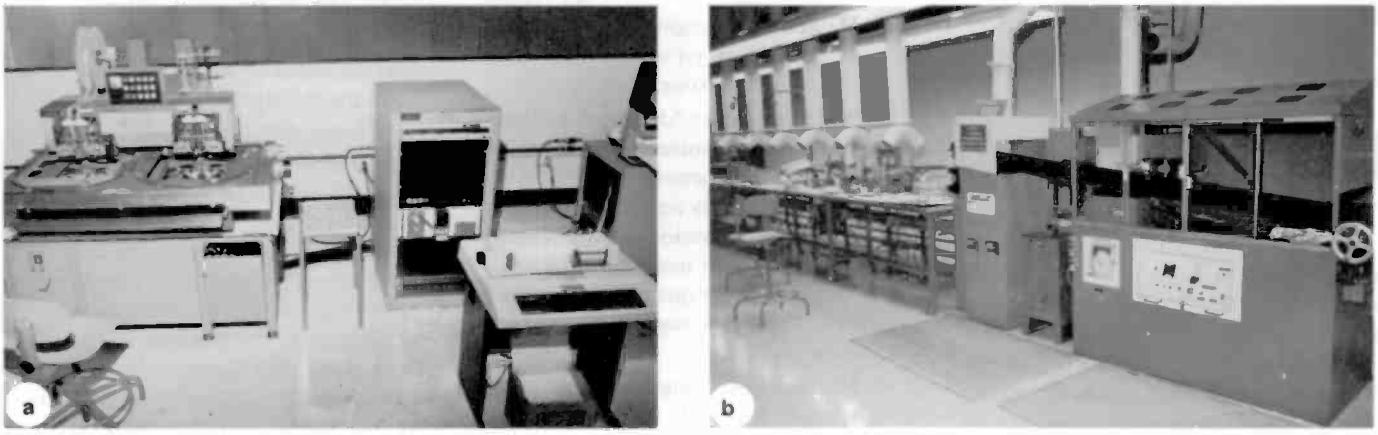

Fig. 3. The basic facility consists of **(a)** Man-U-Sert inserting machine, and **(b)** bidirectional wave-soldering system.

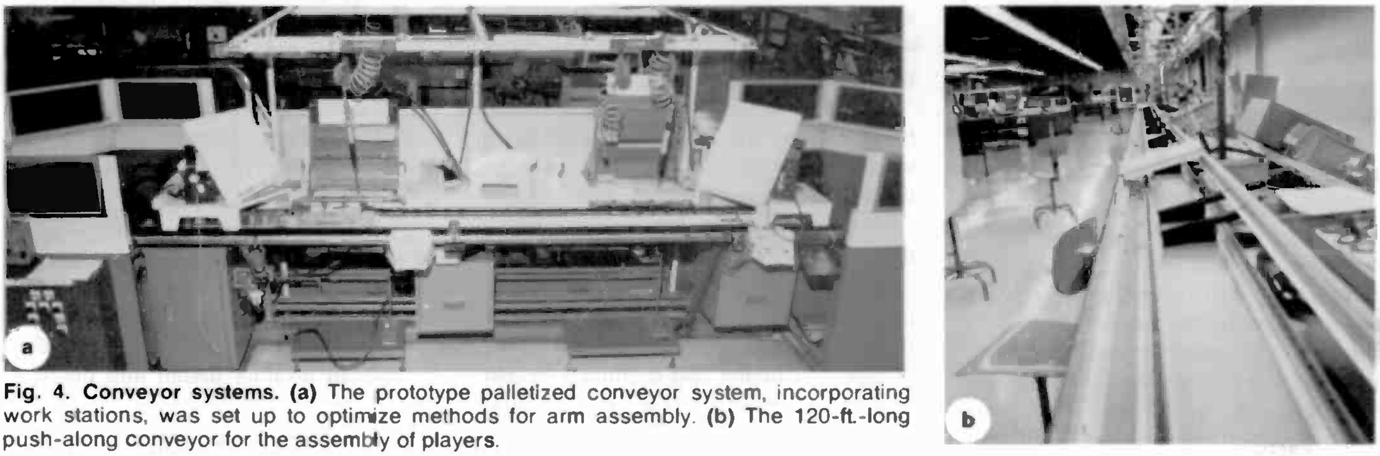

Fig. 4. Conveyor systems. (a) The prototype palletized conveyor system, incorporating work stations, was set up to optimize methods for arm assembly. **(b)** The 120-ft.-long push-along conveyor for the assembly of players.

Fig. 5. Manual and automatic test equipment were used for testing PC boards, electronic assemblies and the player.

ibly in the product-design phase. The interface between these two groups would only be productive if their joint efforts resulted in a synergistic effect to enhance the manufacturablity of the player during the design phase.

The strategic organizational effort to upgrade the technical competence of the Manufacturing Engineering department encompassed the following:

1. Technical experts were developed in key areas of manufacturing technology, adhesive assembly methods, robotics, electronic testing, computerized testing, assembly tooling, inspection equipment, and so on. This was done through planned conferences, seminars, educational programs, and interface with known experts within the corporation.

2. Industrial engineering skills were established in the areas of work measurement, layout design, material handling, and cost analysis.

3. Quality-control engineering was developed to analyze process capability in terms of product specifications, to design the quality-control system and to determine the overall cost of quality.

4. A systems approach to problem solving was enunciated and practiced. The impact of change on a part or operation was analyzed in the context of the whole system. The traditional approach of merely comparing the direct labor for alternatives was replaced with accounting of total relevant costs, including labor, material, and overhead. In addition, the impact on Quality Control, Product Assurance, Material Control, and so on, was also assessed where applicable.

5. Manufacturing engineers were assigned subsystems of the player so that they understood the design thoroughly.

6. A comprehensive "database" of design parameters was organized for the analysis of manufacturing operations. Some of the widely used databases were: characteristics of adhesives used in various assembly operations; labor costs for manufacturing operations; labor costs for quality control; characteristics of materials used in subassemblies; and material costs.

7. Manufacturing engineering activities were reported monthly to specifically answer the basic questions of project management—*what, why, who* and *when.*

8. Planning and scheduling of activities was formally introduced with proper accounting of man-hours expended by major projects.

9. Technical writing skills were upgraded by formatting the engineering reports, to separate summary information and recommendations required for management decision-making from detailed engineering data.

10. Organizational intimacy of Manufacturing Engineering with Purchasing and Finance was strengthened to enhance the former's credibility and usefulness in cost analysis for product redesign decisions.

11. Participation in professional engineering societies was fostered, with certain individuals identified to be closely associated with special groups, such as the robotics group within the Society of Manufacturing Engineers, the work measurement division of the American Institute of Industrial Engineers (AIIE), and so on.

12. To minimize technical obsolescence, engineers were responsible for carrying out a literature survey of important technical journals assigned to them. The relevant information gathered was disseminated to the group members.

The second strategy to involve manufacturing engineers in the product-design phase was a comprehensive set of organizational relationships and programs.

1. Counterparts of manufacturing engineers in the Player Engineering group were identified so that bonds were firmly established for the subsystems of the player. Direct working relationships were established for the engineers dealing with the subsystem of the player in the two groups.

2. In conjunction with PMI, manufacturing engineers determined the "Process Capability" of different vendors and compared it with design specifications.

3. Expected manufacturing yields were calculated, based on incoming product quality and manufacturing process capability.

4. Comprehensive manufacturability studies were made after each build cycle. It was quickly realized that manufacturability analysis led to tangible results only if: (a) alternative solutions were recommended for improving design rather than merely listing a deficiency; (b) the necessity for change was adequately documented and justified quantitatively with economic considerations; (c) the proposed changes were prioritized and categorized to differentiate between critical requirements and nice-to-have features; (d) the inputs for change were timely and were made with the full awareness and cooperation of the responsible design engineer; (e) resolution of problems was attempted at the engineers' level (where proper); and (f) commitments were obtained from Player Engineering for disposition of the agreed upon changes to be made.

5. A manufacturing engineering support program, encompassing tool and fixture design, establishment of methods, manufacturability evaluation and so on, was incorporated in the Player Engineering schedule for overall product design and development.

6. Drawings for customized inspection

tooling and assembly were referenced in the product-design drawings.

7. Manufacturing engineering programs were reviewed with Player Engineering Management before being finalized.

8. Programs dealing with mechanization of manufacturing operations, as envisioned by manufacturing engineers, were thoroughly reviewed by Player Engineering in terms of product-design parameters, expected obsolescence of design, and projected return on investment.

9. Manufacturing engineers represented production personnel adequately in terms of knowledge pertaining to available equipment, manufacturing systems and procedures, operating philosophy, and labor union practices.

10. Manufacturing engineers were expected to be fully informed of the design engineering status for their respective areas of the player. This was achieved by ensuring that the comprehensive weekly status reports issued by Player Engineering Management were read by the manufacturing engineers.

11. Problems encountered in the building of a player design were documented adequately by Manufacturing Engineering and PTC personnel, and reported immediately to the respective engineers and reviewed with them.

Player-build support

The player development schedule of nearly 24 months consisted of four engineering builds in the PTC, in addition to the prototypes built by Design Engineering. This permitted the continual evaluation, modification, and improvement of the player design. Table I shows how the builds were handled in terms of design information available, type of part tools, manufacturing tools deployed, and manufacturing process documentation available. GR1 and GR2 were built by engineering technicians but engineering and manufacturing pilot runs were produced by hourly operators with support from engineering technicians.

Manufacturability analysis of player design

The main philosophy of PTC Manufacturing Engineering was that, to ensure maximum productivity in manufacture of the VideoDisc player, inputs had to be made to the design of the product. Manufacturing design is a process that begins with a concept and ends up with a comprehensive description of the geometry of the product, the manufacturing process, and the material selection for each component. Historically, due to the complexity of the decision-making process and the vast amount of information involved in manufacturing design, no general design procedures have yet been found. Obviously, the quality of a manufacturing design has been solely dependent on the designer's experience and his communication with manufacturing engineers.

An interactive program was set up with Design Engineering where Manufacturing Engineering provided inputs in the following areas:

- Manufacturing process analysis
- Analysis of jigs, tools, fixtures and equipment requirements
- Analysis of process capability versus design specifications in terms of vendor performance, in-house results and industry standards
- Economical manufacturing technology, assembly technique and material selection
- Labor cost and other cost analyses
- Product simplification opportunities in terms of number of parts
- Evaluation of the ease of manual handling by identifying: part symmetry; size; thickness; mass; whether parts will tangle or nest; whether they are slippery; whether they are flexible; and whether they require tools for grasping and alignment
- Economical configuration of PC boards for manual and automatic testing
- Evaluation of the design for guides and tapers that directly affect assembly, determination of accessibility of parts for assembly and test, and ability to assemble in players starting with a stable base part
- Evaluation of manufacturability in the actual builds of engineering pilot runs

The manufacturing guidelines established for manual and automatic testing of PC-board design with respect to insertion and soldering were widely used.

A new database has been initiated that will one day lead to the determination of a Manufacturability Index for a given product design. It is envisioned that a player design will be evaluated in terms of a host of factors, some of which are indicated below, with each one given a weighting factor so that an overall index can be computed to indicate its manufacturability.

Mechanical Design

Number of mechanical parts
Types of parts—screws, rivets, washers, etc.
Number of subassemblies
Volume of product
Weight of product
Number of precision parts
Special handling and packaging requirements
Scuff resistance for critical parts
Number of customized fixtures

Table I. Player Technology Center build evolution.

Phase of build	*Design information*	*Part tools*	*Mfg. tools*	*Mfg. process documents*
GR1	Conceptual, w/preliminary parts lists	Hard & soft (start of sourcing)	Hard	Instruction sheets, Preliminary cost estimate
GR2	Preliminary drawing lists	Soft (critical hard tools sourced)	Hard w/mostly soft mfg. tools	Preliminary process (no time data)
Engineering pilot run	Pre-mfg. drawings lists released	Soft & hard (critical assemblies hard tooled)	Soft mfg. tools & fixtures (critical assemblies hard tooled)	Preliminary process w/time data, Detailed cost estimate
Manufacturing pilot run	Mfg. drawings complete	Hard	Hard	Pro-rated standard, Mfg. process instruction, Standard cost

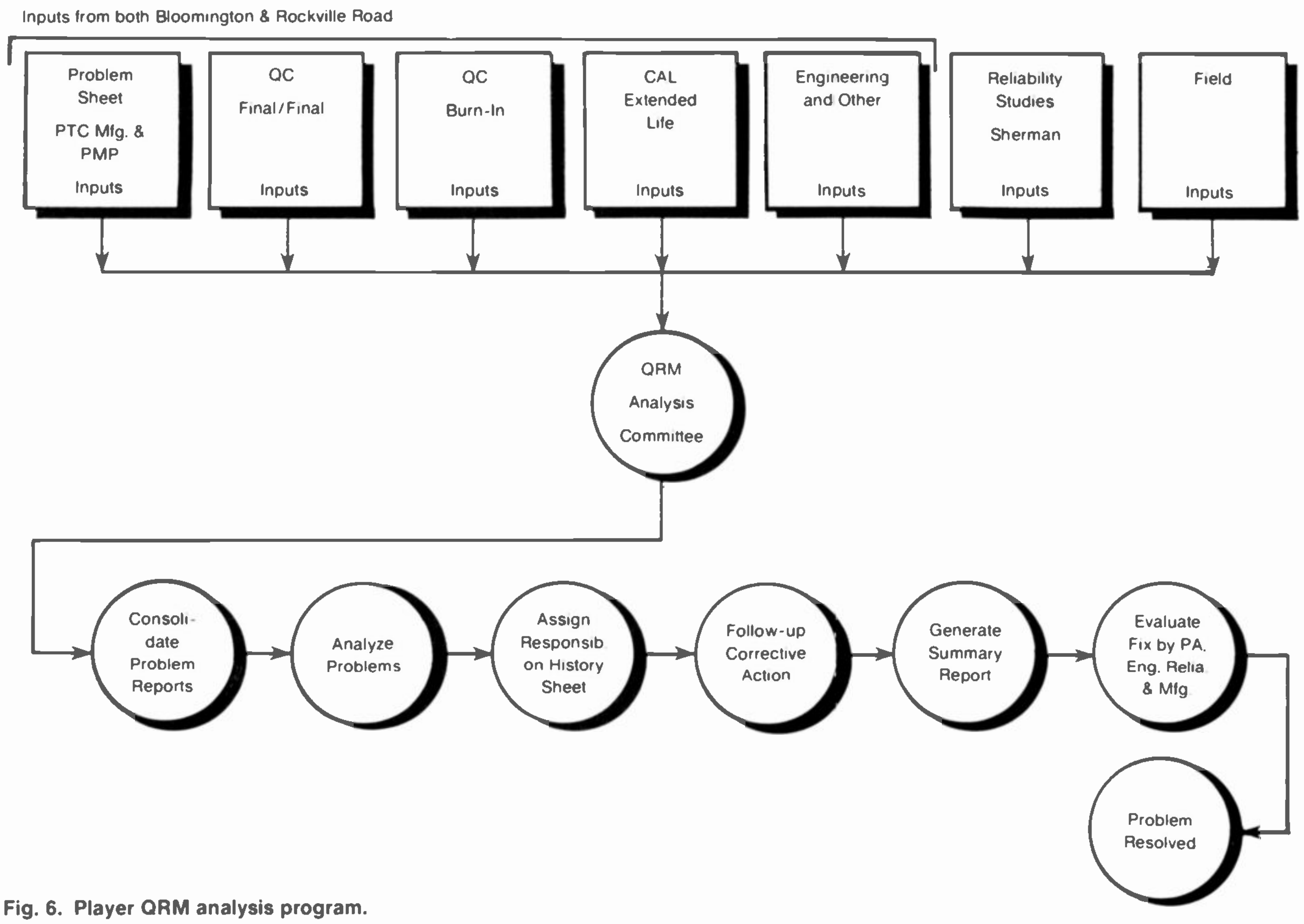

Fig. 6. Player QRM analysis program.

Manual Assembly

Number of of assembly methods
Number of adhesives
Number of assembly operations
Number of critical alignments
Number of subassemblies that cannot be tested independently
Number of assembly fixtures required
Accessibility for assembly
Ease of handling parts

PC Board

Number of electronic components
Number of PC boards
Total board size
Component density
Type of PC board
Number of board tests
Number of board alignments
Number of boards that cannot be tested independently
Number of board interconnections
Board cluster size
Automatic insertion percentage
Number of switches

Others

Number of lubrication points
Number of parts requiring cleaning or special treatment
Number of hipot requirements
Number of mechanical inspections necessary
Amount of contamination generated
Ease of rework

Player Quality, Reliability, and Manufacturability

The basic manufacturing engineering analysis for improved manufacturability was expanded to integrate inputs from other vital areas. The players produced in PTC were subjected to a rigorous analysis for the additional basic requirements of product quality and reliability. The Player Quality, Reliability, and Manufacturability (PQRM) analysis program—formulated by Manufacturing Engineering—was the responsibility of Design Engineering, Quality Control, Product Assurance and Manufacturing Engineering. The objectives of the program were the following:

- To provide continuity and follow-through in the solution of player design problems; and
- To readily provide management with the current status of identified player problems.

Figure 6 displays the basic components of the PQRM program.

Manufacturing system development

The progression of player build through the four stages of Design Engineering required the development of processes, fixtures, and equipment as indicated in Table I. In addition, the requirements for the large-scale manufacturing system to be installed in Bloomington had to be engineered. The program for manufacturing system development consisted of the following:

- Development of manufacturing processes, standards and procedures;
- Development of inspection tools, systems and procedures for incoming parts for RCA and vendors;

- Development of jigs and fixtures for large-scale assembly;
- Design of quality-control systems and procedures;
- Development of manual and semiautomatic test equipment;
- Identification of the requirements for automatic test equipment to be built by Consumer Electronics; and
- Design of material handling and packaging systems.

In retrospect

The charter of the PTC was adequately fulfilled in most of the areas as manufacturing of players was successfully begun. We learned many lessons during this phase. Some are listed below.

Players must be built in a quasi-manufacturing environment during new product development. In addition, assigning that responsibility outside design engineering maximizes inputs pertaining to manufacturability of design and effectiveness of design engineers. The existence of the PTC certainly speeded the development of manufacturing systems. The PTC made manufacturing engineers more productive in improving manufacturability of design, because building of players gave them a hands-on opportunity to analyze the design.

Training of manufacturing personnel was accelerated during the build cycles. Useful training films were produced. PTC and Manufacturing Engineering personnel not only proved invaluable in starting up the manufacturing operation at Bloomington, but also provided a source of talent for the manufacturing plant.

Debugging of test systems and manufacturing equipment destined for Bloomington was effectively done in the PTC. Equipment in the PTC filled numerous voids in the Bloomington facility at start up.

Acknowledgment

This paper is dedicated to the Player Technology Center Operations team who played an important role in the development of the introductory VideoDisc player. The collaborative effort with Player Engineering was professionally rewarding and the support received from Product Assurance enhanced the effectiveness of PTC. Finally, the inspiration and support provided by H. Anderson can never be fully recognized.

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S.J. Mecca

RCA Scranton Quality Circles

Quality Circles are on target, with the RCA Picture Tube Division plant spearheading a program.

A Quality Circle is a group of between 4 and 12 employees from the same work area who meet voluntarily for an hour each week to identify and analyze work related problems. At RCA Scranton, these meetings are held on company time, usually at the end of the shift. The ultimate goal of a QC is to develop proposed solutions to job problems, present them to management, and then have them successfully implemented. A QC is based on a very simple concept: almost everyone will take more pride and interest in their work if they are part of the decision-making process. All participants in a QC have an equal say in making decisions or recommendations, thus one of the main objectives is to have all circle members participate. This responsibility falls upon the circle leader who is usually the area supervisor. The leader, who has equal standing with other circle members, also has the responsibility for ensuring adherence to procedures, smooth-flowing work sessions, maintenance of the minutes of meetings, and training new circle members. The QC technique recognizes the individual worker as a human being with the ability and desire to participate in solving work-related problems.

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Who else would know more about their job and the problems associated with it than the person actually doing the job? With this in mind, the potential for improvements in product quality, reduced product cost, and improved schedule performance, along with improved employee morale, are quite evident.

Where did it start?

The QC idea originated in Japan following World War II. With their economy and many of their factories in ruin, the Japanese embarked upon a total commitment to rebuilding their country. In the early 1950s, the Japanese created an "American boom" by importing a series of American management techniques. To combat the stigma of "poor quality" that was synonymous with Japanese products, they hired many American quality-control experts and delved into statistical quality control, which had been introduced by Dr. W. E. Deming. Lectures and seminars conducted by Dr. J. M. Juran also left a deep impression on Japanese managers and engineers and contributed greatly to application of quality-control techniques and subsequently to the formation of QCs in Japan. From the tremendous inroads Japanese products have made on world markets in recent years, it appears their efforts have not been in vain.

At present, it is estimated that there are well over eleven-million Japanese workers involved in QC activities. Many large manufacturing organizations report a ratio of at least 1 in 8 employees involved in QCs, which has led to remarkable advances in productivity and quality.

Building people

Much of the success of QCs stems from the philosophy of the program, which is to provide training in techniques that will enable members to become an effective problem-solving team. This training, usually held during the initial meetings of the circles, takes approximately 8 to 10 weeks. Techniques such as brainstorming, cause-and-effect analysis, Pareto diagramming, use of check sheets, and the construction of graphs are just a few items that are covered during the instruction period.

Prior to circle training, the leader spends a three-day period of intensive training in these problem-solving techniques and is also instructed in group dynamics, motivation, leadership and communication, and management presentations. This training is usually conducted by the Circles Facilitator. Providing the leader with the necessary skills to train members and operate a circle is extremely important if success is to be achieved. The personal development of circle members is the cornerstone of QCs. When placed on a firm foundation of participation, involvement, and accomplishment, a truly motivated workforce can be built.

The Facilitator's role

The QC Facilitator is the "oil can" that keeps the circle program running smoothly. Having responsibility for organizing, coordinating, and directing circle activities, a Facilitator also trains leaders and members, and is a resource person, a liaison between management and circle members, a publicity agent, and a guidance counselor. In addition, the Facilitator must keep records of circle activities and accomplishments and provide assistance, as needed, to ensure timely response to circle proposals.

A Facilitator is usually responsible for 5 to 12 circles, but this varies in many organizations. Some use part-time Facilitators—members of management who volunteer to facilitate a few circles along with their normal responsibilities—so it is possible to have many Facilitators, depending on the size of the organization. At RCA Scranton we have one full-time Facilitator, currently responsible for 24 circles.

It is extremely important that over-facilitation does not hinder development of the relationship of the circle leader and members of the group. The leader, who is usually the department supervisor, is the one who will benefit most from the improved relations that normally evolve from circle activities. Improved communication, mutual understanding of problems, and a feeling of team effort are very definitely by-products of circle involvement, thus the Facilitator must stay in the background to allow this improvement in the leader-member relationship to incubate and develop. The QC Facilitator wears many "hats" during a normal workday, each more interesting and challenging than the last, but all carrying the reward of seeing people grow with their accomplishments.

Abstract: *Participative problem-solving programs have been used by many industries over the years. The concept has been given a fresh, exciting approach at the Picture Tube Division plant at RCA Scranton with a relatively simple, yet formalized technique known as Quality Circles (QCs). The technique is used extensively in Japan, and in recent years has been gaining in popularity in the United States and other countries. RCA Scranton's involvement in spearheading this program within the Corporation has been both promising and rewarding.*

Fig. 1. The Explorers. Members in the Mount Preparation department go over a cause-and-effect diagram to pinpoint a mount short problem.

Fig. 2. The Assemblers. Mask Assembly members, at a brainstorming session, try to find ways to reduce scrap at their operations.

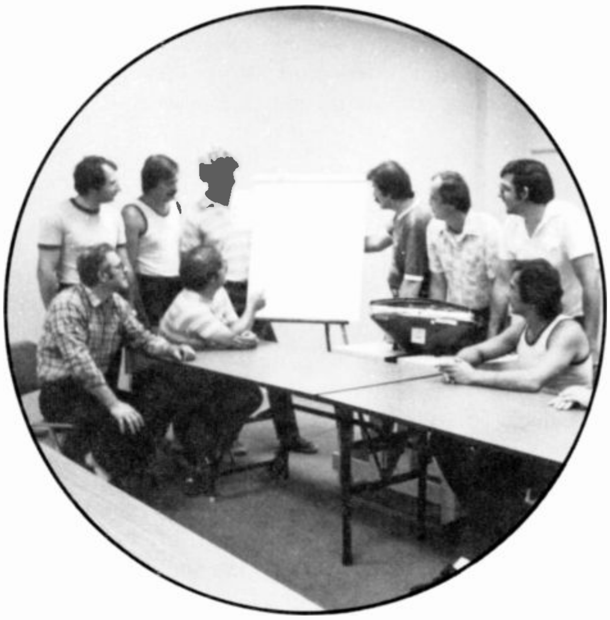

Fig. 4. The Pioneers. Mount Seal/Exhaust members make final preparations for their third management presentation.

How we got started

Our involvement with QCs began in the latter part of 1979. Jeff Trullinger, PTD Manager of Training and Organizational Development became interested in the concept and arranged to have a presentation made by a leading quality circle consultant, W. S. Reiker. Representatives of several RCA Divisions attended the meetings. The Picture Tube Division was represented by Harlan May, Manufacturing Manager, and Vin Kneizys, Quality Manager at the Scranton Plant. Impressed by what they learned, they decided to seek more information, and so arrangements were made to visit the Buick Division of General Motors to observe their circles in action. The reaction to this visit to Buick was so favorable that a formal presentation was made by the Division Manager of Training and Organizational Development to Scranton Plant Manager John Ignar and his staff. This resulted in interest in the potential of the QC concept and a decision was made to try it in Scranton on a pilot basis.

Fig. 3. The Searchers. Mount Seal/Exhaust members attend a training session to learn how to apply QC problem-solving techniques.

Next came a presentation to the Union Executive Board and Plant Superintendents followed by a presentation to middle managers and supervisors to ask for volunteers for the Facilitator and leader training program. Three leaders were selected and the Facilitator's responsibilities were assumed by Joe Santarsiero, one of our manufacturing superintendents, on a part-time basis. Presentations were then made to the hourly workforce in the volunteer leader's departments—exhaust and mount seal, frit seal, and salvage—resulting in 14, 7, and 6 volunteers respectively.

In January 1979, a three-day training program for leaders and a five-day program for our Facilitator was begun by a QC consultant from whom we also purchased our training materials. In February 1979, our hourly member volunteers commenced training, thus creating our first three circles.

A part of developing a QC is allowing each group to select a name that gives them an identity of their own. Our three pilot circles selected the names of *Pioneers, Trailblazers,* and *Qualifiers* as their "handles." These three circles operated successfully through the remainder of 1979, and in January 1980, the commitment was made by the Plant Manager to expand our circles program to encompass all operations. A full-time Facilitator, appointed in February 1980, coordinates the expansion and trains the new leaders and members.

Next move is expansion

In February 1980, QC introductory presentations were made to all first-shift salaried and hourly personnel not previously exposed to our program. The intention was to give everyone an idea of what QCs were all about and to solicit both leader and

Fig. 5. Management and a QC get together. *The Innovators* from the Packing department look on with members of management, as members of the circle present solutions to the problems the group selected as their project.

Fig. 6. The Innovators. Members of Packing discuss their project with members of management after completing their first management presentation.

member volunteers. Response to our effort was good, resulting in enough volunteers to create seven new circles on first-shift operations. After these members completed training, the next step was to bring our third-shift operations on board. Once again introductory presentations were made to the third-shift employees, following the same plan established for first shift. This was done in September 1980 and resulted in the creation of seven third-shift circles bringing us to 17 QCs. In March 1981, we moved to our second-shift operation with introductory presentations for salaried personnel, to lay the groundwork for creating circles on this shift. A total of nine second-shift supervisors volunteered as leaders. With second-shift participation, we now have an additional seven circles, and a total of 24 circles.

There are approximately 200 people involved in QCs ranging in size from 4 to 13 members per circle. Turnover, which has been low, is due mainly to shift transfer, layoff, or upgrades. New members are welcome to join an existing circle as long as membership does not exceed 15 members and open slots are filled very quickly by new members.

What's been accomplished

Our 24 active circles have compiled more than thirteen completed projects, which have resulted in savings in excess of $184,000. In addition, many intangible savings and improvements have occurred. Circle groups at Scranton are eligible to participate in the employee suggestion or CRS programs. Suggestion awards totaling more than $27,000 have been awarded to circle members as a result of the savings noted above.

We do not, however, stress only the dollar savings, because many of the benefits of QC activities show up as improvements in quality, attitude, productivity, morale, and just plain better human relations and working conditions. With this in mind, it is imperative that QCs be a long-range program. In fact, it should not even be considered a program, but a way of life, an integral part of everyday normal operations. Failure to accept it as such will surely make its survival difficult.

The projects a circle chooses are varied and range from improving housekeeping to increasing productivity. The *Trailblazers* of our Salvage Department found ways to increase output of the debead operation by adjusting the water-shock cycle. The same group is working on increasing productivity at the seal land grind operation. By using their ideas for multiple-type fixturing, the equipment can be used more fully, without requiring additional labor.

The *Qualifiers* of our Frit Seal Department found ways to reduce "broken-neck" scrap occurring on process equipment and conveyor lines. The group is now working to improve product identification, to prevent component mix-ups. The *Pioneers* of the Exhaust-Mount Seal area recommended housekeeping improvements and were able to increase loading efficiencies by finding ways to work around a bottleneck in their department. The *Innovators* of the Packing Department completed their first project, which dealt with proper labeling of product before it is shipped. They also identified and found ways to eliminate many high maintenance items on the process conveyor in their department. These are just a few examples of the type of projects the groups have selected as targets for improvement.

It may take a circle from three months to a year, depending on complexity, to complete their project, but they normally come up with answers for improvements. When a circle does come up with proposals for solutions, they take part in a management presentation at which they present their ideas and findings to the Plant Manager and his Staff. These presentations give the circle members an opportunity to be recognized for their ideas and to show how they have used the techniques learned.

It is difficult to describe the atmosphere generated at a presentation. It is one of excitement, enthusiasm, and nervousness.

Sal Mecca is Quality Circles Facilitator, RCA Picture Tube Division, Scranton, Pennsylvania, which is one of two RCA picture tube plants located in the United States. His responsibilities include development, administration and function of the QC Circles Program at the Scranton location.

He began his career with RCA Scranton in 1966 as a production operator. Prior to assuming his present responsibilities, his positions included: machine attendant, manufacturing supervisor, shift operations and supervisor, manufacturing, first-shift operations.

He attended Devry Technical Institute, Chicago, Illinois, studying Industrial Electronics. He trained in Modern Supervision at I.C.S., Scranton, and completed the RCA Work Simplification Program at Scranton. He received his training as QC Circles Leader and Facilitator from Quality Control Circles, Inc., Saratoga, California and is a member of the International Association of Quality Circles and is also a member of the International Management Club, Scranton chapter.

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At the end of the presentation, the circle members can mingle and talk with management. Spirits and the sense of achievement are high with both the circle members and management. If you are a nonbeliever, attending just one presentation is guaranteed to change your mind.

Making it a way of life

RCA Scranton is committed to making QCs a way of life, not just a program that will come and go. It will take time for it to become ingrained in our organization as a natural part of everyday operations.The first steps have been taken to achieve this and we are going in the right direction. No medicine cures all ills, and we don't expect QCs to be a panacea for solving all problems.

By involving our people in helping us solve our work-related problems, we can break down some of the barriers standing in the way of achieving a truly motivated workforce. Improved quality, higher productivity, and an involved workforce will surely result in an improved competitive position for RCA Scranton; a position that is continually challenged in the marketplace and a position we can't afford to lose. We are committed to maintaining and improving our competitive position. We are committed to Quality Circles.

M.A. Blumenfeld | R.C. Shambelan

Equipment decisions for VLSI-circuit manufacture

Rapid industry growth makes the buying decisions difficult.

Abstract: *Equipment suppliers to the semiconductor industry far outnumber companies actually producing devices. Selection of equipment, then, requires difficult choices among competing equipment and manufacturers. Some methods used for the selection are briefly discussed.*

The growth of the solid-state industry has spawned a parallel growth in the semiconductor equipment industry because specialized machines—for processing semiconductors, monitoring processes, and growing materials—are required. Equipment suppliers to the semiconductor industry far outnumber companies actually producing devices.

Another business that has nurtured all of the rapidly growing solid-state business has been the chemical industry. Countless specialized high-purity chemicals are required to build devices. These chemicals include photosensitive lacquers, doping sources such as arsine, phosphine, diborane, boron trichloride, phosphorus oxychloride, and others such as hydrofluoric acid, sulfuric acid, and aluminum.

One key problem facing the solid-state industry, and particularly the solid-state manufacturing engineer, is the selection of equipment to do the job properly. From which vendor should we purchase? What options on the equipment should be specified? Where would be the best location in the factory for installation? What services such as air, water, power, ambient control are required? And, finally, how do we obtain equipment maintenance and service? Do we use an in-house maintenance group or do we enter into a service contract with the supplier? These questions must be answered beforehand.

Two examples of the direction a company can pursue when purchasing state-of-the-art equipment are as follows:

1. Prepare firm specifications related to process and equipment performance, and maintain a hands-off policy when it comes to improving the characteristics of the equipment. If performance does not meet the specifications, the equipment is returned to the vendor.
2. Accept the equipment even though it does not meet specifications and direct the engineering departments to apply the necessary talent to upgrade the equipment to meet existing performance-needs.

History shows that there are solid-state companies that will purchase equipment and, before releasing it to manufacturing, will take it into their shop for extensive modification to enhance performance. In fact, the equipment manufacturer is released from his responsibility to meet performance specifications. To choose this course one must have large equipment-design and process-development departments. Due to limitations, Palm Beach Gardens follows the first example except when minor changes can be made to equipment that will not violate warranties.

There are many factors which influence the equipment-purchase decision. These include cost of equipment, throughput (wafers per hour), equipment capability (for example, resolution and alignment tolerances in the case of photolithographic

Table I. Design comparison: A series versus memory design.

	A Series	*Memory Devices*
Levels of conduction	2	4
Number of polysilicon layers	0	2
Number of contact levels	1	2
Metal pitch	17.8 µm	8 µm
Gate length	7.6 µm	3 µm
Transistor width	7.6 µm	3 µm
Contact size (minimum)	7.6 x 10.2 µm	3 x 3 µm

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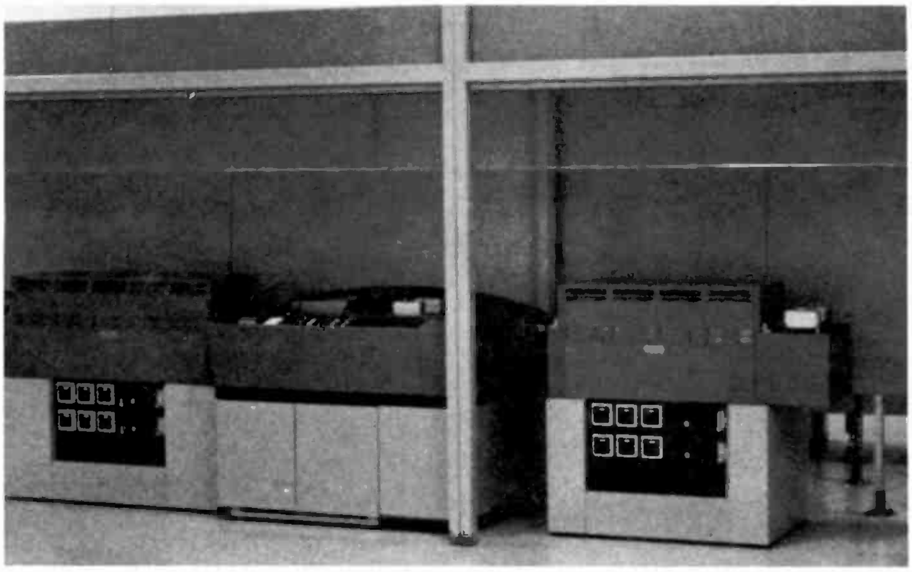

The Kasper Model 4500 system for integrated circuit photolithography incorporates cassette-to-cassette wafer handling and microprocessor programming of processing parameters. Modules shown are designed for dehydration "bakes" of 100-mm. diameter wafers, coating of each wafer by "spinning on" a layer of photoresist of controlled thickness and uniformity followed by a final "soft bake" of the photoresist. A similar module develops the images produced after the wafers have been aligned and exposed through the photomask.

aligners). Still another factor to consider is the requirement of the technology relative to the equipment capability. For example, it would be improper to spend the additional funds for an electron-beam direct-write exposure system capable of defining 0.5-μm features, if the technology for which the equipment is being purchased only requires defining 2-μm and 3-μm geometries. The differential in cost between an electron-beam system at 1.5-million dollars and a projection optical printer at $350,000 is 1.15-million dollars. Furthermore, an electron-beam system can expose only six wafers per hour compared to 60 for the optical projection printer. Obviously, an engineer would select the electron-beam system only if he were working with submicron geometries.

In the above example, the process engineer would have other options available. These include direct-step-on-wafer optical systems and x-ray exposure systems. A direct-step-on-wafer alignment system costs approximately $750,000 and has a resolution capability down to 1.0 μm, with a throughput of 50 wafers per hour. A low-intensity 1:1 x-ray exposure system costs approximately $800,000, and can resolve images down to 0.75 μm. However, a severe restriction on x-ray systems is its throughput rate of only 14 wafers per hour, and its requirement for special boron nitride masks, and photoresists sensitive to x rays. Obviously, in these examples not only the plant's short-term needs but the anticipated requirements of future designs must enter into any equipment selection process.

Wafer handling and defect generation during processing are other factors that influence equipment selection. The Palm Beach Gardens plant has automatic cassette-to-cassette handling systems wherever possible, especially on the photolithographic lines. Photolithography is the prime generator of defects in device fabrication. When working with 3-μm design rules, defects as small as 1 μm caused by contamination or poor handling will cause circuit failure and reduced yields.

Another consideration in selecting equipment is the system's required environment. Temperature, humidity and air-flow patterns all contribute to image reproducibility and process cleanliness, which in turn impact yield and manufacturing costs.

Once a decision is made on which type of equipment to purchase (for example direct-step-on-wafer exposure systems), multiple source vendors are contacted for demonstrations and quotations. Often rental agreements are reached with vendors to permit actual in-house evaluation of the equipment prior to purchase. In some cases, several systems from different vendors are purchased and evaluated in parallel. This approach to equipment evaluations enhances the probability of selecting the best possible equipment available for eventual "volume buys" by manufacturing.

The selection of equipment to do the job efficiently is further complicated by the rapid growth of the industry. Ten years ago, circuits of 1.27 mm on a side were standard; today circuits of 6.350 mm

Diffusion-furnace complex manufactured by Thermco, showing eight diffusion tubes for wafers up to 100-mm. in diameter. Each tube can be individually programmed with its own multi-step sequence for oxidations, diffusions, depositions, anneals, and so on. Programmable parameters include: temperature (400-1200°C.), time for each step, gasses for each step, ramp rates entering and leaving the tube, and boat position while in the tube.

are commonplace. Today's circuits contain as many as 300,000 discrete devices on each circuit, and newly developed designs contain even more.

To squeeze as many devices as possible onto an individual circuit without increasing the chip size, design engineers are constantly shrinking design rules. For example, compare RCA's A-series devices (early-1970 vintage) to RCA's latest bulk-CMOS memory process. Table I shows some key geometries that illustrate the trend.

Still another example of increased complexity is the number of operations required to build devices. In the case of A-series CMOS circuits, seven photolithographic steps are required, compared to the 11 to 14 required for today's most advanced CMOS memory types.

Additional technology in use today (and not common in the early 1970s) include low-pressure chemical-vapor deposition of layers of polysilicon, silicon nitride and silicon dioxide; plasma etching of materials including aluminum, nitride polysilicon and oxides; reactive ion etching; noncontact photo-exposing; direct-step patterning on wafers; sputtering of metallization; and computer-controlled furnace and processing equipment.

With the shrinkage in geometries, support equipment required for the necessary in-process measurements to assure specification conformity has also increased in complexity. Today, at Palm Beach Gardens, RCA has instruments with microprocessor controls monitor oxide thickness, junction depths, line widths, evaporation rates, wafer resistivity, and wafer flatness, among others.

To keep up with the solid-state industry, the equipment manufacturers have had to work in conjunction with the needs of the semiconductor producers. To this end they often have their own device fabrication laboratories. Equipment selection should be the result of extensive dialogue among the device fabricators and the equipment manufacturers. High-technology industries can only succeed when this type of cooperative environment exists.

Bob Shambelan is Manager of Plant and Equipment Engineering at RCA Solid State, Palm Beach Gardens, Florida. During 23 years at Somerville he progressed from tool-and-die maker to Leader Technical Staff in the Equipment Technology group. He is completing an RCA-Philco-Ford joint venture wafer facility in Brazil for the manufacture of bipolar ICs, and is planning a VLSI wafer fabrication line in PBG for CMOS II and CMOS III wafer technologies. He was responsible for eight separate cost-reduction programs; he has four patents with one more pending; and he was RCA Solid State Man of the Year in 1967.

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Marty Blumenfeld is Development Engineering Program Manager at RCA Solid State, Palm Beach Gardens, Florida. He is currently responsible for the transfer of CMOS II—3-micron feature size—wafer technology from the Solid State Technology Center into production at Palm Beach Gardens.

He started at Somerville in 1960 as an engineer in Plating for ceramic packaging and then in Diffusion. As a Leader of Technical Staff, his projects included the early stage of CMOS IC development and manufacturing in Somerville. At Palm Beach Gardens, he was in charge of SOS wafer fabrication engineering and then was Leader of Technical Staff for both CCL and SOS Wafer Process Engineering before becoming CMOS II Program Manager.

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In order to coordinate the decision-making process for new equipment purchases, RCA has established technology committees that meet periodically. These committees consist of technologists from the David Sarnoff Research Center, the Solid State Technology Center, and all Solid State Division manufacturing locations. The committees have been set up for all major technologies including diffusion, chemical-vapor deposition, plasma vacuum, and photo processing. With the cooperation of all equipment suppliers, RCA is now in its strongest position to make effective equipment purchases.

Continuing education for manufacturing engineers

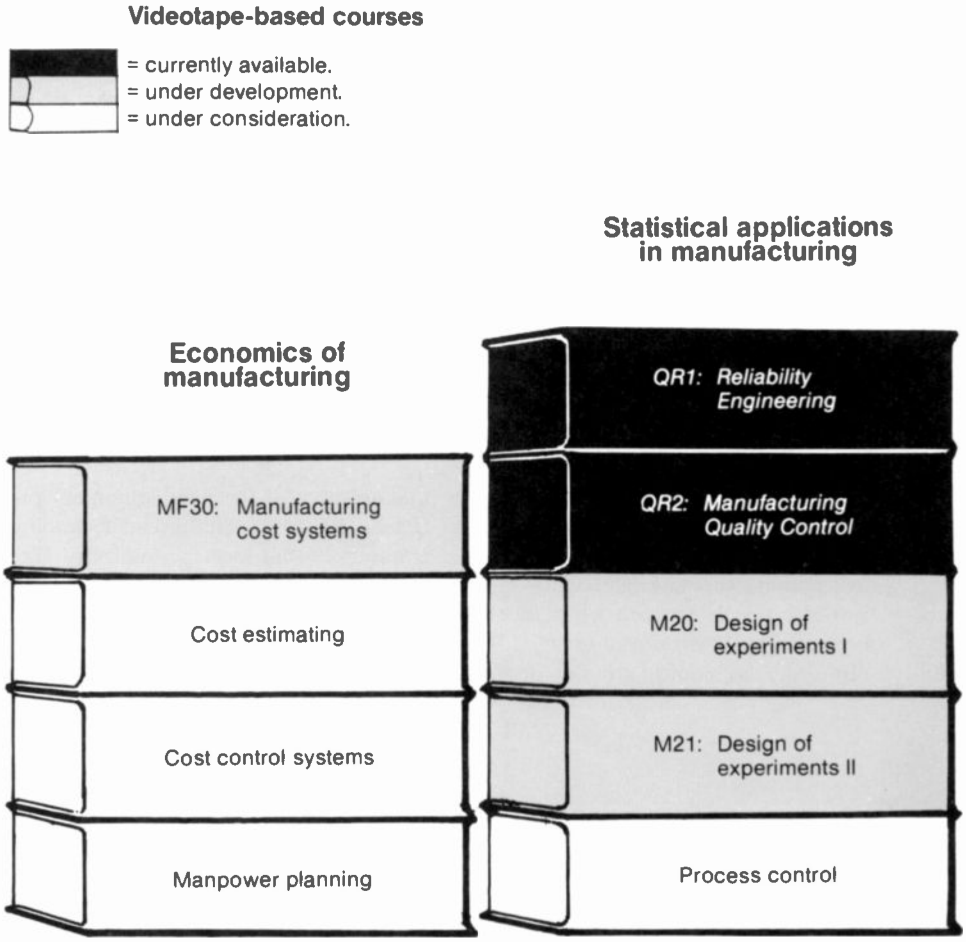
Manufacturing engineering education is a reality at RCA.

The development of continuing education programs geared specifically to the needs of RCA's manufacturing engineers began late in 1979 with the formal announcement of the Manufacturing Engineering Education Program (MEEP) at the second Manufacturing Engineering Productivity Symposium in Indianapolis. Following that announcement, RCA's Corporate Engineering Education (CEE) unit conducted a series of meetings and interviews with manufacturing engineers and their managers to find out what subjects concerned them in their jobs. They were asked to identify the new technologies that have entered their work place, the problems they encounter, and the subjects that new manufacturing engineers must learn, and older engineers relearn. These discussions resulted in more than 130 topics of importance to the manufacturing engineer, from *adhesives, automatic assembly,* and *budget control*...to *vacuum technology, welding techniques* and *work-methods analysis.*

To develop courses that would update and broaden the manufacturing engineer's skills, CEE asked for assistance in refining this list of topics into an essential curriculum for manufacturing engineering education. In further meetings, RCA manufacturing engineers and managers identified five basic disciplines that represent the most pressing areas for course development. These disciplines are listed in Fig. 1 together with specific course titles. Further analysis may result in additional disciplines or refinements to the curriculum.

During the past two years, the Manufacturing Engineering Education Program has evolved into a three-pronged effort by CEE to provide continuing education opportunities for RCA's manufacturing personnel. First, CEE offers video-based course packages that provide a structured learning experience in subjects that are basic to the practice of manufacturing engineering. Normally, these courses are taken as part of the RCA continuing education programs offered at most RCA locations. As of this writing, the program consists of five courses that are currently available, four more that will be completed in 1982, and several others that are under consideration (Fig. 1).

Fig. 1. Five disciplines of Manufacturing Engineering Course offerings.



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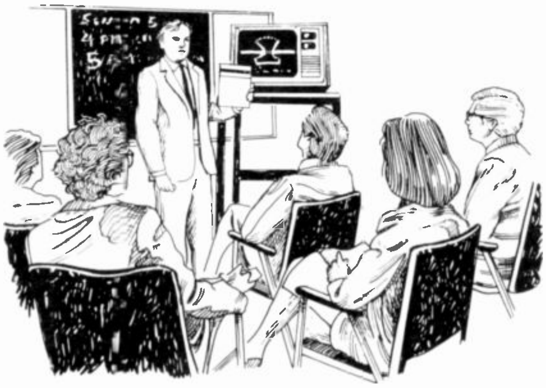
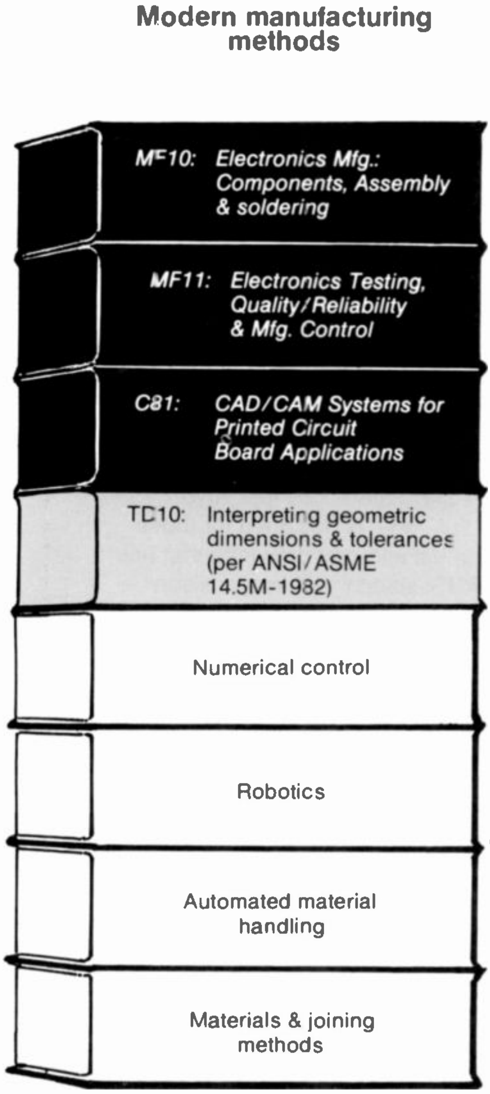
Second, CEE sponsors live short courses on subjects such as *Microprocessor Software, Hardware and Interfacing,* and *Hands-On Microprocessor Troubleshooting* that interest those in manufacturing activities. CEE's planning of these courses takes into account the needs of RCA's technical personnel in general; however, some offerings are geared to the specific needs of the larger manufacturing organizations.

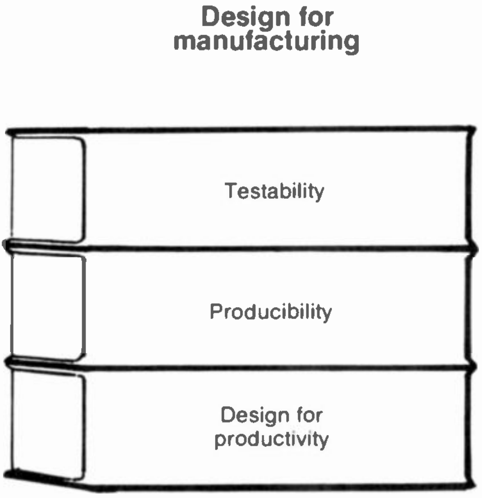
Finally, CEE maintains a library of audio-visual materials from various sources within RCA and from schools and other organizations, such as the Society of Manufacturing Engineers, on topics of interest to RCA's technical personnel. Many of these videotapes and audio-visual programs include subjects of particular importance to manufacturing engineers, and can often meet a need for information or education on new concepts, methods or technologies that cannot be met by a course package requiring 10 to 12 weeks of formal study. Table I gives a representative sample of program titles.

Course contents

MF30: Manufacturing Cost Systems presents the construction and use of standard cost systems, the relationship between product price and product cost, the techniques of cost reduction, the manufacturing "learning curve," as well as capital investment decisions.







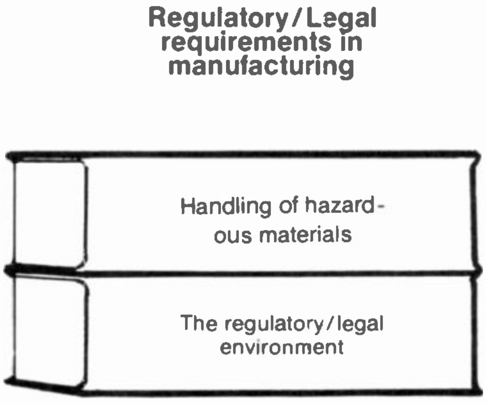


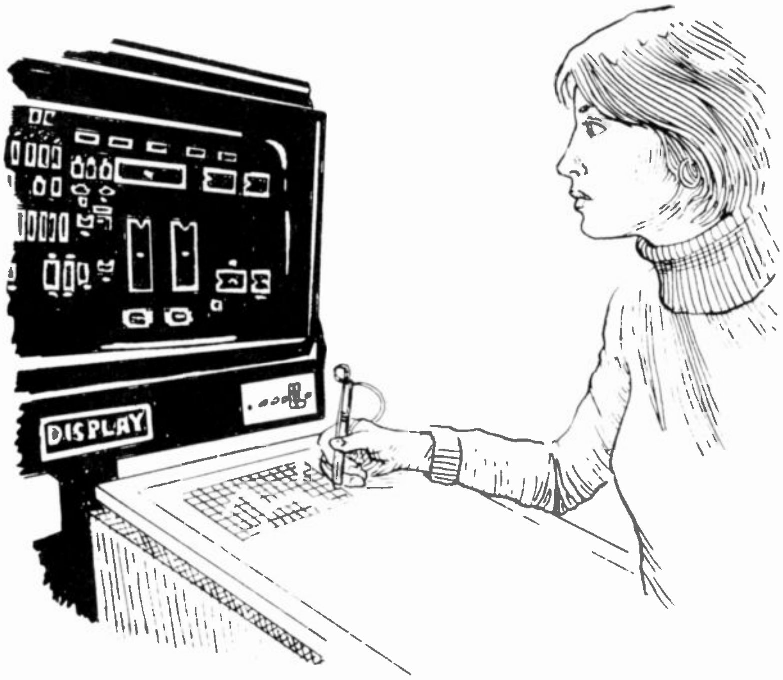
Table I. A sample of videotapes from the CEE Library on subjects associated with Manufacturing.

Tape No.	*Title*
174	"Robots: Fact and Fantasy," by David Grossman, IBM
177	"Tube Division to Picture Tube Division—Mechanization to Automation," by Clifford E. Shedd Picture Tube Division
414	"Experimental Design Seminar," RCA Laboratories, August 1979 by Karen A. Pitts and Russell R. Barton
417	"Quality Circles," by S. Mecca
419	"Productivity Breakthroughs: Begin with Results, Not preparations," by Robert H. Schaffer

QR1: Reliability Engineering presents the concepts and procedures to predict and improve the "time to failure" of mechanical or electric/electronic devices. The course can be used either as an introduction to the fundamentals or as a review of principal topics for those who have had some practical experience with reliability.

QR2: Manufacturing Quality Control presents the fundamentals of a modern quality-control program in a manufacturing environment. Topics include control charting and acceptance sampling plans as well as vendor certification and rating, specifications and tolerances, and product liability.

In addition to the manufacturing engineering curriculum, CEE offers other courses to RCA personnel on such topics as microcomputers, programming languages, mathematics, communication theory, mechanics, physics and electronic troubleshooting. Many of these courses will be useful to manufacturing engineers. For additional information or a copy of the CEE catalog, contact your local education representative or call Margaret Gilfillan, TACNET 222-5255.



M20/M21: Design of Experiments I and II presents the design of statistical experiments for industrial applications, beginning with an introduction to the language and concepts of modern statistics, continuing through the design and analysis of experiments using such techniques as balanced-block, factorial, and fractional-factorial designs, and concluding with the subjects of least-squares model fitting and response-surface methodology.

MF10: Electronics Manufacturing: Components, Assembly and Soldering provides a broad overview of the steps involved in electronics manufacturing, from component specifications, purchasing and handling through printed-circuit-board fabrication and assembly to soldering, inspection and rework. The course, because it is a survey, is suitable for a wide range of personnel engaged in manufacturing.

MF11: Electronics Testing, Quality/Reliability, and Manufacturing Control is a survey course that examines the techniques and equipment for testing electronic components, PC boards and final products, the development and implementation of reliability, QC and QA programs, and the application of material requirements planning, production controls, and facility planning techniques to electronics manufacturing.

C81: CAD/CAM for Printed Circuit Board Applications begins with an overview of a fully integrated CAD/CAM system. Computer-aided manufacturing and the CAD/CAM interface are described and illustrated in detail. Throughout the course, the emphasis is on practical techniques for system analysis, selection, and implementation.

TD10: Interpreting Geometrical Dimensions and Tolerances (per ANSI/ASME Y14.5M-1982) is designed for those who must interpret drawings that use the ANSI standard of true position measurement for dimensioning and tolerancing. The course is taught by internationally recognized consultant, Lowell W. Foster.

Further work to provide continuing education for manufacturing engineers is a high priority with CEE, and comments or suggestions from RCA's manufacturing population are encouraged. For further information on CEE courses, audio-visual library materials or live short courses, contact Jim Schoedler at TACNET 222-5141.

C. Young

Numerical control: The cornerstone of computers in manufacturing

Numerical control is a concept of controlling a process that creates the opportunity for optimization and efficient information transfer throughout the design and manufacturing organization.

Abstract: *The history and the principles of numerical control (NC) exemplify the growing use of computers in manufacturing. The fundamental elements of NC operation are given, together with a mention of the use of computers for part programming.*

Numerical control was born alongside the modern digital electronic computer. For this reason, it has become the cornerstone of computers in manufacturing. By understanding the history and principles of numerical control, an understanding of computers in the whole technology of manufacturing will emerge.

History and concepts of numerical control

Just thirty-five years ago, numerical control and computers were merely concepts for academic discussion. Machine tools were manually operated, and the people who ran them were craftsmen. It was a well-ordered process. Designers designed parts. Drafters drew them. Production people tooled for them. Manufacturing people assembled and inspected them. And marketing people sold them. The process was often slow and cumbersome, but it worked and was superior to anything history had to offer. We were 175 years into the modern industrial age and productivity had never been higher.

At this time, in 1945, a significant but largely unnoticed event occurred. Two young men at the University of Pennsylvania, Dr. John W. Mauchly and Mr. J. Presper Eckert, created the world's first practical digital electronic computer. It was called ENIAC and by today's standards it was crude and cumbersome. It was massive, used energy-consuming vacuum tubes, and was difficult to program. The ENIAC was the result of a high-priority development program sponsored by the government to speed up scientific and engineering calculations needed during World War II.

World War II left its impact in other ways. Aircraft design had reached new levels of sophistication and was placing heavy demands on existing manufacturing technology. Aircraft wings and rotor blades required three-dimensional contours cut to exacting tolerances. Methods had to be developed to produce these shapes accurately.

The required contours could be described by tables of spatial coordinates (X, Y, Z values). It would be desirable to have these coordinates input directly to a machine tool capable of machining to the necessary accuracies. It had already been shown that a single axis could be accurately controlled to return to a single "programmed" location. Thus, if three axes (X, Y, Z) could be simultaneously controlled through a series of points in space, the required contours would be produced. This was the concept behind the development of numerical control. Considerable time and effort were still required to bring this concept to reality.

The development work was sponsored by the Air Force with the contracts going to MIT starting in 1949. These contracts were for the development of servo-mechanisms to drive the machine tool. In 1952, a laboratory-modified vertical milling machine successfully cut three-dimensional contours from a straight-binary paper tape. More work was done and numerical control was announced to the public in November, 1954.

Because mathematical information was the basis of the concept, it was given the name Numerical Control (NC). A more accurate name would actually have been symbolic control, since letters and other symbols are used in addition to numbers.

By definition, numerical control is the control of a process by a series of coded instructions that are composed largely of numbers. In the context of metal-cutting

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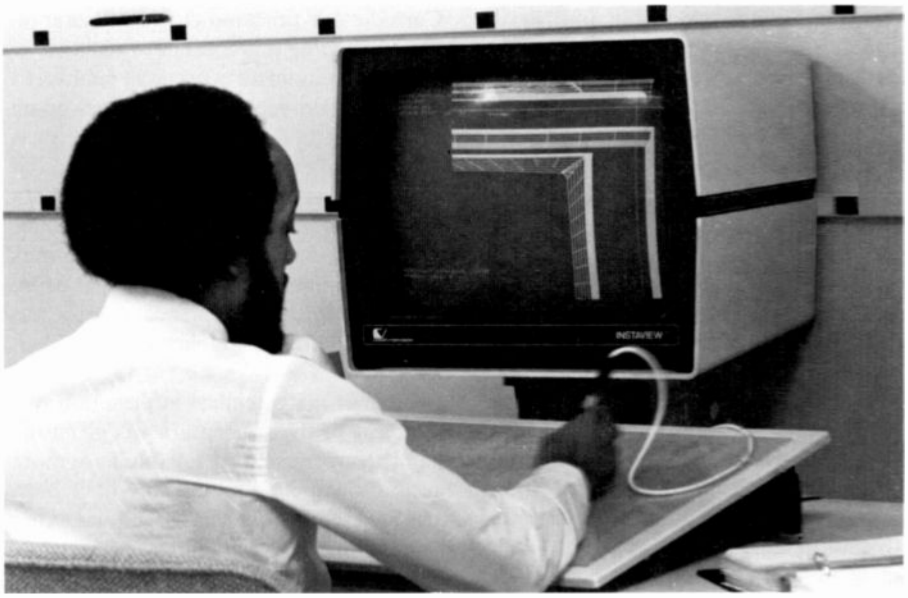
machine tools (by far the most prevalent application of NC), these instructions range from positioning of the spindle with respect to the workpiece to selecting speeds, feeds, and tools. Instructions can even turn the coolant on and off, or control other auxiliary functions.

It is important to realize that the computer made NC possible, for only the digital electronic computer could process the straight-binary tape data in sufficient quantities and with sufficient speed to make the NC concept viable. Although binary-coded decimal (BCD) has made manual programming of NC machines possible, the real value of the NC concept depends upon its successful integration with an overall computer system for design and manufacturing. The manufacturing revolution started by NC has gone far beyond the control of machine tools, and now NC is merely one application of the computer to the whole technology of manufacturing. The computer has been applied to part design, part analysis, tool design, inspection, quality control, inventory control, process planning, data gathering, work flow and scheduling, warehousing, testing, and endless other design and manufcturing functions. By better understanding NC, the cornerstone of computers in manufacturing, it is possible to better understand the concept of an integrated computer system for design and manufacturing.

The Machine Control Unit interprets the NC program instruction and sends signals to cause the desired function to occur. This could be anything from causing a tool movement to turning on the coolant.

NC machining represents a complete departure from conventional machine tool operation where a machinist studies a workpiece drawing and then directs the machining sequence based on his knowledge of the machine tool and his interpretation of the drawing. This traditional manual machine operation is based largely on intuition and skills. These skills are learned through long training and practice. The quality of the part is heavily dependent on the machinist's skill, knowledge, and concentration. These qualities are never fully consistent because they change from operator to operator or from day to day and even from hour to hour within the same person due to fatigue, boredom, and attitude.



An NC programmer uses a computer to develop his toolpaths. The computer displays the part and toolpaths on the screen, thus allowing the programmer to verify his work before the actual machining begins.

With NC, the control of the machine is shifted away from the operator's skill and intuition to an entirely conceptual documentation of all machine motions and functions necessary to produce the part. Thus, an NC program for a part is a clearly defined process plan. This process plan is converted to machine motions by the machine-control unit. This guarantees that a part made in the morning is the same as a part made in the afternoon, and that a part made by operator A is the same as the part made by operator B. It also creates an opportunity to optimize the machining process and to use a computer for this optimization.

NC is not a machining method. It is a concept of machine control. Machining methods are drilling, milling, boring, tapping, and so on. NC can control all of these and more. NC has not changed or altered the basic concept of a milling cutter generating a chip; however, it has affected the ability to drive the cutter efficiently and to produce much closer to theoretical maximum capacity. There is a slight advantage in increasing the speed of the tool a few percentage points. It is far more significant to increase machine use from an average of 20 percent to a new level exceeding 70 percent. This is accomplished since NC improves the control factor to such a degree that wasted, redundant, and nonproductive motions and waiting times can be eliminated. The computer system is used to assist in the elimination of these inefficiencies and thus greatly increases productivity.

In addition to increased machining productivity, NC can generate complex machine motions to a degree of precision far beyond any human capability. This is particularly important for producing airfoil contours and complex mold or die surfaces. If a surface can be mathematically defined, NC can control the machining of it.

NC operational outline

The fundamental elements of NC operation are the part program that contains the instructions, the machine-control unit that interprets the instructions, and the servo-drives and switches that perform the functions.

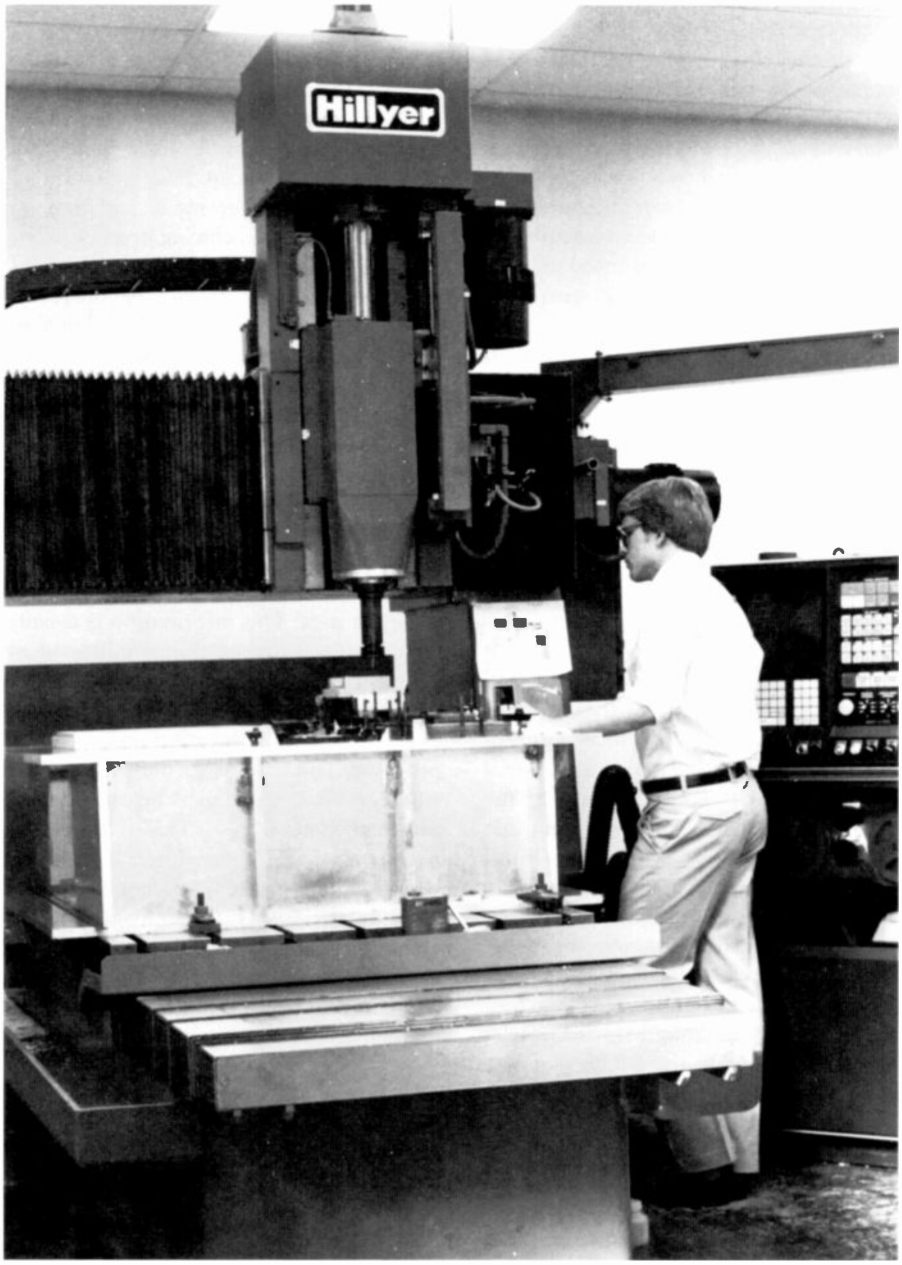
Whether of not a part program is manually written or computer generated, certain fundamentals apply. The generation of part programs with a computer will be discussed in greater detail later. The part programmer may be an engineer, shop foreman, methods man, programming specialist, or anyone who has the inclination and ability to assume a programming function. The programmer must study the part, which can be in the form of a drawing or computer model, to be programmed. In this way, he is very much like the machinist who studies the drawing before starting to machine. The part programmer, however, functions in an entirely different manner. Instead of turning handwheels, operating controls, and proceeding by touch and intuition, the programmer will have to conceptually visualize all of the machine motions necessary to machine the part. He then, with or without a computer, will have to convert these concepts into codes that the machine-control unit will understand.

The effective operation of the machine tool has now become the programmer's responsibility. The programmer determines the moves, sequences, tools, speeds and feeds, and overall motions that the machine tool will take in machining the part. The machine operator's function has changed to that of an overseer with other duties such as workpiece loading and unloading, information feedback, tool replacement, and so on.

What the operator has traditionally done with intuitive insight and training, the part programmer must now do with intellect and reasoning. NC forces the programmer to logically conceive and clearly state all machine actions. Remember that NC machines have no ability to exercise judgment. They will simply follow the instructions they are given, and ill-conceived instructions will produce ill-conceived results. Thus, a by-product of involvement in NC is the necessity to clean house of many sloppy procedures.

The machine-control unit (MCU) converts the coded instructions to obtain the machine-tool action. Thus, the MCU must read the part program and generate the necessary output to cause the motion or function to occur. The MCU is predominantly an electronic device.

A part program can be input to the MCU by two methods: physical media transfer, and direct link to a remote computer. Most programs are on physical media, and paper tape remains the most popular of the various media. Cassette tapes and floppy discs are also used. Direct link to a computer can be significantly more efficient but requires the capital investment of the computer as well as the development of the interface. Clearly, direct link is necessary for a truly integrated design and manufacturing system.



After being started by an operator, this NC milling machine produces a part from an NC program. The part is produced exactly as it was designed on the computer.

The newer CNC (Computer Numerical Control) MCUs feature an internal memory capable of holding a part program, up to a given length. This means that once a program is read or transferred to the MCU, it will remain in the memory until it is cleared. Another feature of CNC is the ability to edit the part program at the machine while it is in the memory. If only minor editing is required, this can be very beneficial. Lastly, CNC allows the controller to perform some crude calculational functions such as circular interpolation (done in hard logic on most NC-only machines) and simple rectangular pocketing. CNC does not replace the need for an integrated design and manufacturing system. Instead, it enhances the ability to make minor corrections very efficiently.

In addition to reading the part program, the MCU serves as the operator interface to the machine. The operator can cause machine motions by communicating to the MCU. This is used primarily for set-up purposes. It is also through the MCU that the operator tells the machine to begin to execute the part program.

Once execution of the program has commenced, the MCU must interpret each instruction and send the necessary electrical signals to servo-mechanisms. During this process, many MCUs monitor certain functions such as table limit switches, and display information such as current coordinate positions. If the program has no catastrophic errors, the part will be produced as programmed and the machine will turn itself off.

The last element of NC operation is the actual control of the machine. The MCU outputs electronic signals that cause servomechanisms to react until the proper condition is reached. Basically, the MCU does electronically what the operator used to do visually.

Using computers for part programming

Computers have been used for NC programming since the very first program written. In fact, computers were an essential ingredient to the development of the NC method. Since this first program, the use of computers for programming has matured considerably.

Three types of information are required for computer-assisted programming. First, the part geometry must be described. Then, the machining parameters such as tool sizes and their speeds and feeds must be entered. And finally, the MCU that will receive the program must be identified.

Depending on the part to be made, describing the part geometry could require the simple definition of a few lines and arcs, or the lengthy definition of curves for complex surfaces. In a system intended strictly for NC programming, this process takes the greatest amount of time and requires the least amount of NC and machining knowledge. This is the key reason why NC must be integrated into a design and manufacturing system to truly realize the benefits possible from both the NC and the design system. If the design is already described in the computer system, the programmer can proceed directly to entering the machining parameters.

Once the geometry has been described, the machining parameters must be defined. This step requires an understanding of how the part will be made and thus an understanding of machining processes. The machining parameters include decisions such as what tool should be used, the speed and feed for that tool, whether or not coolant should be used, where the tool should start, and so on. These decisions can be made very quickly by an experienced programmer since the tools are defined in a tool library and programs are available to help him determine speeds and feeds. After these parameters are defined, the computer uses the information to calculate the toolpaths required to produce the part. This information is usually in a universal format that is independent of the specific machine upon which the part will be made.

This toolpath information must be post-processed (translated) to the specific machine or MCU to be used before the part program can be run. This is necessary because each MCU has different capabilities and thus requires different codes. Efforts are underway to standardize these codes to a greater extent. The post-processing is performed by the computer system and requires very little operator input or skill.

Summary

Numerical control was the first major application of computers in manufacturing. In fact, the very development of numerical control depended upon the computer. NC is an excellent example of how computers can be effectively used in manufacturing. First, NC takes advantage of the computer's analytical capability to generate and optimize toolpaths. This offers substantial productivity benefits through better quality control and higher machine use. Even more significantly, numerical control can take advantage of information already in a design and manufacturing computer system. This reduces misinterpretation and greatly increases the efficiency of information transfer. Numerical control is only one of many design and manufacturing processes that can take advantage of these two key fundamentals of an integrated design and manufacturing computer system. Through numerical control, the cornerstone of computers in manufacturing, it is clear that an integrated design and manufacturing computer system can improve communication and increase productivity.

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Computer-aided design of metal-forming processes

Knowing the influence of various forming parameters on the deformation mechanics is a prime requirement for the proper design and control of metal-forming processes.

Abstract: *PLAFOM, a rigid-plastic finite-element computer program developed by the author at RCA Laboratories, is used as a tool for computer-aided design of metal-forming processes. Unlike the conventional "trial-and-error" method of designing punches and dies, this computer program predicts the workpiece metal-flow and process-deformation mechanics under the influence of various forming parameters, such as workpiece dimensions, punch and die geometries, material properties, and tool-workpiece interfacial friction. The availability of this "prior" knowledge of the forming process enables us to predict the effects of design changes on the final workpiece and to guide the design of punches and dies.*

Metal-forming processes convert the shape and dimension of an initially undeformed, or predeformed, workpiece into a useful object under very high pressure through various arrangements of punches and dies. Because such processes require very high forming loads to deform the workpiece permanently, inadequately designed processes can cause material failure or defective parts; for example, internal cracks (so-called "center-burst" or "chevron cracks") are often found along the center axis of extruded bars (Fig. 1a). In cup stretching or drawing processes, cracks are usually observed near the bottom of the formed cups (Fig. 1b). To produce parts without defects, while meeting the requirements of dimensions and tolerance, is the main concern in designing a successful metal-forming process.

The factors that affect the final products of a forming process include the following: the material properties and the initial dimensions of the workpiece; the friction force between the workpiece and tool surfaces; the punch velocity; and the geometries and dimensions of punches and dies. An understanding of the influence of these forming parameters on the deformation mechanics of the forming process is a prime requirement for successful metal-forming design.

Traditionally, with little available knowledge of the deformation mechanics, the so-called "trial-and-error" method has been used extensively in the metal-working industry, where various sets of punches and dies were tried and modified until the desired parts were obtained. To avoid this costly and time-consuming conventional method, a computer-based metal-forming program, PLAFOM, has been developed using a rigid-plastic finite-element formulation.[1, 2] This program simulates the actual forming processes and accurately predicts the forming loads, the metal flows, the stress and strain distributions, and the shapes and dimensions of the final products. The goal of the computer-aided design is to use such "prior" information, by changing the various forming parameters, for best design of punches and dies and for proper control of the forming processes.

The computer program, PLAFOM

PLAFOM is a generalized two-dimensional finite-element program for axisymmetric and plane-strain metal-forming problems. The program requires input containing information on the workpiece dimensions, the punch and die geometries, the friction condition, and the stress-strain relationship of the material. A mesh system is used to describe the workpiece where the total volume is divided into a number of quadrilateral elements, interconnected by the surrounding nodal points (Fig. 2). The punches and dies are divided into several sections according to the following three categories: straight surfaces, inclined surfaces, and round surfaces. There is no limitation on the total sections of punches and dies; neither is this program restricted to any specific process. Columbu's friction coefficient is used to represent the friction force for each section of the tool-workpiece interfaces. The material work-hardening characteristic is described through the stress-strain relationship from the input provided by the user. The current version of this program is limited to materials that are isotropic and rate-insensitive (that is, the material properties are not affected by punch velocity).

In computer simulation of metal-forming processes, the non-steady-state deformation is treated in a step-by-step manner. A numerical iterative process is used to obtain the velocity distribution at each step, and the workpiece geometry and strain distributions are updated accordingly. The output of this program includes the deformed workpiece geometry, the velocity distribution, the nodal forces, and the element stress and strain distributions.

Application examples

To demonstrate the ability and accuracy of the present computer program, the fol-

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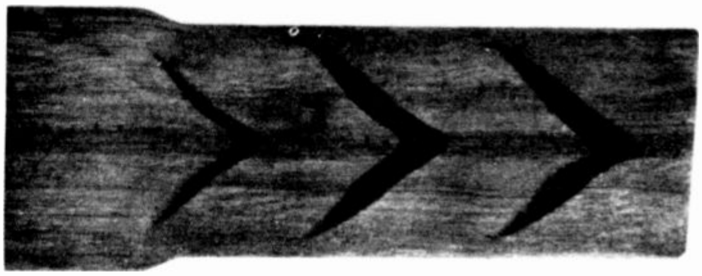


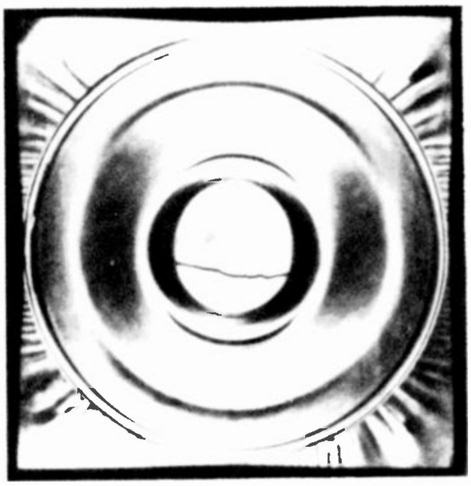


Fig. 1. Examples of defective parts.[6]
(a) Center burst in extrusion.
(b) Crack in cup stretching.

lowing examples are presented and compared with available experimental data.

Example: Punch identation

A flat, circular metal workpiece of various dimensions is indented with cylindrical punches of different punch-nose radii. The effects of nose radius and lubrication on the required punch loads and final geometries for commercially pure aluminum were studied experimentally by Male.[3] We have simulated these processes with the initial mesh system shown in Fig. 2. Note that a very fine mesh was used for the region near the bottom of the punch where the highly localized plastic deformation is likely to occur.

Metal flow

Figure 3 illustrates the computer results of metal flow and the corresponding geometric changes at various stages for an initially flat workpiece of 3.0-inches diameter and 0.5-inches thickness. The arrows in the figure represent the direction and relative magnitude of the particle velocities. At early stages the metal flow is restricted to a small region near the bottom of the punch; the deformation zone enlarges gradually as the punch penetrates deeper. The particles move in a downward direction below the center of the punch, and gradually rotate to an upward direction near the punch nose. When the process reaches a certain stage where almost the entire punch region deforms, the particles in the remaining, undeformed portion of the workpiece start to move upward, which then results in the separation of the workpiece and die. The separation phenomenon starts from the outer edge of the workpiece, propagates toward the center, and becomes very severe as the punch penetrates further.

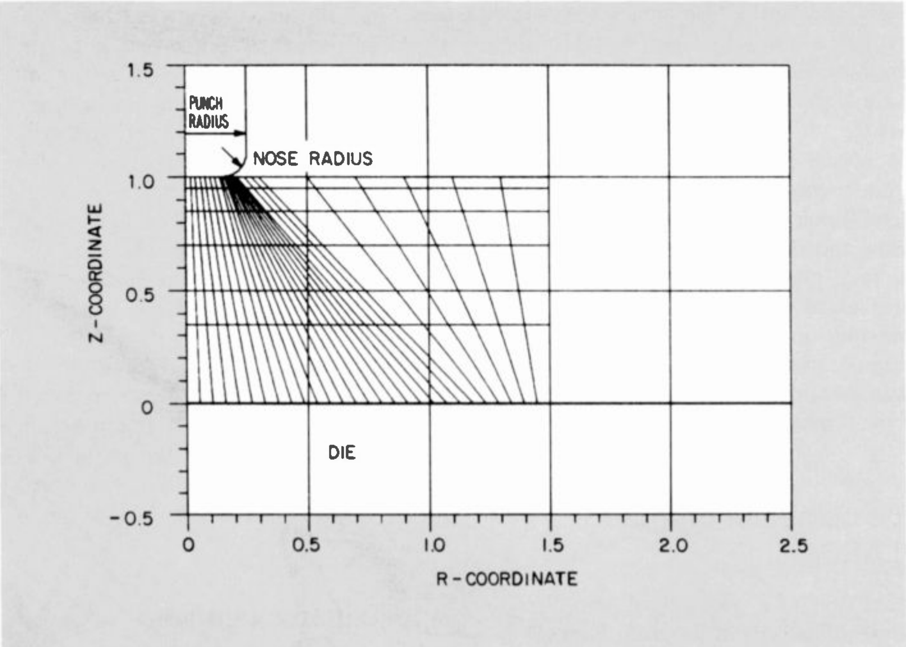


Fig. 2. Finite-element mesh system used in the computer simulation of the axisymmetric punch indentation processes.

Effects of forming parameters

It is well known that, in forming metal parts, a good lubricant will make the whole process easy; but it is not so obvious that sometimes a slight modification of punch or die can make it even easier. This situation is best illustrated in Fig. 4. The solid curves in the figure are the experimental data,[3] where both dry graphite film and machine oil were used as lubricants for tool-workpiece interfaces. Dry graphite film is known to be a more effective lubricant, compared with machine oil. Three different forming conditions were studied for flat workpieces of 1-inch thickness and 3-inch diameter: (1) the better lubricant (dry graphite film) and smaller punch-nose radius (0.1 inch); (2) the less effective lubricant (machine oil) and smaller punch-nose radius; and (3) the less effective lubricant and larger punch-nose radius (0.25 inch). Computer solutions of the required punch forces are also presented in the figure. Comparison of these results shows that the friction coefficients used in computation closely represent the actual lubricants used in experiments, although slight deviations are found at later stages. The forming process with a better lubricant requires less punch force for the same punch-nose radius (0.1 inch), thereby making the process easier, but a slight modification of the punch-nose radius (0.25 inch) reduces the punch

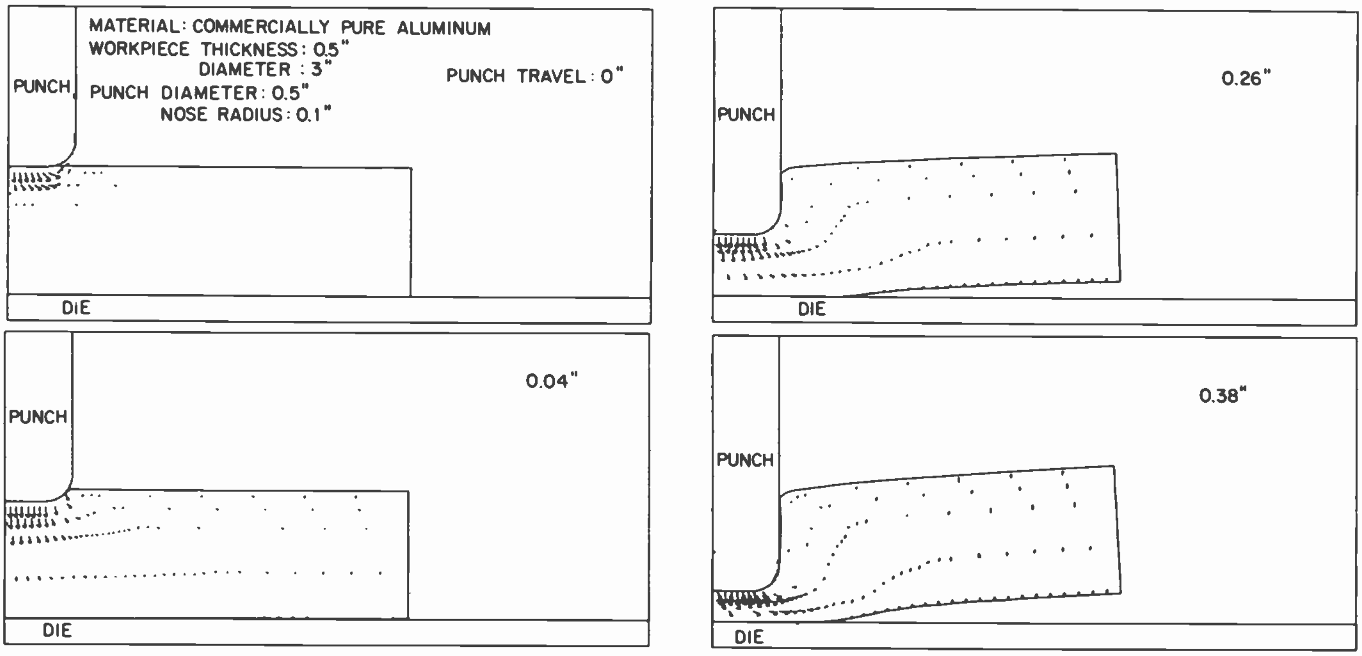


Fig. 3. Illustration of metal flow of the axisymmetric punch indentation process. The arrows represent the direction and relative magnitude of the particle velocities.

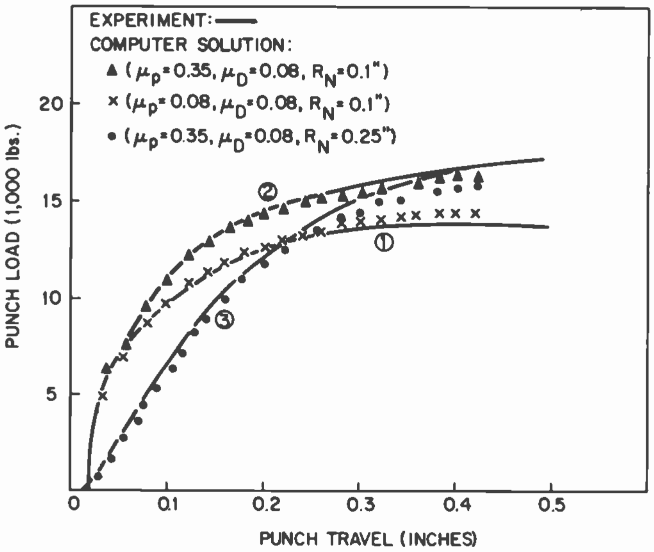


Fig. 4. Comparison of the required loads for the punch indentation processes under different forming conditions.

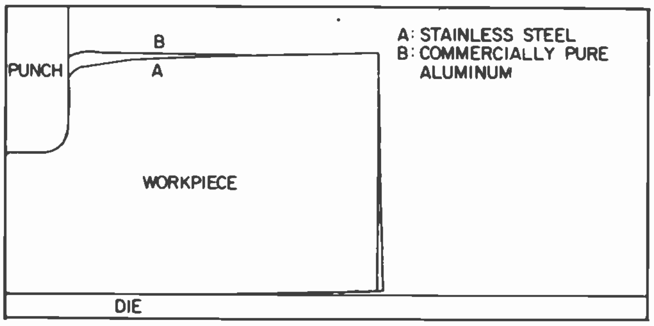


Fig. 5. Comparison of final geometries at punch travel of 0.4 inch for different materials under the same forming conditions.

force even more for punch travel up to 0.25 inch.

Careful examination of the computer results reveals that there is not much difference in the final workpiece geometries at 0.4-inch punch penetration for all of the above three cases. This is no longer true, however, if a different material is used. Stainless steel, for example, is much harder than aluminum and involves more work hardening; the final geometries for both materials are shown in Fig. 5, where the top surface of stainless steel is less flat, expecially near the punch region, due to the severe distortion caused by the highly work-hardening material characteristics.

Example: Punch stretching/deep drawing

The difference between punch stretching and deep drawing to form a hemispherical cup is that, in the punch stretching process, the edge of the blank is clamped securely so that no movement in any direction is allowed, while in the drawing process, radial slippage of the edge is permitted, but controlled by the amount of blank-holding force applied. Both cases were analyzed by PLAFOM with the forming conditions taken from Woo,[4, 5] where the experimental results are also available.

Computer simulation and results.

Figure 6 shows the computer simulation of the deformation patterns for punch stretching at various steps. Note that in this figure a severe thinning element is found under the center of the punch, which indicates the possible location of a fracture. This fracture location will move away from the punch center if a larger friction force is applied instead. Figure 7 compares the computer-predicted punch loads with experimental observations; they match closely. The punch force required for stretching is also larger than that for drawing, as expected. Figure 8 compares the resulting circumferential strains for

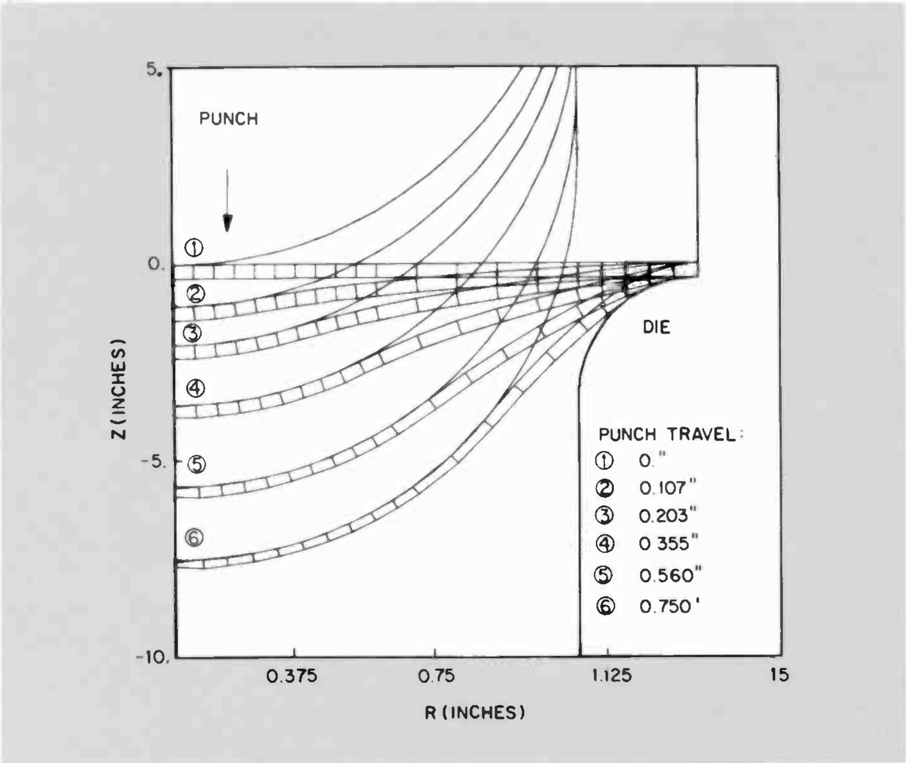


Fig. 6. Computer simulation of the cup-stretching process. The center element experiences severe thinning at later stages, indicating the possible location of a fracture.

both cases; again, the results match the experimental data except for small portions near the center of the punch at later stages. The discrepancy is believed to result from the breakdown of lubricant at these regions in the experiment, which, in turn, increases the frictional force and lowers the circumferential strain. Figure 8 also shows that the strains in the deep drawing are considerably lower than those resulting from punch stretching.

Design considerations.

Deep drawing is the preferred process for forming a deep cup because it requires less punch force and results in smaller strains. In designing deep-drawing processes, however, special attention must be paid to the total amount of the blank-holding force, because an inadequate amount of holding force will cause wrinkling; and too much force will cause fracture of the drawn cups. Note that in the latter case, the metal flow at the blank edge is severely restricted, and the process is similar to punch stretching where large strain is involved, and, therefore, fracture is likely to occur. The present computer program can be used to obtain a series of strain distributions by changing the blank-holding force and other forming parameters. The right amount of blank-holding force and the corresponding safe distance for punch travel can then be predicted by comparing these strain distributions with the experimentally available forming limit curve. Such information is extremely important to someone successfully designing deep-drawing processes.

Summary

The above examples have shown that the computer program, PLAFOM, does provide a useful tool for the computer-aided design of metal-forming processes. It is noted that although PLAFOM is a generalized finite-element program, it is still limited to the cases of two-dimensional axisymmetric or plane-strain problems. Furthermore, since this program was developed based on a rigid-plastic finite-element formulation for isotropic, rate-insensitive materials, it is, therefore, not appropriate to apply this program to the problems with strongly anisotropic or rate-sensitive materials. This program also neglects dynamic effects and elastic unloading processes. The elastic unloading phenomenon is important for studying the spring-back problems in sheet-metal forming. Modification of the present

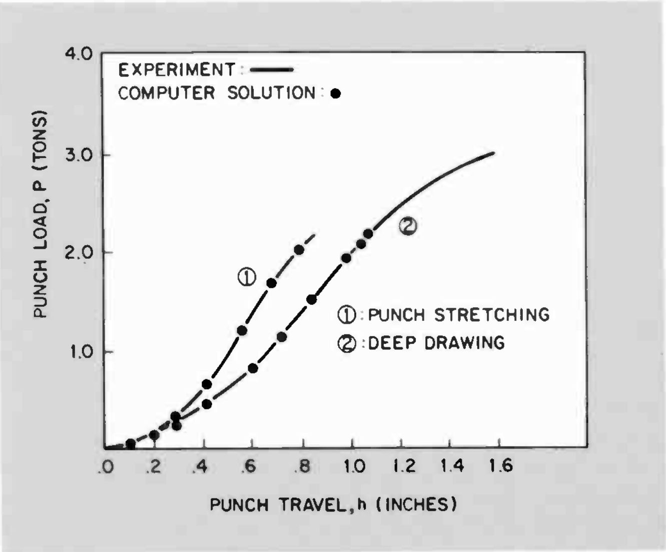


Fig. 7. Comparison of the required loads to form a spherical cup by means of different stretching and drawing processes.

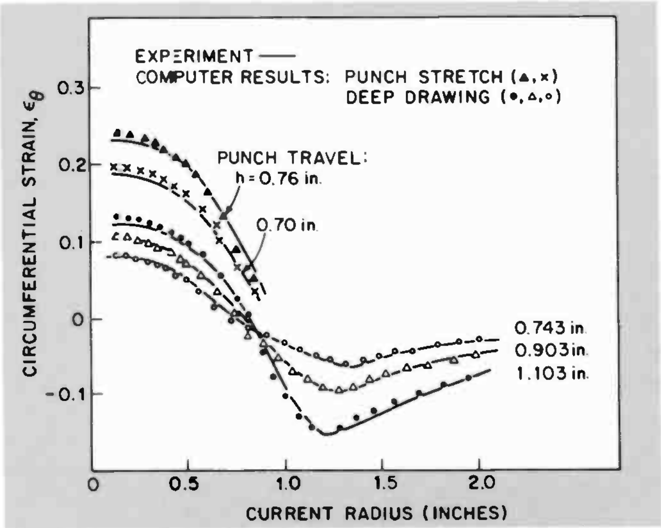


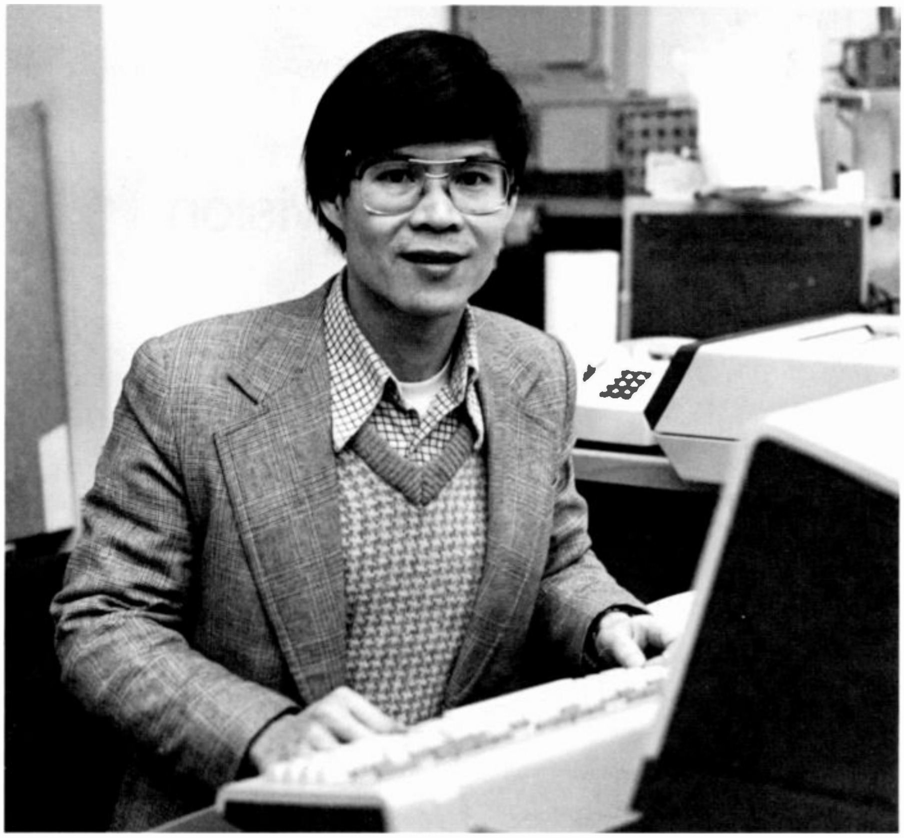
Fig. 8. Comparison of the resulting circumferential strains. The drawing process requires less punch load (Fig. 7) and results in less strain.

program to handle these situations is possible, but this requires new formulations, and is therefore left for future studies.

Despite the limitations mentioned above, the existence of this computer program provides a new avenue in the course of metal-forming design; it enables us to predict the effects of design changes on the final workpiece, and, therefore, to guide the design of punches and dies successfully.

Acknowledgment

The author wishes to express his deep gratitude to many persons from Lancaster Parts Works of Picture Tube Division and Princeton Manufacturing Systems and Technologies Laboratory for their firm support in developing the present program for the computer-aided design of metal-forming processes. Especially, thanks are due to D.P. Bortfeld for his constant encouragement and valuable discussions. The author also wants to thank R.L. Crane for his valuable suggestions, and many colleagues for their helpful discussions. The permission from the American Society for Metals to reproduce Fig. 1 is also acknowledged.



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G.L. Haggerty

Package engineering for the Picture Tube Division

Stringent packaging standards guarantee that the quality of millions of RCA-manufactured tubes will stack up next to the competition, year after year.

Abstract: *RCA, the largest manufacturer of color-television picture tubes in the world, recognizes that packaging is essential to the manufacture of the product. The duties of the Package Engineer within Picture Tube Division show the process of package design; the criteria used to develop the package are explained; packaging for component parts and subassemblies are described; and trends are given.*

RCA Corporation is the largest manufacturer of color-television picture tubes in the world. Annual volume is in the millions. This efficient, high-volume production demands equally efficient methods of packaging the tubes as they are produced. Packaging is essential to the manufacture of the product. It must protect the product throughout a distribution system having several hazards. The Picture Tube Division successfully delivers products worldwide that meet stringent inspection and operating requirements, attesting to the performance of the packaging. It also accomplishes this job at a competitive cost.

When packaging was first recognized as a vital company function, most large corporations placed it under research and development. This is essentially true of the Picture Tube Division, where Package Engineering has remained a part of the Development Shop for twenty-five years. The latter has been renamed the Pilot Development Shop.

For certain aspects of package design, the close association with the Tube Design and Development Engineering Groups at the Lancaster headquarters has distinct advantages. Information, on new product designs and on revisions to existing lines, is available early in the development phase. This is particularly important when the package design may have some influence on the final product design. Prototypes, a virtual necessity in packaging, are produced by the Pilot Development Shop.

Coordinating the package development

In a company that has no formal packaging organization, the entire responsibility for coordinating the development of new packages is on the packaging engineer. In the Picture Tube Division, this coordination frequently includes contact with other departments.

The Traffic department is consulted on package designs that progress to the shipping evaluation stage. They may find it necessary to apply for a test permit for shipping a new package by common carrier. Later, formal hearings held by national transportation boards are attended by the Traffic Manager and Packaging Engineer, who testify to the need for the new package design. Variations in the size of the packaging or in the density of the product per cubic volume of the truck trailer may change the transportation cost to RCA or to the customer. This is a key point for Traffic and Marketing in pricing the product.

Marketing and Applications Engineering are advised when changes in packaging may affect the customer's unpacking procedure or handling of the product. Samples of the revised package are reviewed with the customer by a representative of one of these groups.

Material Control must be aware of prospective changes in packing-material requirements. Inventory levels often dictate the timing for introduction of a new pack-

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age. Materials in stock should be liquidated, if possible. New materials must be checked out in advance so that the changeover can be made smoothly.

Purchasing and Package Engineering have a close working relationship and share a mutual goal in obtaining from suppliers the required packaging materials. Engineering works with the suppliers on the technical aspects of the surface and structural design for the packaging. The vendor may be requested to assist in solving problems of package failure on the production line or in the field.

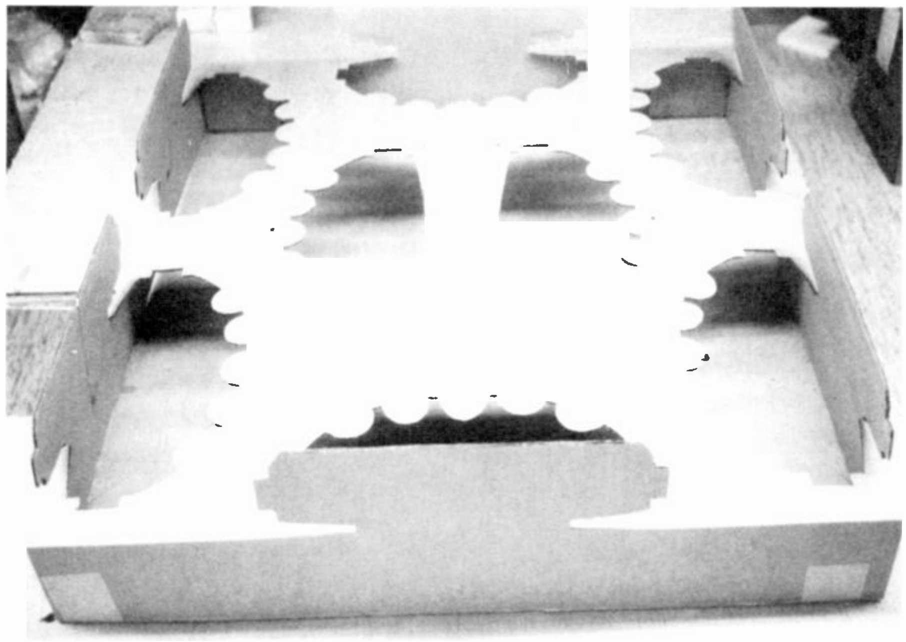
In the multi-plant operations of PTD, the packaging engineer coordinates his projects at each factory by traveling to the location or by communicating with a locally designated representative. The full-time responsibilities of these representatives are in areas such as Industrial Engineering, Material Control, Engineering Standards, or Product Engineering. On a part-time basis, they function as packaging specialists and provide valuable assistance in solving the day-to-day problems. They work with local vendors on manufacturing variations, approval of parts, and cost-reduction ideas. They coordinate information from the pack line and other departments. In the glass plant at Circleville, the packaging responsibility has been handled totally by the Industrial Engineering department since the opening of that factory in 1970.

Semiannual meetings of the plant representatives were organized in 1977 as a further means of coordinating projects. Other plant departments—such as Purchasing, Plant Engineering, and Quality—have participated in these meetings, which have been successful in reviewing common problems and in providing an opportunity for the various points of view to be discussed.

Speakers both from within and outside the company are invited to make presentations on materials or equipment associated with packaging. Tours are arranged at local industries as well as at the host plant to acquaint the members of the group with the handling and packaging methods used by others.

Why change the package?

Packaging design services may be needed for many different reasons. The most common one would be the design of a new picture tube. Very similar to that would be modifications to tubes in the line. These revisions include contour changes in the glass bulb (such as the open-throat funnel design) and dimensional changes (such as lengthening the electron gun). Parts may be added to the picture tube, which drastically change its profile. In this category are the stamped metal mounting lugs attached at the four corners of the face panel, and the deflection yoke, which is a factory-assembled component on the neck of certain tube types.



Corrugated fiber board die-cut design is typical for 21V 110° and 25V 110° tubes.

Because nearly all picture tubes are packaged in multiple quantities on pallets for conventional truck trailers, the variables in tube shape and size directly affect the tube-to-tube spacing and, therefore, the overall size of the container. Unfortunately for the package designer, all of the tube's design changes do not occur at the same time. Thus, the packaging may experience several revisions to keep pace with the evolution in tube design.

Other factors may cause a change in package design. Cost reduction is always a good reason to evaluate new layouts or materials. Present handling techniques may be improved or labor content reduced with a design revision. The trend toward automation has already begun to affect the packaging area.

Last but not least, a packaging-related field problem may develop that calls for prompt response from the packaging engineer. Generally, this situation is resolved with a modest change to the package, because most of the shortcomings of a design are found during the testing phase.

Development of a package

With mention of package testing it would be appropriate at this point to consider how a package is developed for commercial shipments of picture tubes. Since 99 percent or more of RCA picture tubes are produced for volume shipment, the focus of package design is on the multi-pack, pallet-sized container. The criteria used to develop a package are among the following:

- Protect the product from the hazards of the distribution environment.
- Select the size of the package to optimize the loading of standard truck trailers and export containers when applicable.
- Design the package for ease of assembly in high-volume production as well as for tube loading/unloading by manual labor.
- Specify materials that are commercially available and cost competitive with other tube makers.

The end result represents a compromise in most cases. Every condition cannot be met to the complete satisfaction of all interested departments. Product protection takes priority; cost and accessibility compete for secondary importance.

After conception of one or more designs, the next step is the preparation of sample packages. Standard practice has been to use an all-corrugated fiber board design for the lowest cost in materials. Corrugated fiberboard is produced by a

25V100 tubes in a package assembled in Scranton.

great number of manufacturers and, therefore, is very competitively priced. The material is easy to fabricate into a wide range of sizes and shapes.

The Package Engineering shop is furnished with box-making equipment and hand-operated cutting tools to make prototype packaging in-house. This capability saves time, when samples must be created. A typical project will be completed within one week compared to the 2 to 4 weeks required by a vendor. Design changes in midstream are easily handled when the cutting of the patterns is performed close by.

But the value of the design and sample-making services of RCA's vendors is not overlooked. When a vendor has an engineering staff, they may be requested to critique an existing design or to develop a package of their own design. Frequently, they suggest ways to make the individual parts match their manufacturing procedures. These refinements help to optimize the overall design.

Evaluation of a sample package is performed with a full pallet load of picture tubes. The current line of packaging covers tube sizes of 13V, 15V, 16V, 17V, 19V, 21V, and 25V (25V stands for the 25-inch diagonal dimension of the viewable screen). There are 15 tubes per 13V package, 10 tubes per package for 15V through 19V, 8 tubes per 21V package and 25V/110° types, and 6 tubes for all other 25V packages. The entire line is unitized with two packages or layers per pallet except for 13V, which has three layers.

Because tubes are visually and electrically tested for certain parameters both before and after the package testing, there is a substantial investment of time and materials in each test. The lack of an impact-testing machine in Lancaster requires that all tests be conducted at the Corporate Packaging Laboratory in Camden, New Jersey, or at a vendor's facility.

The package testing simulates shock and vibration, the two most commonly encountered hazards in the distribution environment. Vibration will occur continuously over the transportation life, while shock will occur at isolated points during the trip. The magnitude and duration of shock and vibration is not usually known for a particular distribution cycle. Standard practice has followed, in part, the ASTM D999 procedure for vibration testing on a low-frequency mechanical vibration table.

Resonant frequencies, a source of potential damage, generally occur at values above the 4-Hz to 5-Hz capability of the mechanical tables and cannot be evaluated. However, testing at a set of conditions that causes the pallet load to bounce (acceleration of 1g) is believed to be a severe condition that is, in some way, equivalent to a longer time at varying vibration conditions. Different interpretations are given as to what this equivalence is, but the author believes no fixed equivalence can be made.

Horizontal shock, commonly called impact, is the second hazard in the distribution cycle. The importance of this hazard has long been recognized in rail cars. Although the PTD ships no tubes in rail cars and very few by piggyback, impact testing is conducted to simulate the shifting of pallet loads in truck trailers and export containers, and handling by fork-lift trucks.

An incline-impact tester with a 10° incline is used in the impact test. The pallet load of tubes is placed on a dolly a distance away from the barrier (Fig. 1). The vertical free-fall distance is determined by the product of the distance down the tracks and the sine of the track angle: $h = dx \sin 10°$, where h is the vertical free-fall distance, d is the distance from the edge of the package to the barrier, and 0.174 is sin 10°.

To approximate the velocity of the dolly at impact, the following formula may be used: $V = \sqrt{2gh}$, where V is the velocity of the dolly at impact, g equals acceleration due to gravity, and h is the vertical free-fall distance.

Most of the picture-tube package tests involve impacts on each side at a distance of 3 feet. If friction losses in the dolly are ignored, the resulting velocity at impact is just under 5.8 feet per second, or 4 miles

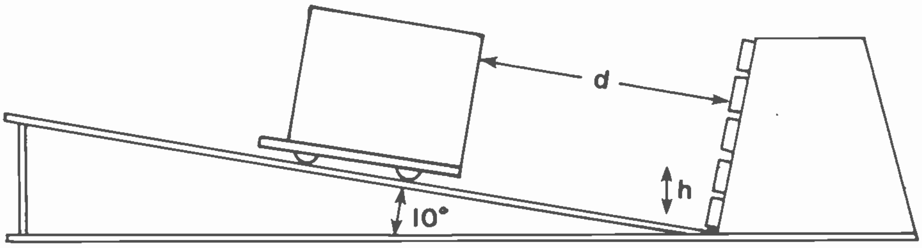


Fig. 1. Incline impact test set-up.

per hour. This value is within the probable range of impact velocities; the four impacts per package exceed the expected real-life occurrence in truckload shipments.

The impact test does not control the duration nor the wave shape of the shock pulse. More sophisticated test equipment would be necessary to precisely control all of these factors. The peak g-forces measured with an accelerometer mounted on one of the tubes in the package range from 7 to 40 for the horizontal impacts. Vertical shocks created by the bouncing on the vibration table range from 3 to 9 g's.

A laboratory compression test is no longer performed since the change to packing the tubes on their sides. The glass bulb is the main supporting structure in the package; the packing components separate and hold the tubes in position. However, a stacking test is made at a later point in the program to evaluate stability under actual long-term dead load.

After satisfactory completion of the laboratory testing, a sample package is reviewed with the management staff at the using plant. This review may result in recommendations to make minor revisions to the package design. If such changes are not critical to the basic design a new sample is prepared, but this time it is made by one of the eventual suppliers. This step acquaints the vendor with the design and confirms all of the dimensional details.

At this point, engineering specifications are prepared to describe each of the components of the pack, together with the procedure for assembly. The specifications must be submitted to Engineering Standards for circulation through the system for approval. Such a request notifies all departments involved that, temporarily, a new package will be evaluated.

In most cases, the Consumer Electronics Division is the primary customer and receives the initial shipments. Close scrutiny of these first shipments is given by the Receiving, Material Control, and Engineering Departments at Bloomington. Acceptance by these groups clears the way for similar shipments to OEM customers.

Finally, when all customers have accepted the package change, and any problems associated with the packaging have been satisfactorily resolved, the Engineering Specifications are distributed for approval on a permanent basis. The total time for a completely new design, from initial concept to formal standardization, will span more than six months.

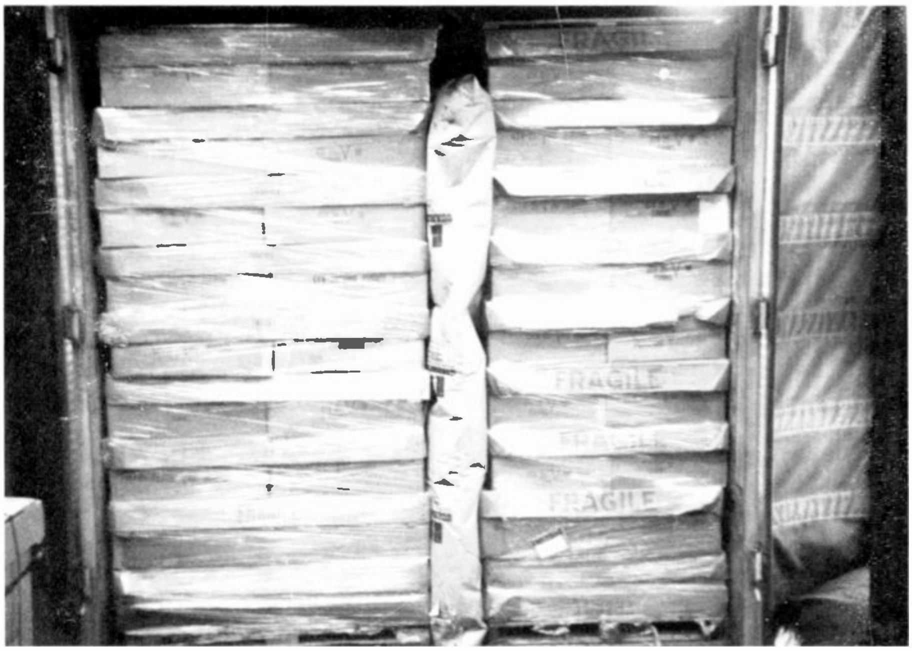
Packaging for component parts and subassemblies

The glass components, the face panel, and the funnel represent the greater part of the weight and bulk of the color-picture tube. When RCA entered the glass-making business with the construction of the Circleville, Ohio plant, the packaging method selected was identical to that employed by the two outside suppliers of picture-tube glass. This conformity was dictated mainly by the program that credited the tube makers' accounts for packaging materials returned to the glass makers. The glass suppliers reused the packaging materials for a cost savings.

A substantial amount of the packaging

Incline impact test of 16V 90° tubes at Camden Packaging Lab. Four impacts per package exceed the expected real-life occurrence in truckload shipments.

Vibration testing of two double pallet loads of 25V 90° tubes at Camden.



25V funnels, stretch-wrapped, seen at the doorway of a trailer arriving in Scranton from Circleville.

Humidity testing for Brazil: 16V tubes covered with large poly bag. Picture was taken at the Humidity Test Chamber in Camden.

design for the glass components is coordinated by the Jt-10.7 Subcommittee of the Electronics Industry Association. The continuing goal of the committee is to establish standard packaging designs when more than one company is involved in manufacturing the glass parts for a particular tube size. The high cost of transporting the heavy glass parts has led to recent innovative designs for the funnel package. Increases of 40 percent or more have been achieved in the loading density without raising the cost of the packaging.

Over a year ago, Circleville installed a plastic stretch wrap to unitize the pallet loads of panels and funnels. A new application to the picture-tube glass industry, the automated equipment replaced a manual strapping operation. The stretch wrap was a particular improvement to the funnel pack that tended to compress and loosen the straps; the plastic wrap maintains tension even after several months in warehouse storage.

Aperture masks are manufactured in Lancaster and Barceloneta, Puerto Rico for shipment to the Marion, Scranton and Midland tube plants. The masks, chemically etched thin sheets of steel, are highly sensitive to rusting, foreign particles, and improper handling. The package developed to provide the necessary protection includes a special wrapper with an impregnated corrosion inhibitor.

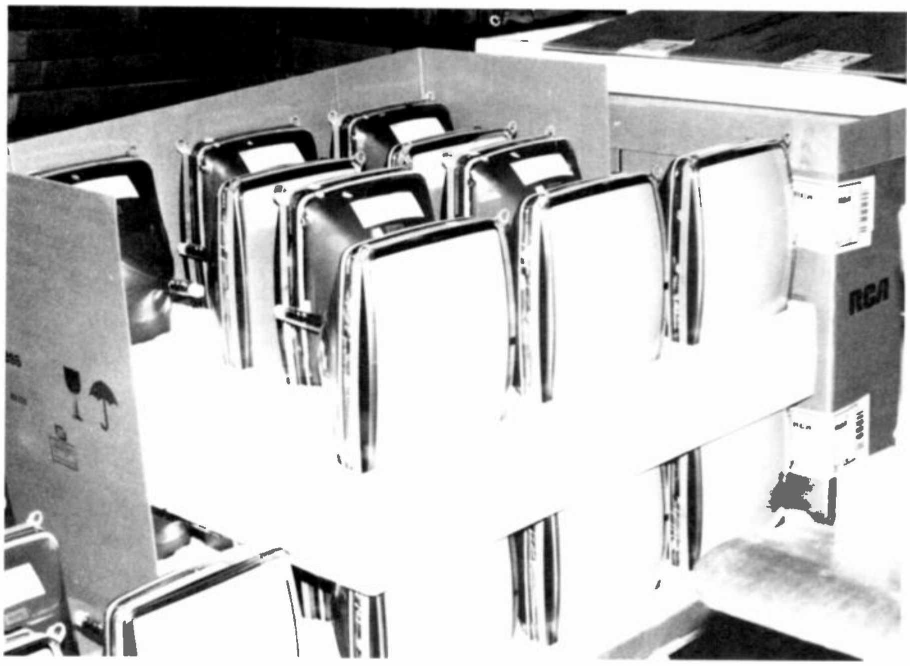
Picture-tube manufacturing locations in Mexico and Brazil depend entirely upon the domestic factories to supply the front end of the tube, the screened panel/mask assembly. A substantial amount of the tube technology is contained in the accurate positioning of the phosphor screen and the spring-mounted formed-aperture mask.

The phosphor coating is damaged progressively by humidities over 55 percent R.H.; the contoured aperture mask is easily indented by contact. Packaging must protect the assemblies from moisture, dirt, and physical damage on a long overland haul to Mexico City with a carrier change at the border. The month-long trip to Jaquaré, Brazil is a more arduous survival test of trucking, ocean carriage, and a high humidity environment. The present package encloses the assembly and a desiccant in two sealed polyethylene bags. The bagged units are then stacked in corrugated fiber board cartons with corrugated pads to separate the layers. Several cartons are strapped to a pallet. Product has been held in the packaged state as long as four months without deterioration.

More than 250 different parts for the various mount designs are packaged in Lancaster after the completion of certain processing and inspection procedures. Millions of these often tiny parts are shipped annually to the mount manufacturing locations in Brazil, Mexico, and Puerto Rico. The method of handling the huge volumes of parts has been simplified so that three boxes and six different poly bags are used for nearly all of the parts.

After assembly, the electron-gun mounts are placed in thermoformed styrene trays. Only two different designs of the low-cost trays are necessary to accommodate the many types of mounts. The full trays are loaded together with cushioning pads in standard cartons, which are palletized for truck or ocean container shipments. Individual boxes may be overpacked and shipped via truck or aircraft.

Mount tray shows easy access for packing and handling.



New 19V molded foam tray pack at the Bloomington unpack area after shipment from Marion.

Gene Haggerty, Member of the Technical Staff, joined RCA in 1964 as a Production Engineer in the Screening and Matrix areas of picture tube manufacturing. He transferred to the Pilot Development group in 1972 and worked with the Pilot Screening Process. Since 1976, he has been responsible for all package design for the Picture Tube Division. He received a BSME degree from the University of Rochester in 1960.

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The plastic trays, used for many years in Juncos, Puerto Rico, have just recently been implemented in Brazil and Mexico. Replacing a labor-intensive method of hand wrapping each mount, the trays significantly improve packaging and handling costs. Further savings accrue from a recycling program between the tube factories and Juncos. Prior to the establishment of a local vendor for the trays, a foreign customer requested delivery of mounts from Brazil in the more convenient packaging. To avoid the import duty on the trays, a portion of the stem requirements were shipped from Lancaster in the mount packaging. The mount order was then shipped in the same materials from Brazil to England.

Picture-tube manufacturing requires a large number of chemicals to prepare and to clean the component parts. Many others are used in the coatings applied to the panel and funnel. Though a majority of the chemicals are received directly from the manufacturer and consumed in the production processes, a substantial number are formulated into coatings for application at other locations.

When chemical analysis classifies a material as hazaradous for transportation purposes, packaging must be specified that complies with regulations established by domestic and international agencies. Incorrect packaging, marking, or labeling can result in expensive delays and rehandling. Citations imposed by inspectors may lead to severe fines. RCA's commitments in the Russian and Polish Tube Contracts included the supplying of over 100 different chemical products.

Trends

Through cost-reduction programs in tube packaging and by designing for more efficient use of materials and transportation, the cost of packaging and shipping the Picture Tube Division's products has been held below the general rise in prices. All of the tube multi-packs have been redesigned in the past five years for these reasons. A portent of the possible future trend in the tube packaging for RCA may be seen in a design, under evaluation for the 19V size, using molded trays of polystyrene foam in a corrugated box. This design with fewer parts simplifies assembly at the tube factory and is received more favorably at the television-set line. The life of the foam parts will be the determining factor. Other plastics or composites of materials will be evaluated in future efforts to reduce costs by extending the life of the packaging or to satisfy the requirements of an automated handling system.

Package testing equipment at RCA should be updated so that the state-of-the-art procedures may be applied to package designs. Eliminating some of the present trial-and-error approach will reduce costs that arise from over-packaging. Technology in packaging must keep pace with RCA's technical expertise in picture tubes.

G.O. Philip

The parylene-coating process at MSR

A modern process using vacuum deposition techniques to polymerize this protective material on almost any surface is a key to complete electronic circuit protection at MSR.

Abstract: *Some form of protective coating has been a standard requirement for military electronic equipment since the introduction of printed circuits. Commercial use of coatings is also becoming widespread, especially with the increasing emphasis on product reliability. This paper describes the processes and applications of "conformal" circuit coating with special thermoplastic polymers called parylene—compounds with properties ideally suited to environmental protection of modern electronic circuitry.*

Since World War II, the armed services have required that electronic circuit modules and chassis be coated with conformal materials to withstand tropical heat and humidity as well as seaborne salts, which can corrode the hardware. Electronic circuits, ceramic substrates, and module assemblies that have a protective coating of a conformal material are better able to resist degradation caused by the growth of fungus in a humid environment or the growth of metallic filaments in humid or corrosive environments. Because greater emphasis is being placed on reliability of consumer products these days, conformal coatings are also used to reduce failures of electronic equipment in steel-mill operations, chemical plants, and even under the dashboards of automobiles.

The military specification, *Insulating Compound, Electrical (For Coating Printed Circuit Assemblies)*, MIL-I-47058, groups conformal coating materials into five major categories according to their chemical composition: acrylics, epoxies, silicones, polyurethanes, and parylenes. Parylene has been specified by the military as the coating material for electronic parts in equipment being built in Moorestown, such as guidance computers, flight recorders, signal processors, fire-control systems, and power supplies. The parylene-coating process involves heating a parylene dimer, which splits to form a monomer that polymerizes on the surface of the equipment to be coated.

Traditional coatings

Initially, when the copper tracings on printed circuits were wider than 20 mils, coatings of polyurethanes, epoxies, varnishes, silicones and, later, acrylics were considered acceptable. As circuit densities increased, circuit-path widths decreased and spacings between circuits narrowed; once both the circuit lines and the spacings narrowed to 10 mils, short circuits increasingly occurred because of fungal growth and the development of metallic filaments. The introduction of dual, in-line packaged (DIP) circuits permitted more circuit functions to be placed on a given printed-circuit board area. As a result, some circuit-path designs that utilized spaces beneath the DIP component for interconnecting lines became increasingly difficult to protect with coating materials.

These traditional coatings continue to be used, and are applied on equipment and parts by a variety of means. Assemblies can be submerged in silicone or they can be dipped or sprayed with dilute solutions of epoxies, polyurethanes, or acrylics. These materials, however, require curing cycles after application, a process that necessitates a clean environment and, usually, staged temperature cycles. Also, several coats may be required to obtain the specified thickness. Uneven coatings, thin at the corners and thicker on flat surfaces, are still another problem.

The parylene family

To overcome some of the deficiencies of conventional coating materials, the parylene family was developed. "Parylene" refers to a series of thermoplastic polymers that were developed by Union Carbide, based on a chemical compouind, poly (*para*-xylylene). Three members of the parylene family are most used: parylene "N," or poly(monochloro-*para*-xylylene); parylene "C," poly(chloro-*p*-xylylene), to which a chlorine atom is added to the aromatic ring of the compound; and parylene "D," with two chlorine atoms added to each aromatic ring.

These polymers can be deposited on almost any solid surface by a vacuum process that resembles metal evaporation. In addition, parylene-coated products are ready for use immediately after the conclusion of the deposition cycle. They have distinct properties favorable for specific applications: ability to elongate easily, high yield and dielectric strengths, low water absorption, and high volume resistivity (Tables I, II, III, and Fig. 1). Parylene's outstanding abilities in penetrating and covering spaces between component bodies and circuit paths make it a preferred coating material. Because uniform coating thicknesses are routinely achieved, heat sinks, mechanical interfaces, and optical interfaces can be

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Table I. Mechanical properties of parylene N, C, and D, according to Union Carbide figures.

	Parylene N	*Parylene C*	*Parylene D*
Tensile strength, psi.	6,500	10,000	11,000
Yield strength, psi.	6,100	8,000	9,000
Elongation to break, %	30	200	10
Yield elongation, %	2.5	2.9	3
Density, gm./cm.^{3}	1.11	1.289	1.418
Coefficient of friction			
Static	0.25	0.29	0.33
Dynamic	0.25	0.29	0.31
Water absorption, 24 hours	0.06 (0.029")	0.01 (0.019")	—
Index of refraction, n_D 23°C.	1.661	1.639	1.669
Melting or heat distortion temperature, °C.	405	280	>350
Linear coefficient of expansion, (10^{-5}/°C.)	6.9	3.5	—
Thermal conductivity, (10^{-4}cal./sec./cm.^{2}-°C./cm.)	~3	—	—

Table II. Electrical properties of the three parylenes, according to Union Carbide figures.

	Parylene N	*Parylene C*	*Parylene D*
Dielectric strength, short time, volts/mil at 1 mil	7,000	5,600	5,500
Volume resistivity, 23°C., 50% RH, ohm-cm.	1×10^{17}	6×10^{16}	2×10^{16}
Surface resistivity, 23°C., 50% RH, ohms	10^{13}	10^{14}	5×10^{16}
Dielectric constant			
60 Hz	2.65	3.15	2.84
10^3 Hz	1.65	3.10	2.82
10^6 Hz	2.65	2.95	2.80
Dissipation factor			
60 Hz	0.0002	0.020	0.004
10^3 Hz	0.0002	0.019	0.003
10^6 Hz	0.0006	0.013	0.002

Table III. Barrier properties of the three parylenes, according to Union Carbide figures.

	Gas permeability cm.^{3}-mil/100 in.^{2}-24 hours-atm. (23°C.)						*Moisture vapor transmission, gm.-mil/100 in.^{2}-24 hours, 37°C.-90% RH*
Polymer	N^2	O^2	CO^2	H^2S	SO^2	Cl^2	
Parylene N	7.7	39.2	214	795	1,890	74	1.6
Parylene C	1.0	7.2	7.7	13	11	0.35	0.5
Parylene D	4.5	32	13	1.45	4.75	0.55	0.25

coated without detriment, eliminating the need for masking those surfaces.

Parylene adheres to any solid surface—even the edges of a razor blade. Because of its uniform coating ability, parylene now is routinely applied to hybrid circuits. In addition, parylenes sometimes are used as overcoatings for chips in hermetically sealed packages to reduce damage from microscopic debris and to strengthen the wire bonds.

Unlike most plastics, parylene is not produced and sold as a polymer. It is not practical to melt, extrude, mold, or calendar, as is done with other thermoplastics. Neither can it be applied from solvent systems, because it is insoluble in conventional solvents.

The process

The elements of the coating system (Fig. 2) include a vaporizer to heat the granular parylene dimer, a muffle furnace to pyrolize the dimer, a deposition chamber in which the objects are coated, and a cold trap that collects unused parylene and prevents it from contaminating the oil in the mechanical vacuum pump. The complete cycle is conducted under vacuum to protect the hot gases inside the coating system from oxidizing.

At MSR, the parylene-coating process has been used since 1976 to encapsulate a variety of circuit modules ranging from hybrid circuits to large chassis-type boards (Fig. 3). In this process, a dimer is converted to a polymer, as shown in Fig. 4. In the first step, printed-circuit modules are loaded into a coating fixture (Fig. 5), which is placed into the deposition chamber. A specific amount of dimer is loaded into a boat and placed in the vaporization chamber. When the system is up to the desired temperature, the entire system is pumped down to a predetermined base pressure, typically 65 microns-Hg. Liquid nitrogen is added to the thimble of the cold trap to enhance pumping speed and to provide a positive condensation surface for excess parylene. The vaporizer is turned on, and the heated dimer sublimes into the muffle furnace.

In the second step the dimer is split into a monomer by means of pyrolysis (very high temperatures). The monomer passes into a deposition chamber, which is at room temperature, and condenses on the printed-circuit modules as a polymeric coating. (It also condenses on the walls and fixtures of the coating chamber.) Because deposition occurs at a controlled rate of pressure (in microns-Hg or torr) the system returns to base pressure and the coating cycle stops once the dimer has been expended in the vaporizer. No additional curing or aging processes are required.

Electrically heated jackets that are regulated with set point controls are used to prevent dimer, monomer, and polymer vapors from sticking to the walls of the vaporizer, valves, and piping. As a result, a buildup of parylene in the equipment is reduced.

How much dimer?

The quantity of dimer to be used depends on the amount of surface area to be coated. Surface areas are established, catalogued by part-number sequence, and stored in a process file. As the masked modules are

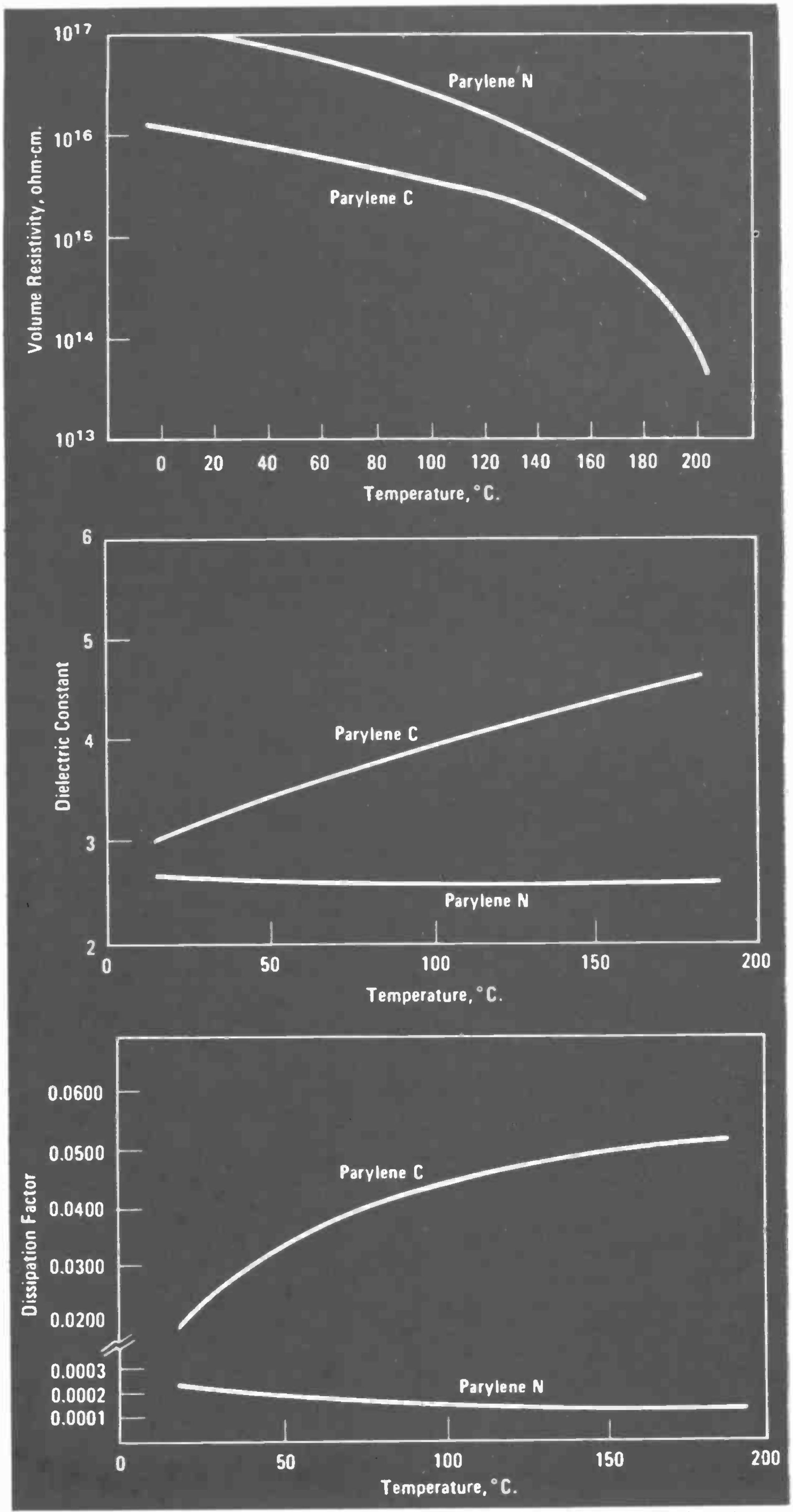


Fig. 1. Three graphs, derived by Union Carbide, compare various properties of parylene N and parylene C.

loaded into the coating fixture, the surface area for each module type is logged on a separate form and extended by the quantity for each type. The totals for each type are summed and become the total surface area of the load.

Test runs (Fig. 6) are made initially to establish a coating constant (gm/in^2), which takes into account the surface areas of the fixture and the interior surface of the coating chamber. The constant is derived by loading a fixture with a known surface area of dummy modules and using a given amount of dimer. After coating, a diagonal strip from a "witness card" is measured for thickness in five places; these measurements are averaged for each module, and averaged again for all modules. Both the average thickness for each module and the total average for all modules must exceed 0.5 mil. When the test runs show a tolerance band of ±0.2 mil around the center band of 0.7 mil, the dimer amount used to achieve this thickness is divided into the surface area to obtain a gm/in^2 multiplier.

A constant has been derived for each of the four types of coating fixtures and the three coating chambers at MSR. Coating efficiencies, assuring uniformity of thicknesses, are maintained during the process by keeping surface areas equal in size to the surface area used during the qualification runs. If, for some reason, not enough modules are available to fill a fixture, dummy plates are added to provide the required surface area.

Deposition rates are typically 1.5 gm/min to 1.8 gm/min. Rates faster than 2 gm/min can cause incomplete dimer conversion in the pyrolysis section of the coater, the result being an undesirable coating that is whitish, translucent, and brittle. Deposition rates below 1 gm/min are time consuming and, therefore, more costly. A typical run of 140 three-inch by four-inch modules, using 170 gm of dimer, takes about 2 hours to process after loading the fixture into the coating chamber.

Outgassing

The parylene-coating process cannot proceed until the vacuum chamber has reached a predetermined base pressure. The time required to reach this pressure is dependent on the amount of solvents, entrapped air, and moisture on the module and fixtures. A loaded fixture can take up to 5 hours to outgas, during which time the coating machine cannot be used. The outgassing system at Moorestown (Fig. 7) has four chambers that can be used simultaneously, permitting up to four fixture loads to be processed and then outgassed overnight.

Adhesion

To enhance the adhesion of the parylene film to the assemblies, adhesion promoters are used, the most common type being of silane. The silanols are generated by the controlled hydrolysis of silane, during which halogens or alkoxy compounds react with water. Silanols are believed to provide the mechanism for adherence to such inorganic surfaces as glass, ceramics, metals, and metallic oxides. When the hydrolyzate (silanol) comes in contact with the inorganic surface, it changes that surface, giving it reactive organic groups that can combine with a variety of plastics. Silane A-174, an effective coupling agent for electronic circuit boards, is used in solution with a mixture of isopropyl alcohol and deionized water.

Fig. 2. Parylene-coating equipment with coating fixtures being inserted.

Cleaning and masking

Assemblies must be cleaned prior to coating, a step that is critical to obtaining good adhesion. All printed-circuit modules are first vapor degreased in Freon TES to remove surface contamination caused by fluxes, fingerprints, oils, or greases. These contaminants are difficult to see beforehand, but if they are not removed the results will show up during the temperature and humidity cycles as blisters and measled surfaces. In addition, conductive mating surfaces—connectors, grounding surfaces and test points—must be covered or masked to prevent contact with parylene.

The several process options for parylene coating depend on the number of modules to be coated at one time, the capacity of the coating chambers, and the complexity of masking conducting pads and contacts. For batch quantities of less than 20 pieces, the boards are cleaned, and an adhesion promoter is applied before masking. Even so, all masking and loading steps must occur within 30 minutes to prevent the silane/alcohol/water dip from losing its effectiveness due to exposure to air.

For larger batch quantities, the assemblies are masked before the adhesion promotion cycle and after the initial Freon cleaning steps, thereby providing optimal curing. Also, liquid masking material such as latex can be cleaned up without having to go back through the adhesion promotion steps.

The cleaning and adhesion promotion steps for modules contained in coating fixtures are accomplished by submerging the fixture and boards into tanks containing the alcohol/silane/water solutions. Typically, 140 three-inch by four-inch boards are processed simultaneously. After the last cleaning dip, the fixtures and modules are air dried for 30 minutes, after which they are loaded into the outgassing chamber.

Inspection requirements

Because the transparent parylene film on module surfaces is of uniform thickness, coated and uncoated surfaces are not easily distinguishable by visual methods. For

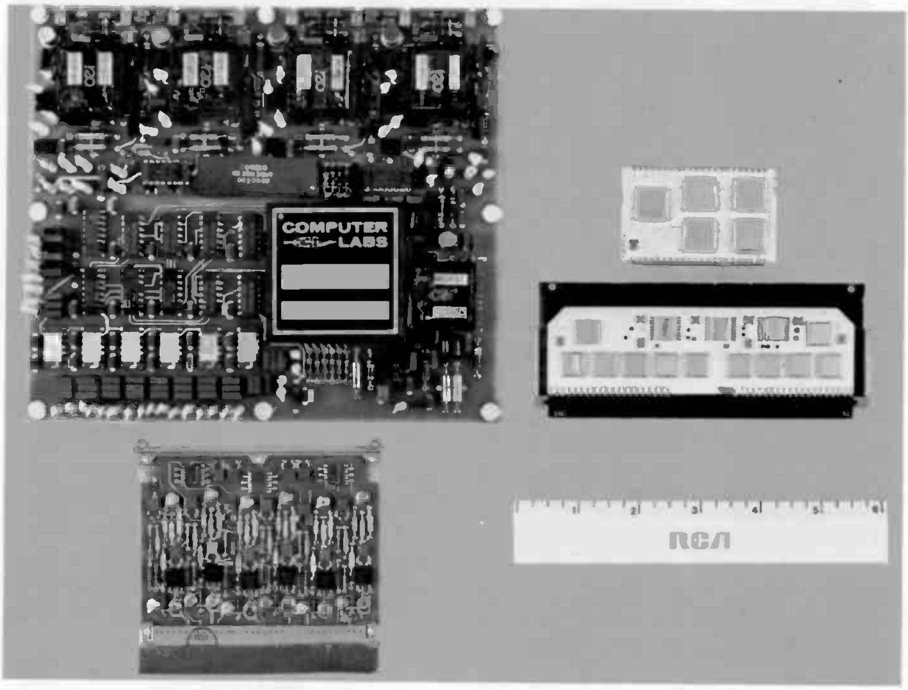


Fig. 3. Electronic modules from the larger, printed circuit boards (left) to the smaller hybrid circuits (right) are coated with a transparent parylene film. Prior to coating, the modules are masked with boots, caps, shrink sleeves, and liquid latex.

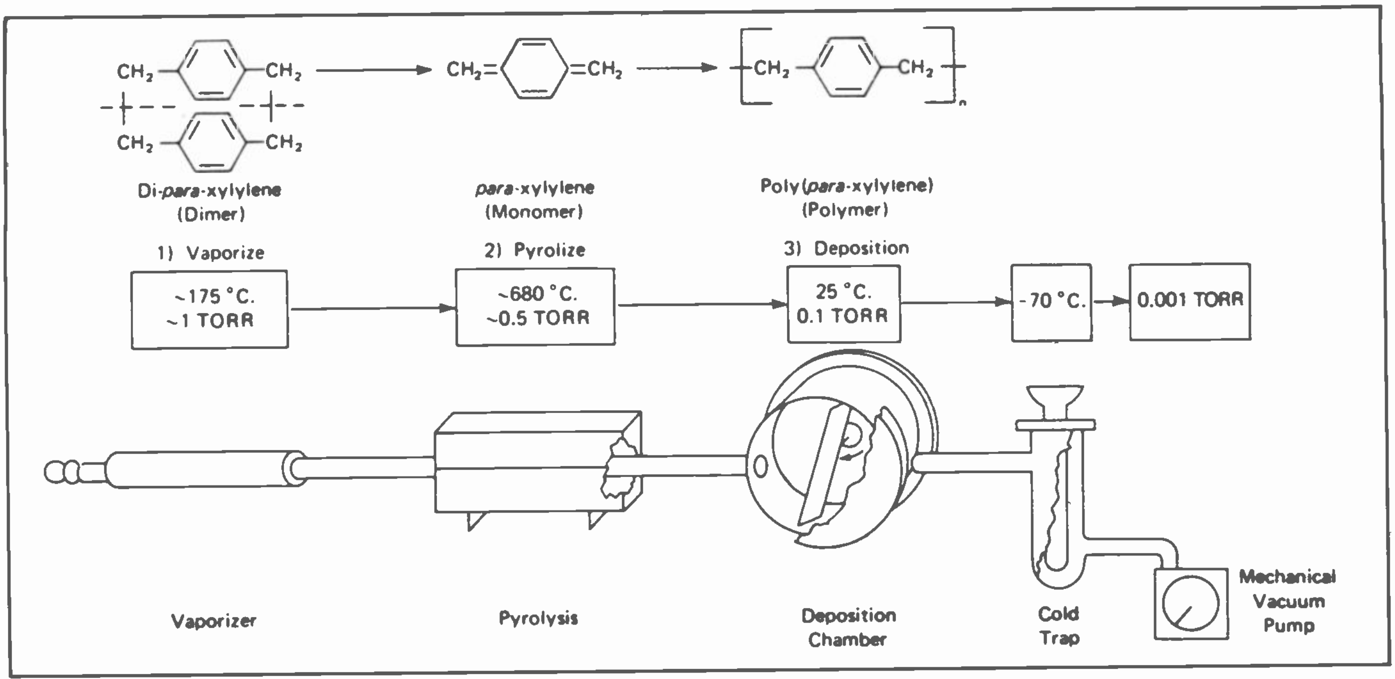


Fig. 4. The parylene coating process, as developed and patented by Union Carbide, involves vaporizing a dimer of *para*-xylylene, which splits into a monomer during pyrolysis. The monomer is deposited on the modules to be coated and polymerizes.

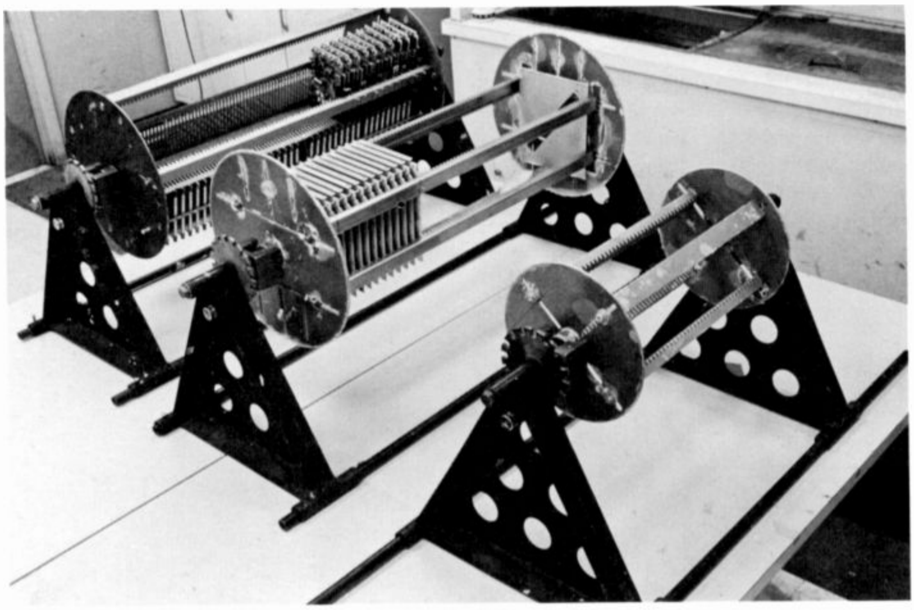


Fig. 5. Various types of coating fixtures.

inspection purposes, a fluorescent crystalline material, anthracene, is added to the dimer at concentrations of 0.03 percent by weight. The anthracene goes through the conversion process unchanged and codeposits uniformly with the parylene polymers.

The coated and unmasked modules are inspected under black light of 3660 angstroms, the wavelength at which anthracene fluoresces. The masked and unmasked areas become readily visible, and, as a result, inspection of the surfaces is quickly accomplished. All modules are inspected under black light.

To assure adhesion, peel tests are performed on a sampling basis. A strip of tape is firmly attached to an open area of a module board and ripped off at a 90° angle to the coated surface. Delamination of coatings shows up as blisters and large voids, and is cause for rejection.

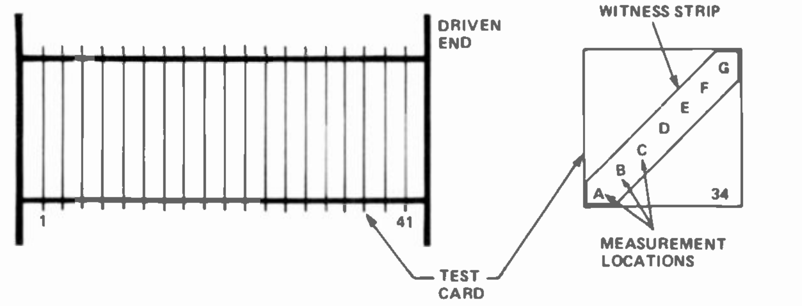
Coating thickness is established by the measurement of films on calibrated witness strips. Each fixture load has a number of witness strips that are fastened to dummy boards and inserted next to modules. At least three witness strips are in each load, one at each end and one in the middle. At the end of the coating run, the strips are removed and measured at 1- inch intervals. Five spots are measured and averaged, and the averages of the three samples are again averaged. The final number is the coating thickness of the run.

Film thickness is measured with a calibrated dial indicator that is equipped with a preloaded weight and a flat surface foot. The film is directly measured from the witness strip and becomes the record for the run.

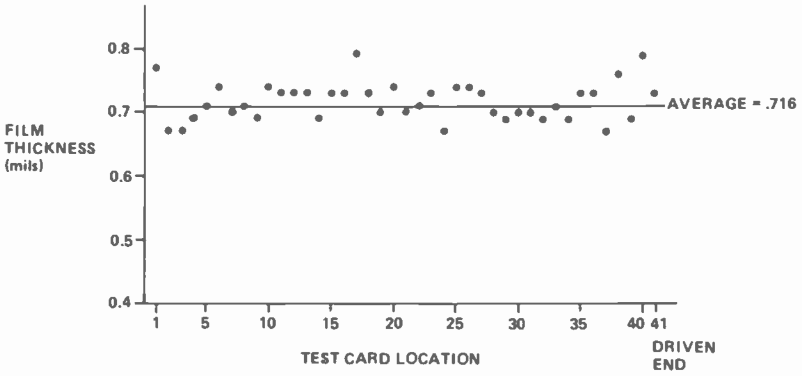
Removing excess parylene

Parylene coatings are difficult to remove because they can be dissolved only in solvents that are inappropriate for electronic modules, such as hot, concentrated sulfuric acid. Thin coatings can be abraded with air streams of dry sodium bicarbonate or finely ground walnut shells. Films can be scraped with X-acto knives and, under some special cases, can be removed with hot soldering irons (≥750°F).

The replacement of components on coated modules is generally accomplished by removing the parylene film from the solder pads by carefully scraping and desoldering the component. After replacement of the components, the bare pads are touched up with polyurethane conformal coating material. Because of the difficulty in removing parylene from surfaces, all electrical testing and adjustments are accomplished before the conformal coating is applied.



A. COATING FIXTURE WITH 41 TEST CARDS



B. AVERAGE FILM THICKNESS, CARD VERSUS CARD LOCATION
TEST RUN No. 4 10/30/81

Fig. 6. The amount of coating. In order to determine how much dimer to use in the coating process, 41 test cards are coated and film thicknesses are measured, using witness strips. The thicknesses are averaged and the dimer amount to be used is derived.

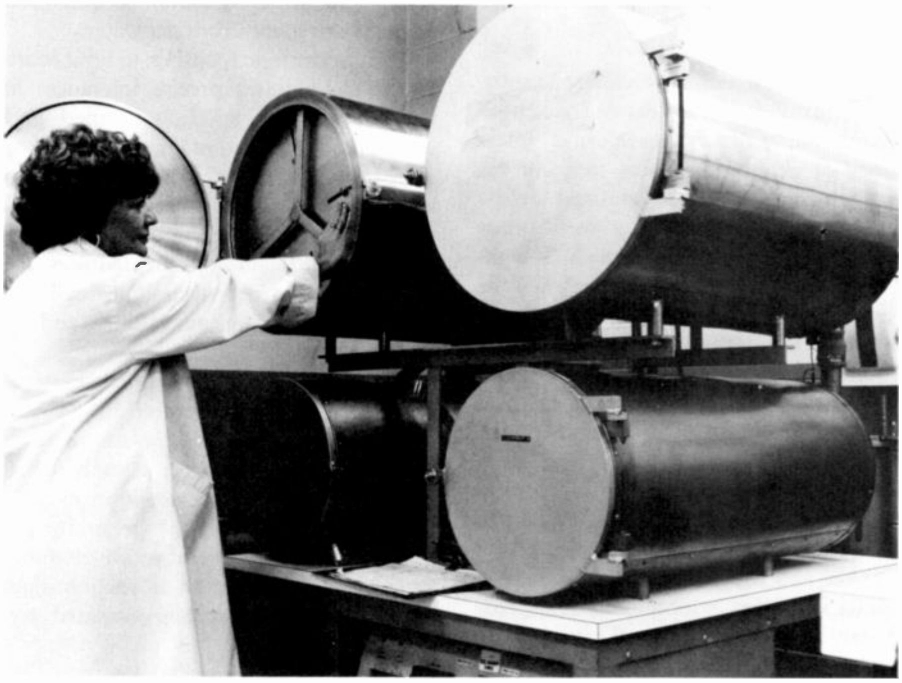


Fig. 7. The four outgassing chambers used at MSR for the parylene-coating process.

Conclusion

To obtain optimum effectiveness for parylene coatings, the design engineer must consider producibility factors in the process. Coatings and markings that may bleed out or dissolve during the cleaning and adhesion promotion process have to be avoided. Rubber boots and caps are used for masking parts because of the low cost involved. Mechanical hardware that can interfere with masking operations, such as handles or brackets, should be added after conformal coatings. These and other procedures are considered by the engineers responsible for the parylene-coating operation.

Because the coating process is complicated, and in order to minimize mishaps and rework, careful process documentation and controls have been established concerning such factors as the quantity of dimer, the resulting thickness of the parylene film, and the type and quantity of boards coated. Personnel responsible for the masking and coating operations undergo training programs and receive certification, which must be renewed periodically. This type of quality control has been set up to ensure that conformally coated electronic equipment manufactured at Moorestown is of high quality and reliability as well as easily producible.

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W.S. Lynch | R.E. Reed

Producing neutral beam ion sources for the Mirror Fusion Test Facility

The industrialization (value engineering and manufacture through shipping) of a major electronic component requires detailed study and innovation in organization, methods, and procedures.

Abstract: *The existing Lawrence Livermore National Laboratories (LLNL) designs of the 20 and 80kV deuterium-fueled Neutral Beam Ion Source Modules (NBSM) have been industrialized and are being produced successfully for the Mirror Fusion Test Facility (MFTF). Industrialization includes value engineering, production engineering, cost reduction, quality control, fixturing, facilitation and procurement of components. Decades of experience in high-voltage, high-vacuum power tubes is being applied to the procedures and processes. Scheduling of the various engineering, procurement and manufacturing tasks is performed by the use of a Critical Path Method (CPM) computer code. Innovative, computerized grid alignment methods were also designed and installed specifically for this project. Testing and shipment of the first four 80kV NBSM occurred on or ahead of schedule with a balance of forty-three units remaining to be produced.*

RCA was the successful bidder to Lawrence Livermore National Laboratories (LLNL) for the value or cost-effective engineering, production, test, and delivery of 48 Neutral Beam Source Modules[1] (NBSM) for use in a controlled nuclear fusion project. These large electronic components will provide the deuterium ion beams for the government's Mirror Fusion Test Facility (MFTF) in Livermore, California. The contract calls for 26 sustaining (80kV, 80A, 1/2s) and 22 startup (20kV, 100A, 10ms) NBSM. Each NBSM measures approximately 3-feet long, 2.5-feet deep and 1-foot wide, and weighs about 750 pounds.

The project

Producing a plasma in the MFTF requires evacuating a 40-foot diameter by 60-foot long cylindrical fusion chamber to an almost perfect vacuum. Thereafter, 20 start-up Neutral Beam injectors mounted around the wall of the chamber insert bursts of deuterium atoms to form the target plasma which is confined in the center of the machine by powerful magnets. Once the plasma is formed, 24 high-powered Neutral Beam injectors will be used to raise the plasma temperature to the more than 100 million degrees Celsius required for fusion to occur.

Thus, the MFTF system will be composed of a vacuum fusion chamber, the cryogenically cooled, super-conducting plasma containment magnets, the 44 Neutral Beam injectors, as well as all of the associated computer-controlled power supplies and support systems. The entire facility is housed in a building of approximately 38,000-square-foot floor area with a 100-foot high ceiling.

The 48 Neutral Beam injectors being built by Solid State Division's Electro-Optics and Power Device's activity (EO&D) include two spares of each type. Each consists of an arc chamber to ionize the deuterium working gas as well as an accelerator assembly to inject and focus the ion stream, which is later neutralized to form atoms, into the vacuum chamber. Deuterium is more commonly known as the heavy isotope of hydrogen in which a neutron as well as a proton are contained in the nucleus of the molecule. Deuterium is available in nearly unlimited quantities through extraction from sea water.

The electrostatic focusing, to limit beam spreading, requires precise tolerances in the complicated, specially shaped grid structure to be maintained at plus or minus three-tenths of a thousandth of an inch. Such precision exceeds that normally used in electronic components. Thus, the Neutral Beam injector requires the development of new techniques in high-precision machining, assembling, and inspection methods.

As mentioned, three major subassemblies are being manufactured by RCA: a three-grid 20kV accelerator assembly, a four-grid 80kV accelerator assembly (Fig. 1), and an arc-chamber assembly (Fig. 2) that is common to both accelerator assemblies. Each accelerator/arc-chamber assembly is enclosed in a vacuum-tight housing with high-voltage-insulated ter-

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Table I. Neutral Beam Source Module mechanical and electrical characteristics—MFTF.

Arc Chamber Assembly
Filaments — 226: 10 volts, 25 amperes each
Total $I_F = 5650$ amperes
On-time: 3.5 sec
Arc: 60 volts at 4000 amperes
Time: 800 msec

80-kV Accelerator Assembly: 10 x 46 cm
Four grids: 77 wires each
Entrance or accel grid: + 80 kV
Gradient grid: + 67 kV
Suppressor grid: — 2 kV
Exit grid: 0 kV

20-kV Accelerator Assembly: 10 x 45 cm
Three grids: 105 wires each
Entrance grid: + 20 kV
Suppressor grid: — 2 kV
Exit grid: 0 kV

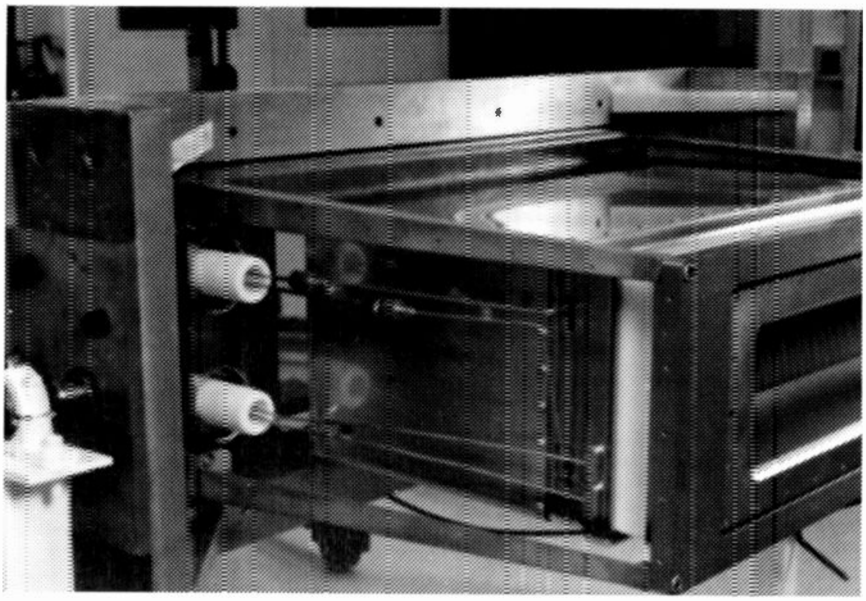

Fig. 1. The four-grid 80kV accelerator assembly. The recessed exit grid is visible at the right of the photograph. High-voltage insulators, water-cooling pipes and the plasma shields can also be seen

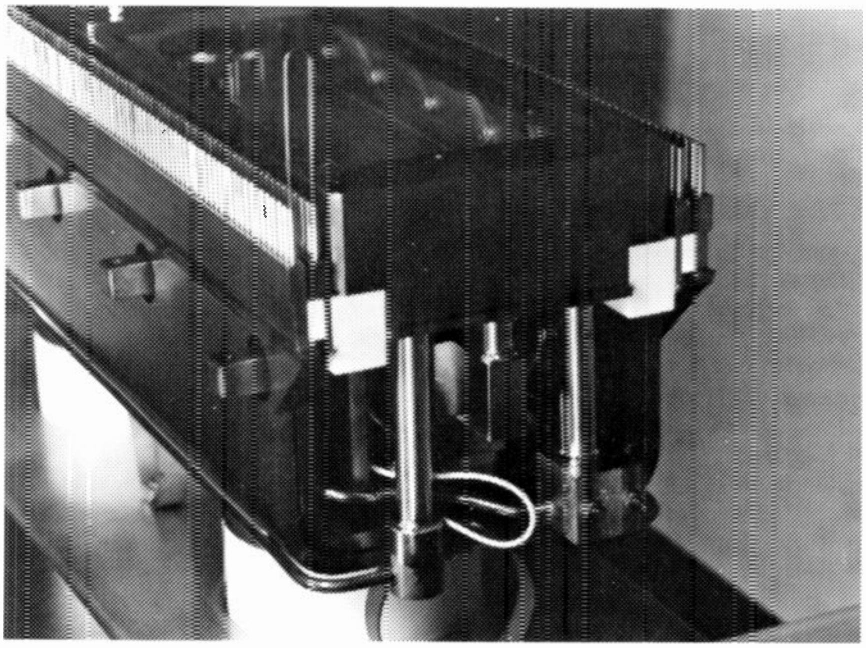

Fig. 2. The arc-chamber assembly. One of the 226 tungsten hair-pin filaments has been mounted in the dual rows of chucks and the first of several anode bars is visible in the upper left of the photo.

minals available for the electrodes and inputs available for cooling-medium and gas injection. Table I shows performance objectives and grid configurations.

As the first step in the industrialization process, a value-engineering study of the prototype design drawings and proposed manufacturing processes was made by RCA to optimize manufacturability, reliability, maintainability, and economics. As a result of this study, the cost objectives set by the U.S. Department of Energy (DOE), defining that major, U.S.-produced ion sources be manufactured for the least dollars per Watt, have been met.[2] RCA has manufactured, tested, and shipped the first four 80-kV NBSMs on or ahead of schedule. The first 20-kV module is now being manufactured for delivery in 1982, with the balance of 43 NBSMs to be delivered in fiscal years 1983-84.

The skills, facilities, and techniques required to produce the NBSMs are similar to those that have been employed by RCA Lancaster in similar projects [3, 4] and during four decades of the design and production of very large power tubes. Low-vapor-pressure materials, thermionic emitters, high-voltage operation, beam optics, high vacuums, extreme cleanliness, and precision alignment are commonplace functions and operations at Lancaster. It is the sensitivity to these capabilities that qualifies RCA to participate in the industrialization of major components for such large projects as the Mirror Fusion Test Facility.

The success of this government-funded, joint laboratory/electronics-industry venture has been interpreted in some quarters as justification for seeking industry involvement earlier in the design phase of such large-scale projects. In this way, design choices can be better guided where they involve the cost, interchangeability, manufacturing method, and yield considerations common to industry. Costly, time-consuming redesign efforts and duplicate specifications can thus be avoided.

Organization

Project team

RCA's extensive experience in major projects comparable to the industrialization and production of the Neutral Beam Ion Sources has shown that effective project administration, as measured by contract compliance, can best be attained through the development of an organization dedicated to that singular objective. Accordingly, a separate department has been estab-

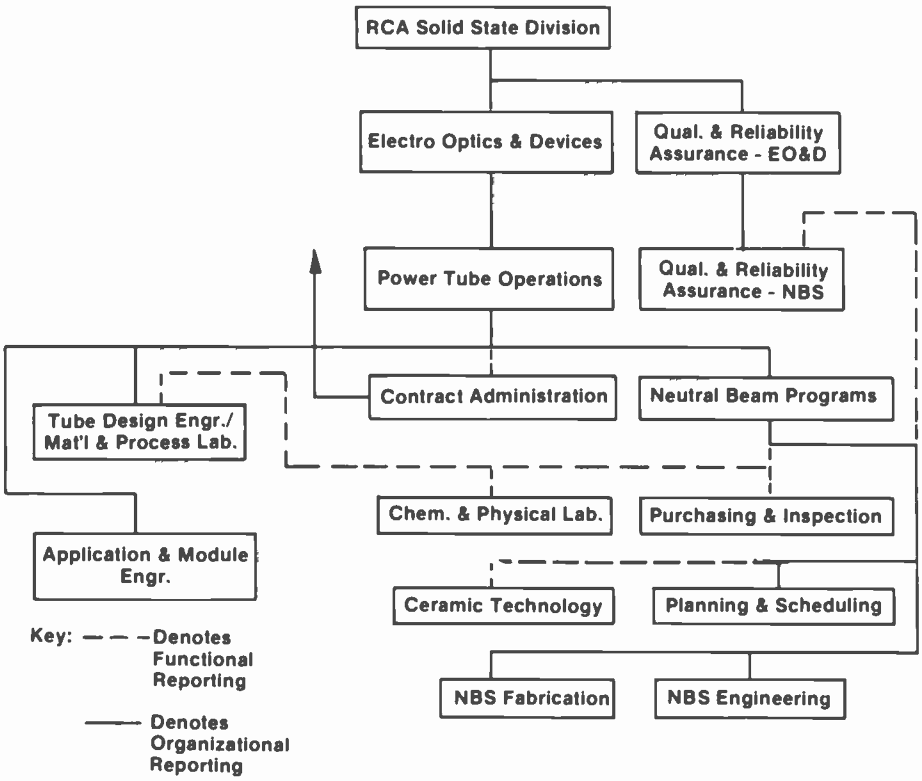

Fig. 3. Organization for industrialization of the Neutral Beam Ion Sources. Note that the Q&RA organization is independendent of the Operations organization.

lished and staffed with experienced personnel from the power-tube design and manufacturing functions to address the intricate requirements of source industrialization (Fig. 3). Design, manufacturing, and quality organization locations have been unified to improve group cohesiveness and communications. Peripheral support functions, such as Contract Administration, Purchasing, and Production Scheduling/Planning have dedicated personnel to the project. These personnel are functionally responsible to the Project Manager, while retaining direct organizational responsibility to their parent activities.

Project success has been enhanced through the assignment of key areas of responsibility to leading individuals in the quality, engineering, and manufacturing functions. For example, the Project Fabrication Manager was responsible for the layout and construction of the white room, acquisition of facilities, scheduling and stocking of parts, and fabrication scheduling. Coordination of the support activities of Design Engineering, Plant Engineering, Production Scheduling, Quality, and Purchasing is also required of this individual.

The Manager of Engineering Development for this project is responsible for product design and value engineering, identification of required equipment, location of critical vendors, development of Critical-Path-Method schedule (described below), and drawing-package upgrade. Support coordination required of this function includes the Fabrication, Quality, Purchasing and Equipment Engineering activities. Similarly, the Quality and Reliability Engineer is responsible for the control of drawing package, administration of the change-order system, development of the traceability system, development of inspection procedures, vendor evaluation, and vendor conformance monitoring.

Project status reviews are held weekly to evaluate the status of all program elements. The restructuring of priorities, assignment modifications, and the acquisition of support from various plant-population skills are all used to resolve critical-path-schedule deficiencies.

Quality and reliability assurance

The Lancaster Quality and Reliability Assurance activity (Q&RA) is responsible for all quality-related functions connected with the NBSM subcontract. This activity is separate from the project-team organization and reports directly to the Vice-President, Electro-Optics and Power Devices. Q&RA activities include:

- Audits of incoming parts/materials,
- Certification and assessment of the results of corrective action taken to reverse nonconformance,
- Auditing of product processing and fabrication,
- Completed-item inspection and test results,
- Approving product release for shipment,
- Performing sampling inspections as specified by the contract, and
- Auditing test and inspection calibration, handling, storage, and delivery functions.

The drawing change-order system and standardizing activity are also included in the responsibilities of the Q&RA organization.

RCA mandates that all vendors and suppliers have their own quality-control systems capable of fulfilling the NBSM quality requirements. RCA's goal is to implement or have implemented, at an optimum cost, those quality systems necessary to produce final manufactured products that meet the contract objectives.

Planning and control

The overall project planning and tracking functions required to assure compliance with schedules for deliverable materials, parts, assemblies, and equipment are controlled by means of a computerized scheduling method.[5] This Critical-Path Method, CPM, provides not only critical-path information in time/date sequence, but also Gantt milestone charts (Fig. 4) that show the earliest and latest allowable dates for the completion of each work element or task. Next to PERT, CPM is the most widely accepted of the planning and control systems that use the networking principle.[6]

The critical path is denoted on the Gantt charts by solid black bars; this path is also printed on a companion "Muscle Chart." Several hundred significant jobs or tasks are listed on the "Muscle Chart" with the estimated time period required to complete each. The effects of overtime, as well as holidays and vacation days, on these time periods can be evaluated by the computer program. The "Muscle Chart" also lists the slack or "float" times for noncritical-path tasks and responsibilities. This guidance provides management with a valuable tool for reassigning resources in advance of a problem to avoid delays in the critical path.

Accounting to the CPM schedule is accomplished by a charge-number system matched to the project task and to the work breakdown structure (WBS) numbering system. Monthly tabulations of the charges are then used to prepare an earned-value report for LLNL and DOE to use in monitoring the project status by milestones.

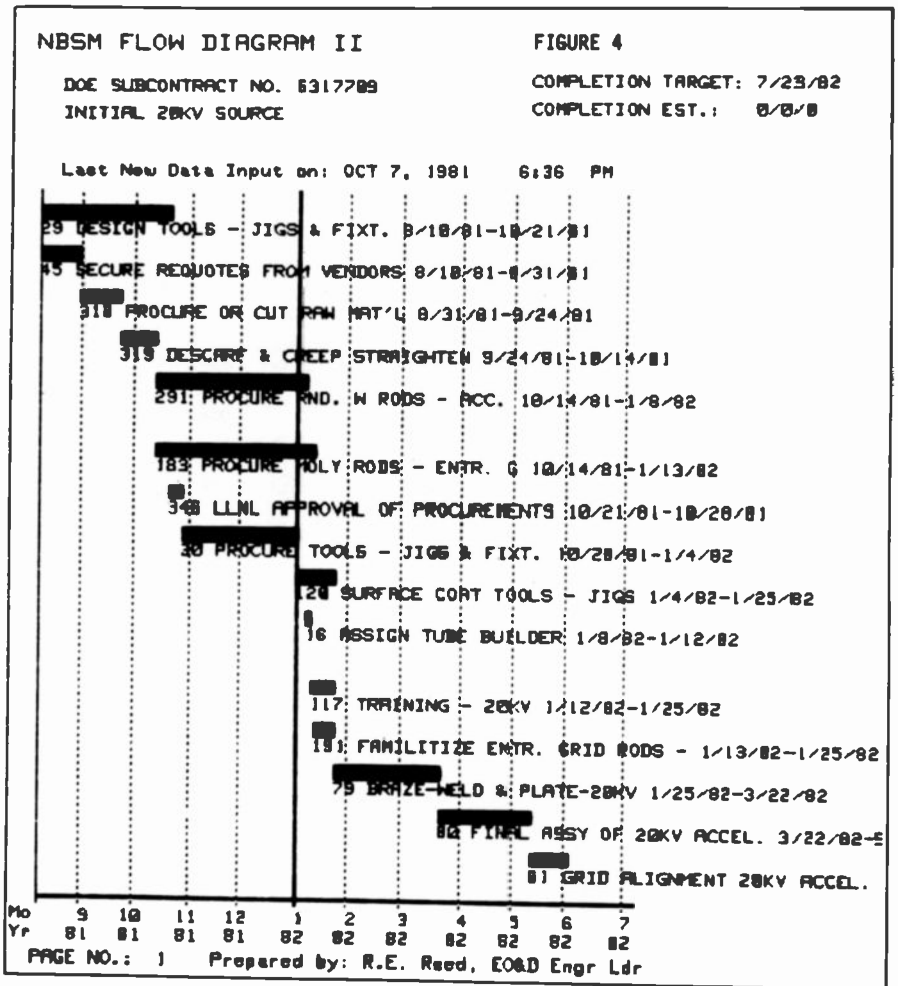

Fig. 4. CPM Gantt milestone charts. Black bars denote all items are in the critical path.

Vendor qualification and evaluation

Of paramount importance to the production of quality systems is the evaluation and qualification of vendors. Lancaster's Procurement Section, consisting of experienced buyers, order clerks, and expediting personnel, in conjunction with Q&RA and engineering personnel, perform on-site evaluations of potential vendors. Qualified shops and suppliers are thus certified capable of the fabrication of the high precision (±0.0003-inch tolerance) components for the NBSMs.

The Lancaster facility also has in-house machine shops that can be used for cost-effective, repetitive production or a unique one-time task, and to provide parts in an emergency to assure that delivery commitments are met. However, more than eighty percent of all NBSM parts are procured through three or more competitive bids (a practice that assures effective cost control) from qualified sources outside of RCA.

Technical assistance provided by the project team aids in selecting economical tooling levels, improving quality and yields, and decreasing costs. Periodic reviews of vendor performance are conducted. Factors evaluated are quality, price, ability to deliver, and conformance of product to specification. All incoming parts are inspected again by RCA before being stocked for use in fabricating the NBSMs.

Facilities

The requirements established for fabrication of NBSMs were sufficiently unique to require the construction of a separate clean room and cleaning facility covering approximately 3500 square feet. Class 100,000 requirements were exceeded in parts of this area, with Class 10,000 requirements met consistently by actual particle count in the final assembly area, where gloves, caps, and coats are mandatory.

Product flow from the parts storage and pre-assembly area through the cleaning area and into the final assembly area is carefully planned and controlled. Brazing, plating, and other pre-assembly operations are provided by facilities normally used in power-tube production.

However, special facilities were procured for some portions of the NBSM manufacturing process; these include the Cordax computerized coordinate-measuring equipment (Fig. 5), a computerized optical comparator, a sensitive helium-leak detector, a ceramic bonding press, Heliarc™ (Union Carbide) welders, an adjustable high-voltage power supply, and large-scale handling equipment.

Final testing of each completely assembled NBSM is performed in the clean room to prevent contamination of the finished device.

Technology development

Value engineering

The manufacturing drawings supplied by the major contractor for the 20-kV and 80-kV accelerators and arc-chamber designs were reviewed carefully by RCA engineers for fits, tolerances, and consistency of assembly dimensions by means of the ANSI Y14.5 True Position Tolerancing System. Statistical methods were applied to the analysis of dimensions and tolerances on component parts to predict the probability of achieving the overall dimension of the most complicated assemblies. Many drawings were found to be satisfactory as submitted, while studies of others indicated a probability that more than half the product produced according to their specifications would be unacceptable, and lead to unacceptable amounts of scrap and rework and, ultimately, higher costs. Drawing changes were made where probabilities were less than approximately 85 percent of making a successful assembly. In this way excessive tolerances, erroneous dimensions and overlapping fits were corrected.

An example of such a dimensional review is the examination of a portion of

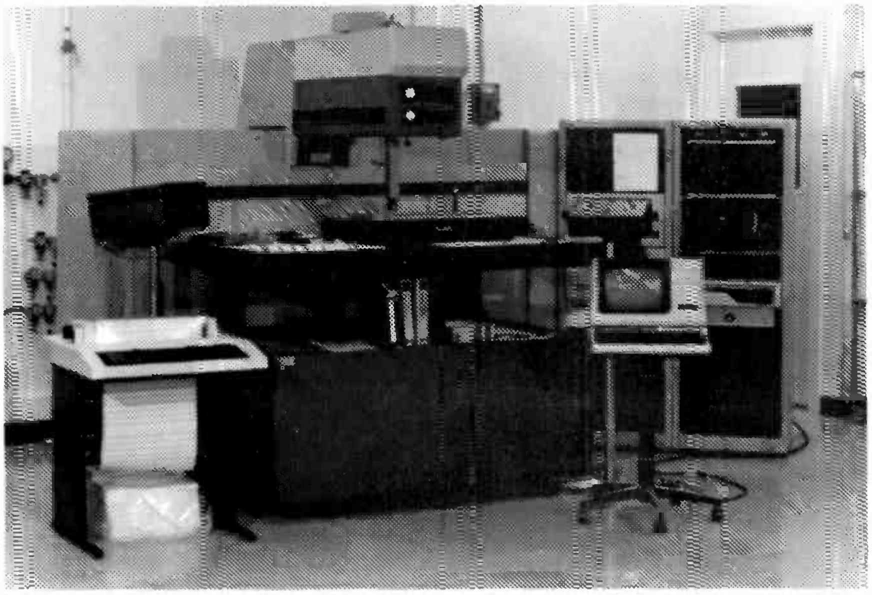

Fig. 5. Bendix Cordax computerized coordinate-measuring equipment. A sensitive probe measures surfaces and contours automatically to an accuracy of ±0.0003 inch. The results are printed as a traceability record.

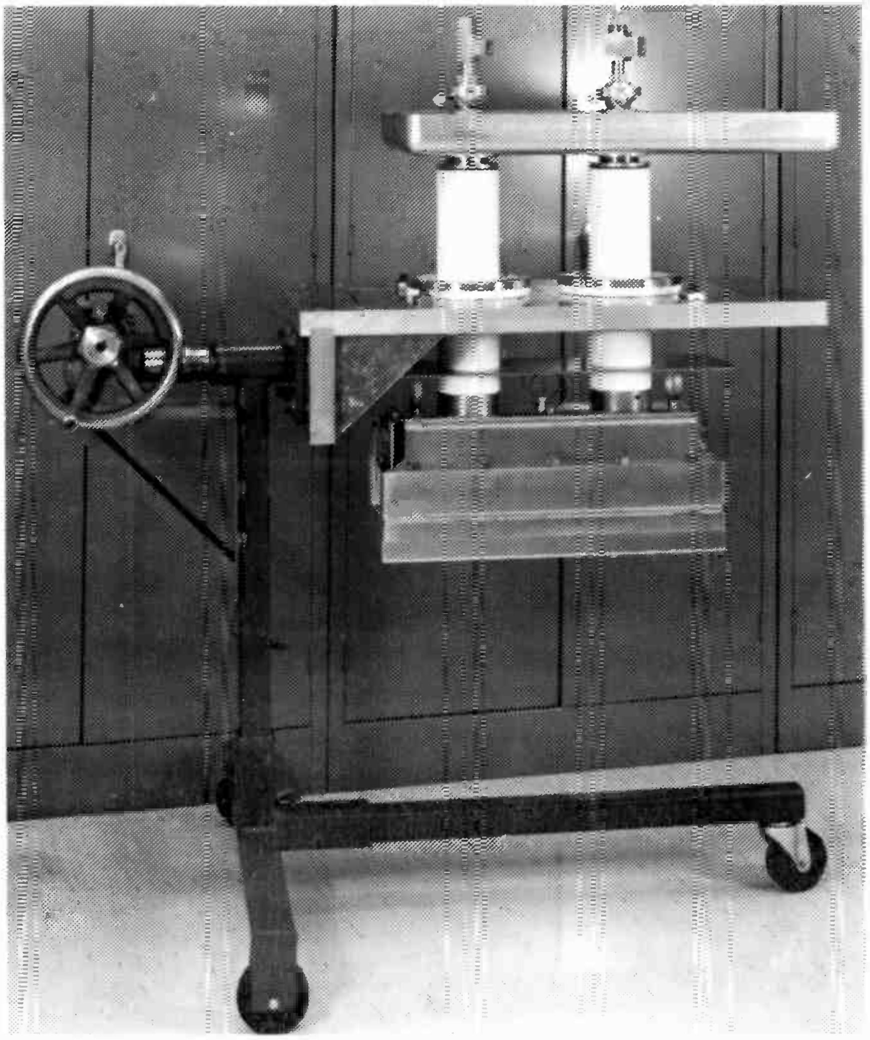

Fig. 6. Complete arc-chamber assembly. The tri-axial feed-through insulators (white cylinders), corona shield (top) and arc-chamber covered by wall electrode (under table) are all visible. The tilt cart facilitates assembly work.

the arc-chamber assembly(Fig. 6) in which an important dimension is specified from the mounting surface to the end of the wall electrode. This dimension locates the deuterium plasma with respect to the entrance grid of the accelerator assembly. The mating dimensions and tolerances of the seven component parts in the design originally supplied to RCA were such that there was almost a 100-percent probability that none of the assemblies made from these parts would produce the required finished dimension. The ring-support shim on each assembly would have required machine thinning to meet the specification.

RCA's value engineering team changed some part dimensions and tolerances and, with LLNL's approval, redefined the mean assembly dimension. These modifications enable all parts to be used as made. There is now almost a 100-percent probability that all arc-chamber assemblies will be within specification.

Other assemblies were analyzed similarly and minor design modifications made to increase the probability of achieving the assembly specification without rework. Interchangeability of parts was also improved by these revisions to the drawing package.

Another example of value engineering involves the grouping of the curved grid rods used in the grid assembly into families whose critical dimension varies by 1 to 2 mils. A family of rods can then be used with the assurance that most of the final adjustment and reworking that would otherwise be required at final assembly will be eliminated.

Process refinements

A review of the processes used in constructing the prototype unit revealed that most were satisfactory. However, some processes were modified during the value engineering phase; the machining of the titanium grid frames is an example.

Titanium frames have large polar moments of inertia, but small rectangular moments and, therefore, a tendency to warp. Excessive warpage of these parts was eliminated by the use of flame-cut rather than sheared blanks, descarfing with milling cutters rather than grinding, and thermal-creep straightening rather than mechanical flattening.[7] The importance of flame cutting with an acetylene rather than a plasma torch was emphasized by LLNL personnel. The nitrogen in the plasma-torch gas supply would have produced titanium nitride at the cut edge, a harder alloy than tungsten carbide.[8]

Metrology

To assure a high yield of in-specification and interchangeable assemblies, computerized inspection facilities procured especially for this project, as noted above, are used in both parts and assembly dimensional verification. These facilities consist of an Opticom OQ-14 precision optical comparator and a Bendix Cordax (Fig. 5). Both have accuracies of measurement of within ±0.0003 inch. The inspection operation is computer-controlled; a print-out of the results of the inspection, as well as any deviations from specification, provides a traceable quality-control record for each part and assembly.

Accessories designed and procured for and adapted to these facilities permit the measurement of a number of unique dimensions associated with the ion-optics of the accelerating grid assembly. These accessories include sensitive Renashaw probes that exert less than one gram of force on the delicate parts being measured, air-actuated probes for measuring grid-rod curvatures, and an RCA-designed probe that measures spacings between grid assemblies for verification of the "curvature eggshell" required for focussing.

Acceptance testing

A dual-step vacuum system, helium-leak detector, and adjustable 100-kV 2-milliampere power supply were installed for use in the acceptance testing of each major subassembly and the complete source assembly prior to shipment. Each NBSM must pass high-voltage, vacuum-integrity, water-flow-pressure-drop, and pressure-leak tests prior to shipment. The vacuum integrity and voltage hold-off tests are repeated by LLNL on receipt of the unit. In addition, LLNL performs plasma tests to verify that diffusion, density, and other source design parameters have been maintained.

Packing and shipping

Prior to shipment, the vacuum environment surrounding the NBSM is replaced with N_2 gas and the entire assembly hermetically sealed to prevent contamination during shipping or storage. Of several methods evaluated for shipping the completed sources coast-to-coast without damage, a fork-lift-movable reusable steel drum fitted with helical shock-and-vibration isolators was selected(Fig. 7). A finite-element computer code was used to evaluate resonances in the NBSM assemblies. These results were compared with the resonance values for trucks and airplanes, allowing for the damping characteristics of the "helicals." The mounting of the NBSM and its vacuum-tight protective cover was designed to coincide with the center of gravity of the complete assembly. Continuous recording and upset-type accelerometers are used to monitor the shocks encountered in transit. The first four 80-kV units were shipped successfully by this method by air freight, with trucking to and from the airport freight terminals.

Fig. 7. Complete NBSM mounted in shipping container. Note that the coils of the helical isolators are visible just inside the front edge of the steel drum. Accelerometers (box and short cylinders in foreground) as well as high-voltage insulators (white cylinders) are also visible.

Conclusions

The advantages and wisdom of utilizing the experience of an existing, proven industrial-electronics capability in conjunction with the design of a major fusion-energy research component by a laboratory has been verified by the on-time delivery of four 80kV Neutral Beam Ion Sources costing within one-percent of the budgeted cost and meeting all contract specifications.

Acknowledgments

The dedication and expertise of the entire project team and the supporting activities are gratefully acknowledged. Guidance and support were also provided by the scientific and experimental staffs of Lawrence Livermore National Laboratories.

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Automated measurement of transistor I-V characteristics

Current-voltage relationships are vital characteristics of transistors. Now, an automated method measures, stores and "distills" for presentation the voluminous data required to completely determine transistor I-V characteristics.

Abstract: *An automated system for the measurement of the I-V characteristics of transistors has been constructed. The system can multiplex up to ten transistors in an environmental chamber, remotely measure devices on wafers, and characterize bipolar transistors, MOS transistors, and Darlington transistors. It can provide a collector (or drain) current ranging from 10 microamperes to 10 amperes, and can measure beta in the range from 1 to 10,000. Collector (or drain) voltage can be changed, but is usually kept at either 5 or 10 volts.*

The data can be presented in many different forms. In this report we show examples of log (I_c) *and log* (I_b) *versus* V_{be}, log *(beta) versus log* (I_c), d *log (beta)/*d *log* (I_c) *versus log* (I_c), *drain current versus gate voltage, and transconductance versus gate voltage. Furthermore, beta-*I_c *curves are shown as functions of temperature.*

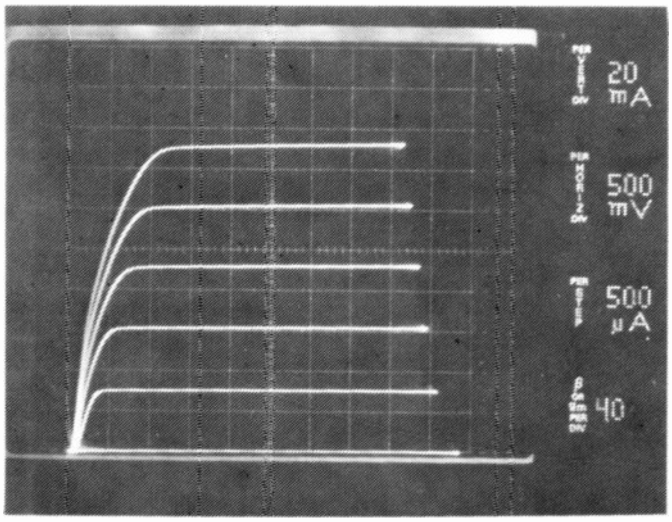

Fig. 1. Conventional I-V characteristic of a bipolar transistor using a Tektronix curve tracer.

The DC behavior of bipolar transistors is fully characterized by the relationships between the base and collector currents and the base and collector voltages. For MOS transistors, the relationship between the drain current and the gate and drain voltages serve to characterize them. The usual way of obtaining this information is to observe the I-V characteristics on a characteristic curve tracer, as shown in Fig. 1. Here, we present the collector current over a range of collector voltages for several values of base current. Unfortunately, many such pictures are required to observe the collector current over a wide range (for example, three orders of magnitude). Finally, condensing the information to a usable form, that is, plotting log (beta) versus log (collector current) and preparing the data for analysis, requires a considerable effort. For these reasons, an automated test system was developed. The system measures the I-V characteristics of the transistor, stores the data, and prepares graphs of the data for presentation in many different forms.

The system, originally developed for use on a single bipolar transistor at room temperature, has been extended to allow multiplexing of up to ten devices in an environmental chamber, remote sensing for measurements performed on wafers, and I-V characterization of MOS and Darlington transistors. It can provide a collector (or drain) current ranging from 10 microamperes to 10 amperes, and can measure beta in the range of 1 to 10,000. Collector (or drain) voltage can be varied, but is usually kept at either 5 or 10 volts.

The data can be presented in many different forms. For example, log (beta) versus log (I_c), log (I_c) and log (I_b) versus V_{be}, and d log (beta)/d log (I_c) versus log (I_c) are some of the presentations that have been used.

System design

A block diagram of the automated I-V measurement system is shown in Fig. 2. The system is composed of four main blocks: the MINC-11 laboratory system; the analog measurement circuits; the multiplexer; and the environmental chamber (test sockets). The MINC-11 laboratory system contains a full 64-

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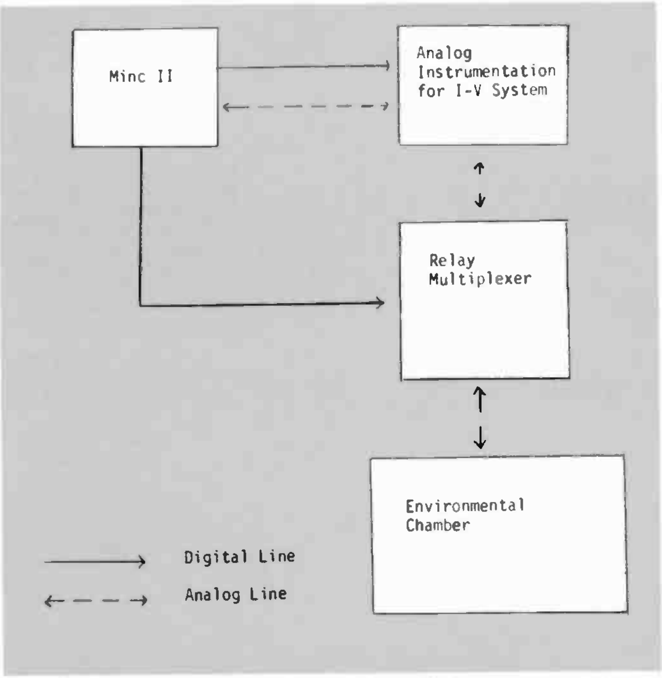

Fig. 2. Automated Power Transistor (APT) test-system block diagram.

kilobyte microcomputer along with a set of analog and digital input and output modules that interface between the computer and the experiment. The analog measurement circuits are used to scale and preprocess the data so that it is compatible with the MINC-11. The multiplexer is controlled by the MINC-11, and switches the appropriate transistor socket to be measured. The environmental chamber is a standard refrigerator/oven wherein temperature can be varied from −50 to 200 degrees Celsius. It contains ten transistor sockets.

Hardware

The analog instrumentation necessary for measuring the I-V characteristics of a transistor is shown in Fig. 3. The digital-to-analog module (D/A) of the MINC-11 sends a voltage to the voltage-controlled current source (VCCS), which controls the base current in the transistor under test (TUT). The digital-out module (DOUT) of the MINC-11 gates the VCCS so that the current is sent to the TUT as a short pulse (13 ms). Precision resistors (±0.05 percent tolerance) and high-quality instrumentation amplifiers are used to measure the actual current flow in both the base and collector circuits. The collector supply is a standard power supply connected with remote sensing to correct for voltage drops in the current-sensing resistor.

The schematic for the voltage-controlled current source is shown in Fig. 4*. The VCCS consists of three elements: an operational amplifier, a current-sensing device, and a feedback amplifier. The operational amplifier is used to compare the input voltage and the voltage developed across the current-sensing element via the feedback amplifier. In this manner, the current through the sensing element is made to be proportional to the input voltage. We selected for the operational amplifier a Burr-Brown model 3572 power op-amp, which upgrades the measurement system's current drive capabilities from the 10-mA limitation of the MINC-11 to the 2-A maximum current output specification of the power op-amp.

Two back-to-back diodes (1N5404) are used for the current-sensing element. These diodes yield an exponential relationship between the input voltage and the output current. A 10 kΩ resistor is placed in parallel with the diodes to smooth the zero current crossing where the diode impedance becomes very large.

Similar to the base channel, the collector channel is set up to

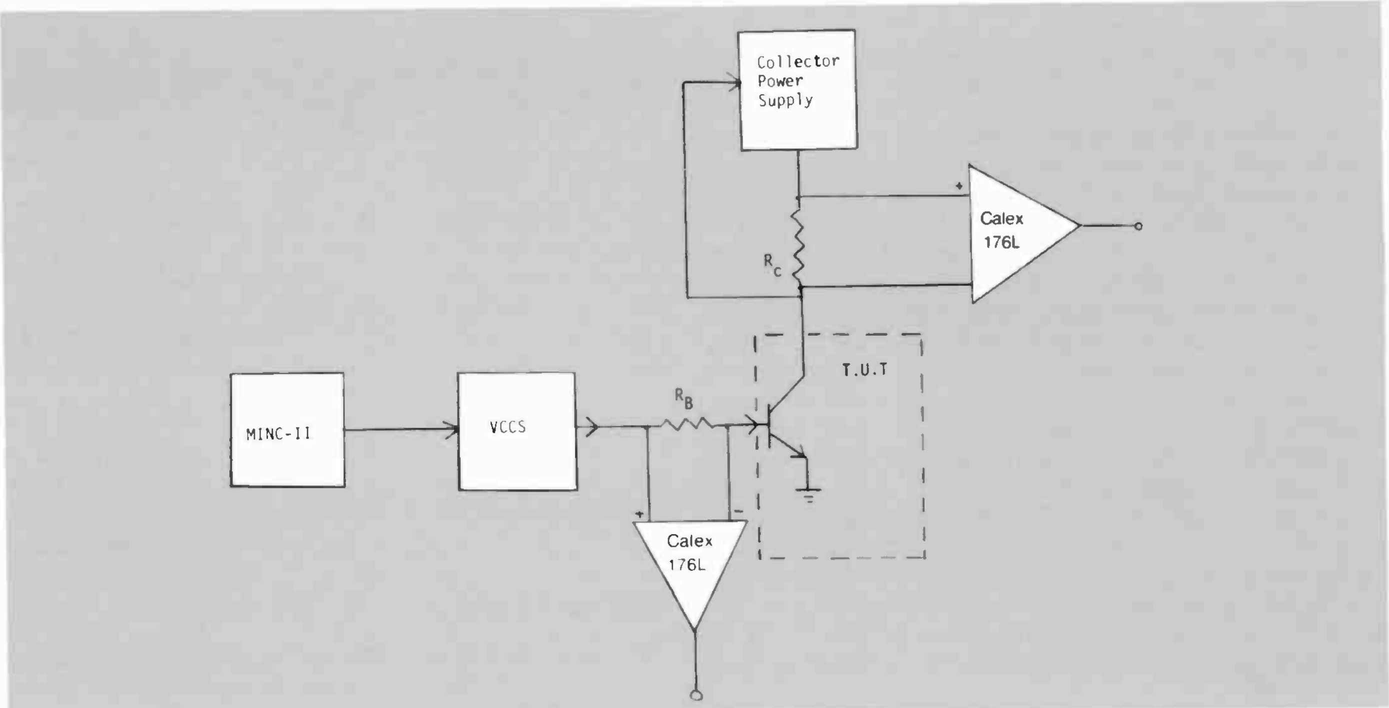

Fig. 3. The measurement system. The MINC system controls the bias point of the device under test. Current flow is sensed using precision resistors across the inputs of the instrumentation amplifiers.

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*An improved current source has been designed. It is stable over a much wider range of current. Contact M. Snowden for further information.

NTAR: New Technology Applications

The NTAR group is a branch of RCA Laboratories located at the Solid State Division in Somerville. Its main function is to provide prototype IC designs to the Consumer Electronics Division. This group is located at Somerville to advantageously use evolving technologies that originate in the Solid State Technology Center and to provide an interface between CE and SSD on many IC designs.

The MINC-11 is very satisfactory as a tester controller and for medium-sized design programs. It is compatible with other RCA PDP-11 users. It has a well-documented, fourth-generation operating system (RT-11). Disadvantages include its fan and floppy-disk noise and its high cost compared to personal computers. MINC is used for the following functions.

- *IC test compatibility with the New Products Laboratory, Indianapolis.* Programs can be exchanged between MINC and NPL's PDP-11/70. Software may be developed on the larger machine, then downloaded to MINC and other small PDP-11 satellites for execution.
- *Piezoresistivity measurements.* The measurements determine IC package-induced effects on diffused and ion-implanted resistors. Comparisons are made among measurements on wafers, and ceramic- and plastic-packaged parts.
- *Breakdown testing.* A MINC-controlled fixture was designed by the Product Assurance group to identify weak IC pins. Corrective protection is then implemented as necessary.
- *Design.* MINC can do statistical tolerance analysis based on Gaussian distributions for the pulse-width output of the monostable circuit used in the TA10708 Horizontal, Vertical, Regulator IC. Digital Signal Processing FFT and filter-design routines have been cost-effectively executed on the limited-memory MINC.
- *Miscellaneous.* MINC has been used in the off-line program preparation for the DEC-based Keithley test system and the word processing for reports and papers.

—*Steve Steckler,*
RCA Laboratories at Somerville

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provide proper transistor biasing, precise current-sensing capabilities, and feedback correction of voltage drops in the sensing resistors. A standard power supply, with up to 10-A maximum output current, is used as the collector supply. It is connected in a standard remote-sense configuration, with the current-sensing resistors in the feedback loop.

The actual current flow, in both the collector and base channels, is measured by passing the current through precision resistors (±0.05 percent tolerance). The voltage developed across the resistors is amplified by Calex model 176L instrumentation amplifiers. The signals proportional to the base and collector currents are compressed into a four-decade range by log amplifiers and then are acquired by the MINC-11 for processing.

The gate of an MOS transistor is driven directly from the MINC-11 D/A module. Only the drain current need be resistively sensed, so the base resistor is shorted in this measurement.

Software

Three programs were developed that will run the experiment and display the measured data. A structured approach and

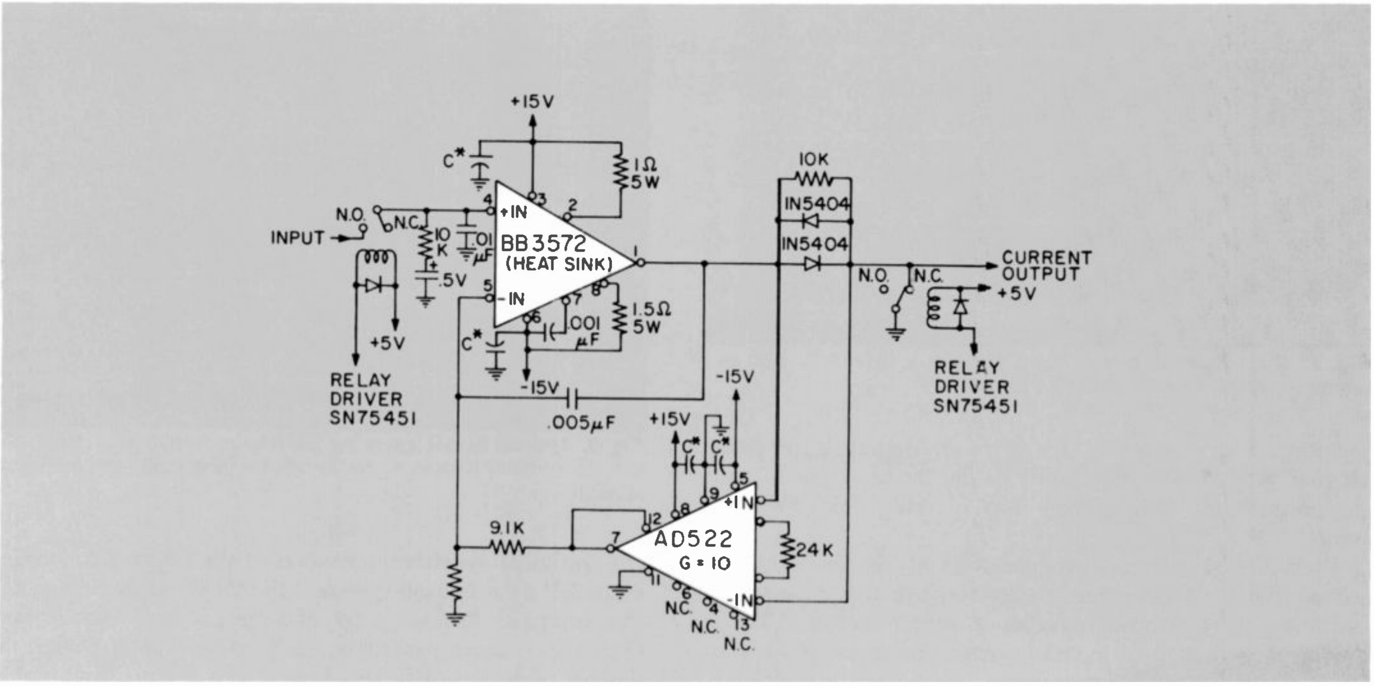

Fig. 4. The voltage-controlled current source, which is driven by the MINC, provides base current for bipolar and Darlington transistors. MOS transistors are driven directly from the output of the MINC system.

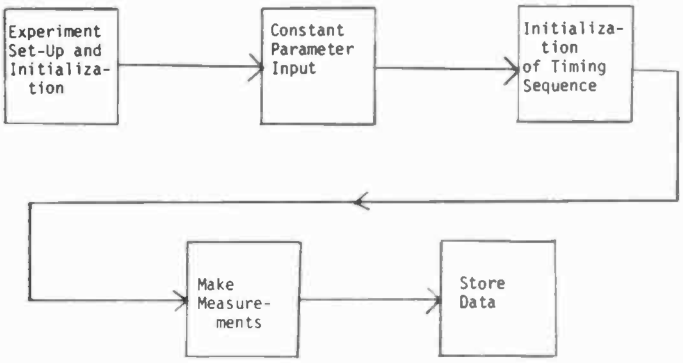

Fig. 5. Program flowchart.

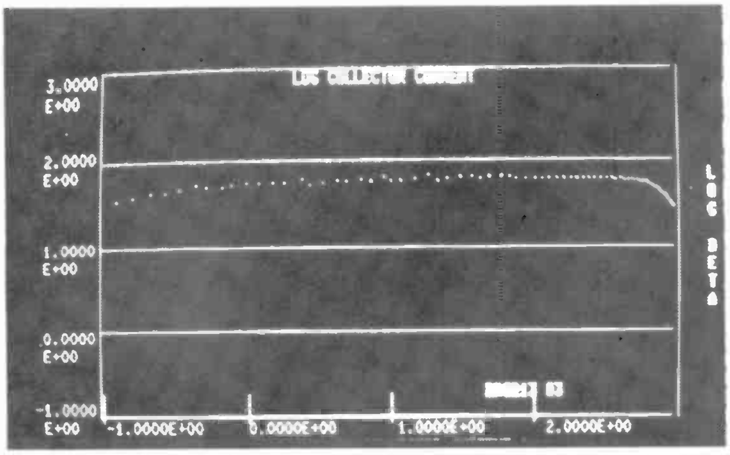

Fig. 6. Beta-I_c characteristics showing a four decade range of collector current. The larger collector current range allows for a more detailed evaluation of overall device performance.

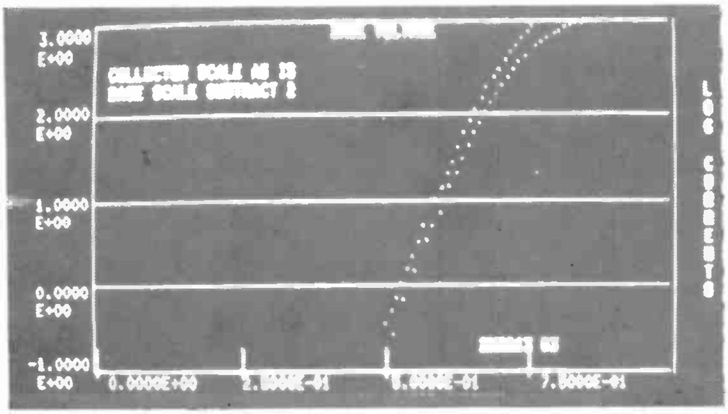

Fig. 7. The "Gummel plots," log I_c and log I_b versus V_{be} can be used for explicit modeling of the transistor.

input menus were adopted. This approach supplies the unfamiliar user with enough information to run the experiments, and the programmer with an easy way to track down possible errors.

The main measurement program (one for bipolar devices, a second one for MOS devices) steps through the sequence of operations that are shown in the block diagram of Fig. 5. There are five distinct parts to the measurement program: set up and initialize experiment; input necessary parameters; initialize the timing sequence; take measurements; and store data into the MINC-11 floppy disk.

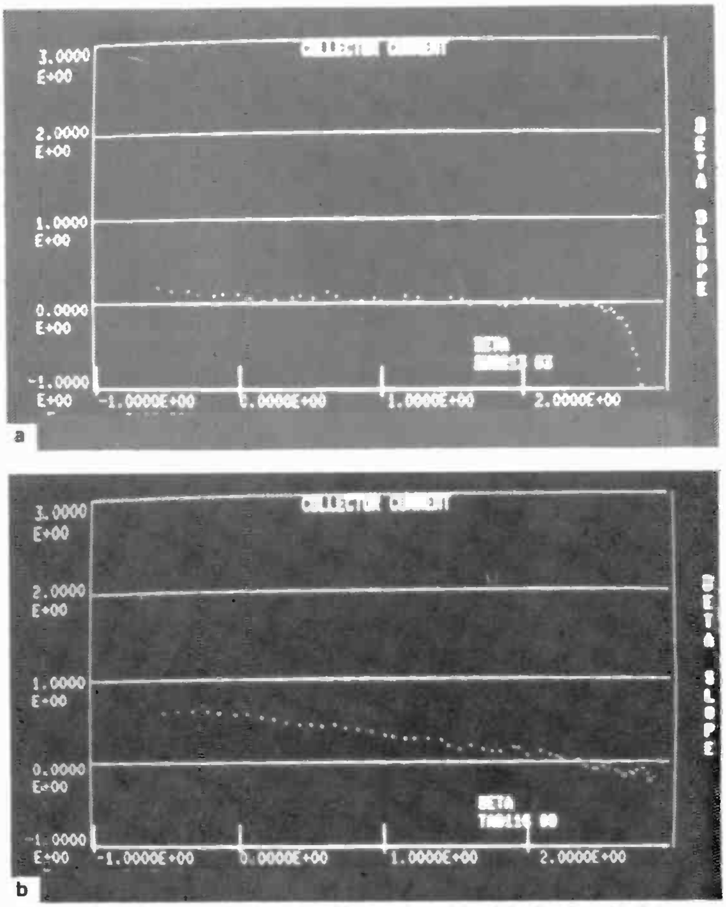

Fig. 8. Problems associated with any nonideal behavior of the base diode that affects the high-current beta can be easily viewed in a graph of the slope of the beta-I_c characteristics. Devices that have a "flat beta," that is, a slope equal to zero **(a)**, in general perform better than devices with a sloped passage through zero **(b)**.

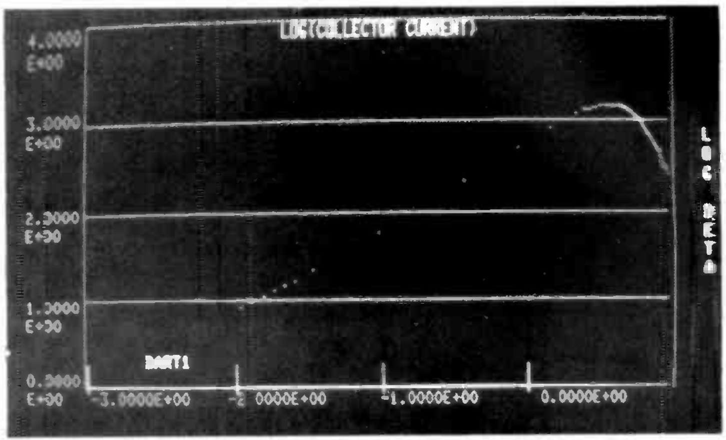

Fig. 9. Typical beta-I_c curve for Darlington transistor. Note that at low currents the beta-I_c curve shows the base-emitter shunt resistor.

Experiment initialization consists of the physical connection of the I-V measurement system to the MINC-11 minicomputer. The computer displays a list of connections for verification. Once this is done, parameters such as the type of device, the number of devices to be tested, and the collector-current range are entered.

After the system initialization is completed, the measurement

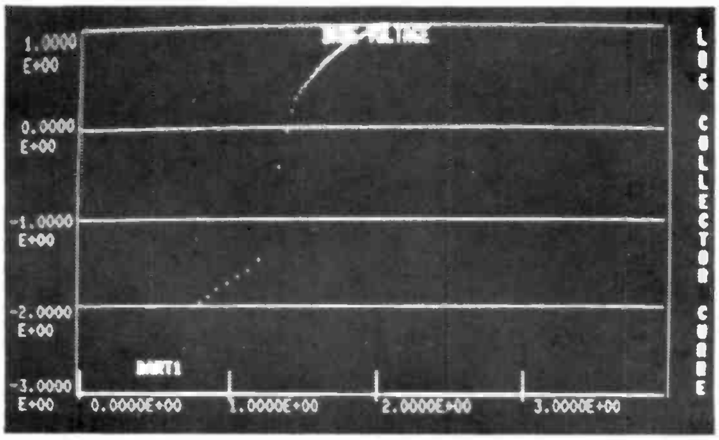

Fig. 10. Turn-on characteristics for the Darlington transistor. These curves are similar to the Gummel plots in Fig. 7, but the compound structure of the Darlington makes interpretation of these characteristics very difficult.

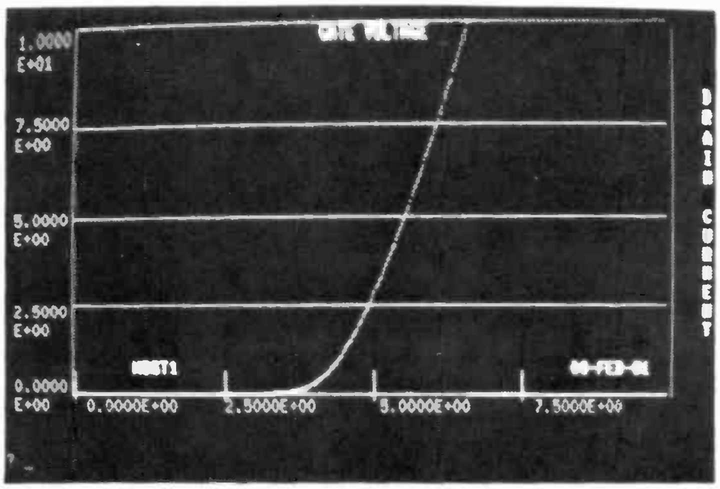

Fig. 12. The operating characteristics of a nMOS transistor are illustrated in the plot of drain-current versus gate voltage.

is begun. A one-second measurement-cycle time is used for each data value. The program sets the base-current (gate voltage) value. The corresponding MINC-11 output voltage is gated onto the VCCS (or MOS gate). This applies a pulse of current to the base (a pulse of voltage to the gate) of the TUT. The pulse width is 13 ms, which is enough time for the total system to stabilize and for the MINC-11 to acquire the data. The remaining cycle time reduces heating effects in the test devices.

Measurements

Figure 6 shows a photograph of the beta-I_c characteristics (log (beta) versus log (collector current)) of the same device that was measured in Fig. 1. In contrast to Fig. 1, the four-decade range of collector current provides a more complete characterization of the device's behavior. Low-current effects, peak beta, and high-current effects are all shown simultaneously. The only action required from the engineer is to plug in the device and answer a few questions.

Often, it is important to analyze the device characteristics in several different ways. For example, Fig. 7 is for the same device again, only this time the "Gummel plots" are shown (that is, log (I_c) and log (I_b) versus V_{be}). These plots reveal information about the series resistances of the device and the ideality of the base-emitter diode.

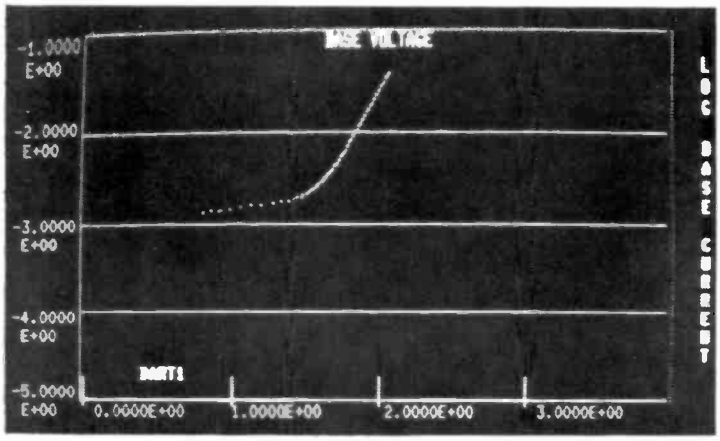

Fig. 11. More turn-on characteristics.

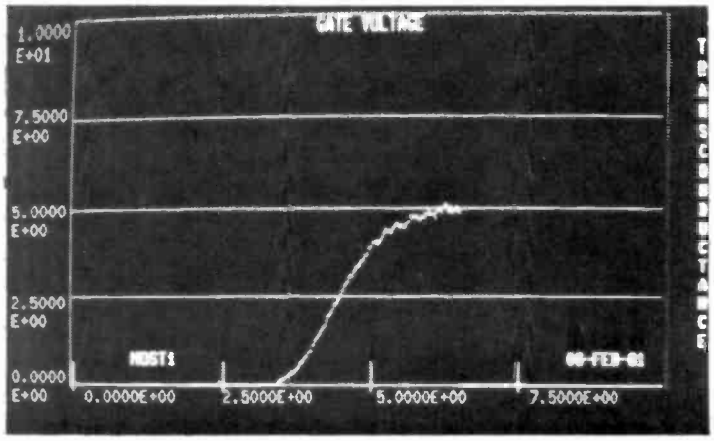

Fig. 13. Transconductance versus gate voltage. An important modeling parameter, threshold voltage, can be obtained from this plot by extrapolating the straight line portion of the curve back to the interception of the gate voltage axis.

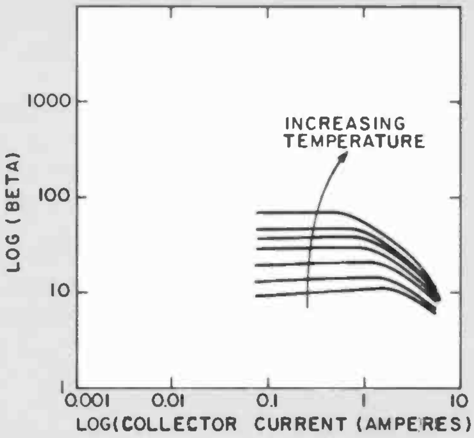

Fig. 14. Minimizing the temperature-dependent spread of the beta-I_c characteristics makes it possible not only to improve device performance but also to increase yield in manufacturing the devices. This graph enables us to evaluate changes in processing quickly.

Authors Robert Amantea (standing) and Michael Snowden (sitting).

Robert Amantea joined RCA in 1965 and has worked in the area of power semiconductor devices. He has previously authored papers on power transistors, TRAPATT devices, gated-diode physics, and gate-turn-off thyristors. Until recently his interest has been in the area of power semicondictor device modeling and computer-aided design. Dr. Amantea is a Member of Technical Staff in the Satellite Communications Research Group of the David Sarnoff Research Center where he is currently working on automatic testing and fault isolation.
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Michael Snowden joined RCA in 1980 and has worked on the development of laboratory automation equipment for semiconductor power devices. He is currently a Senior Technical Associate in the Silicon Device Research Group of the David Sarnoff Research Center where he is responsible for updating laboratory techniques.
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Another way to view the measurement is by providing a plot of the slope of the beta-I_c characteristics (Fig. 8). This characteristic (d log (beta)/d log (I_c) versus log (I_c)) can illustrate definitively any nonideal behavior of the base diode that affects the high-current beta. For example, the device shown in Fig. 8a exhibits a region of the characteristic that is zero and flat while that in Fig. 8b shows a sloped passage through zero. Figure 8a implies that the beta-I_c characteristic is flat in the region adjacent to the peak beta. Therefore, the nonideal base diode does not affect the high-current behavior. If, on the other hand, the curve passed directly through zero without going flat, as in Fig. 8b, then the nonideal base diode does affect the high-current beta.

The I-V characteristics for Darlington transistors can be displayed in a manner similar to those of bipolar transistors. Figure 9 shows a typical beta-I_c curve. Betas ranging from 1 to 10,000 can be measured and displayed. The corresponding "Gummel plots," Figs. 10 and 11, also can be displayed for further information on device behavior.

Figures 12 and 13 show some results obtained for MOS transistors. Drain current and transconductance versus gate voltage are shown, respectively. Although these are our first such measurements of MOS devices, we see that they are going to be very useful in the future.

Photographs of the screen are but one way to observe the data. Hard copy also can be obtained with a screen printer or a digital plotter. Figure 14 shows a sequence of plots of the beta-I_c characteristic for various temperatures that ranged from −50 to +150 degrees Celsius. Plots like these are very useful in determining the physical mechanisms responsible for the temperature dependence of the gain.

Conclusions

In this report we have shown how to automate the I-V characterization of transistors. Results for bipolar, MOS, and Darlington transistors are given. In each case, full characterization of the relationship between the currents and voltages is possible. Currents that range over four orders of magnitude, and temperatures from −50 to +200 degrees Celsius, present no obstacles to the measurement. The automated test system is an excellent engineering tool, providing accurate measurements and rapid graphical presentation of the data.

Acknowledgments

The authors would like to thank the engineers in the Device Development Engineering Group of the Solid State Division, Mountaintop, Pennsylvania for supplying all of the devices that were tested for this paper and throughout the development of our system. We would also like to express our appreciation to C.J. Nuese for his managerial support.

W. Schneider

Making telescopes is my hobby

The painstaking steps to make a high-quality telescope are pursued by many enthusiasts, who even have an annual convention. This RCA man succeeded after 13 years.

I have had a lifelong interest in astronomy, but my hobby of making telescopes started in 1955, when I enrolled in a mirror-making class at the Hayden Planetarium, sponsored by the Amateur Astronomers Association of New York. These classes, which still continue, teach students how to grind, polish and figure a six-inch paraboloidal mirror of 48-inch focal length.

After finishing the mirror, the next couple of years were spent designing and building a mount to make the mirror into a telescope. In my case, I decided to make a Springfield mount. This type of mount enables the observer to sit in a fixed position, while the telescope may be turned to any direction. Unfortunately, the Springfield design results in a rather large and unwieldy telescope, difficult to move in and out of the house.

I then became familiar with the catadioptric telescope, which uses a system of mixed lens and mirrors. The catadioptric telescope is based on the principle of optical folding, hence, a much shorter lens barrel can be used for a given focal length. The compactness of the design intrigued me, so I decided to construct a telescope with a focal length of 94.5 inches. For this large focal length the lens barrel is a mere 15.5-inches long.

As noted previously, I began my hobby by learning how to make a telescope mirror. The art of making a mirror is not all that hard, but it does require plenty of patience and a careful touch. Making a lens, however, is considerably more difficult. It entails grinding and polishing two surfaces that must be concentric to one another, with the lens thickness held to very accurate tolerance.

Along the way, I became fascinated with the commercial "Questar" catadioptric telescope so I decided to include all of its features in my telescope. Therefore, I added a built-in "finders lens," doubling lens, and a focusing mechanism that functions by moving the mirror rather than the eyepiece.

As is often the case when biting off more than one can chew, I wound up buying a secondhand lathe, a bench grinder, and a drill press. Then I went through the process of teaching myself to become

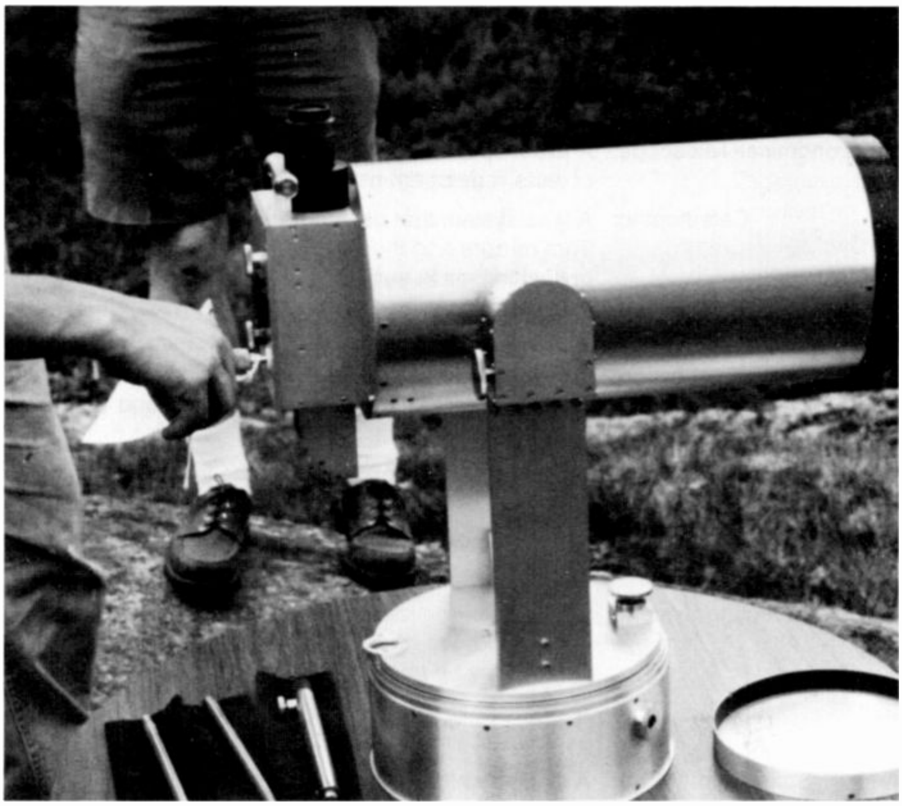

Fig. 1. The telescope, in altazimuth position, at the 1980 Stellafane Convention of amateur telescope makers. The convention is held on a hilltop near Springfield, Vermont. Professionals often come here to learn new techniques.

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a machinist, all as a prelude to constructing my dream telescope.

From the inception of the idea to make a catadioptric telescope to its completion took thirteen years, but I now have the satisfaction of knowing that it came out the way I wanted it. In addition to the personal satisfaction I gained by making the telescope, it was also a great pleasure to be awarded the first prize for "mechanical excellence" at the 1980 Stellafane Convention, held in Springfield, Vermont. A view of the telescope, with identification tag, is shown in Fig. 1. Other views of the complete telescope, mounted in equatorial position on top of a small table in my living room, are shown in Figs. 2 and 3. The pieces that comprise the telescope are shown in Fig. 4. The additional parts of the control box are shown in Fig. 5. The perforated mirror, before aluminizing, is shown. The meniscus corrector lens is shown in its cell; the brass tubing that carries the mirror for focusing is shown; and the main telescope tube with the dew and lens caps is shown. Parts for the side-arm supports and base mounting, the base parts, and telescope in the equatorial attitude, are shown. The single-lens-reflex camera coupler and its component parts, the declination control and setting circle parts are shown. Note the slow-motion control gear, and the ascension control parts, magnifying index and calibrated setting circle. For an idea of the construction time involved in making some of the

Fig. 2. Telescope, in the equatorial position.

Fig. 3. Another view of the telescope in the equatorial position.

Glossary of telescope terms

Altazimuth Mounting:	A telescope mounting providing for rotation about a vertical axis (azimuth) and about a horizontal axis (altitude).
Ascension:	That portion of the telescope mounting that permits adjustment of the telescope for viewing in an arc from the horizon to the celestial body.
Astronomical Telescope:	A telescope intended for use in observing celestial objects. It does not contain an erecting system.
Catadioptric:	A lens system that uses both the reflection of light from mirrors and the refraction of light through optical lenses in such a way that the physical length of the telescope lens barrel is considerably shortened to obtain focus.
Declination:	One of the coordinates used for locating heavenly bodies, it represents the distance North and South of the celestial equator.
Dew Cap:	A cap used to cover the telescope lens to prevent the formation of dew on the lens surface.
Equatorial Mounting:	A telescope mounting so arranged that one of its axes is parallel to the axis of the earth.
Erecting System:	A subsidiary optical system in an instrument, used for the purpose of erecting an image. Prisms or lenses may be used.
Meniscus Lens:	A lens whose surfaces have curvatures in the same direction.
Springfield Mount	A design which permits the observer to sit in a fixed position while the telescope moves to compensate for the earth's rotation.

Fig. 4. All the parts that make up the telescope.

Many old RCA hands will recognize the 44BX microphone mounted on the plaque, a fitting testimonial to Bill's NBC career and its origin in radio. The other microphone in the photo was used by Bill to express his heartfelt appreciation to all those who came to wish him well at his retirement. But Bill reminded them all, that his retirement would be like one of the old radio serials, it would go on and on — and on.

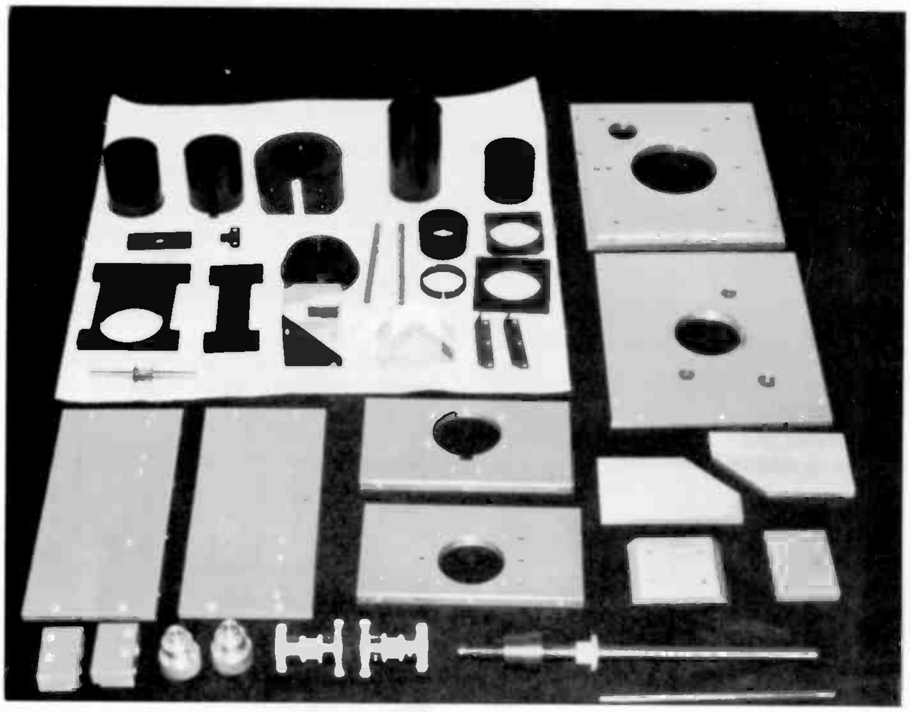


Fig. 5. All the parts that make up the control box.

parts, it may be noted that the ascension-setting circle on the right took one day to machine and two days to engrave.

As we can see from the photographs, anyone with a bit of mechanical skill, a certain amount of leisure time, and a penchant for "doing it yourself," can make his own high quality telescope.

Bill Schneider worked for three years at the Western Electric Company until called to serve in the U.S. Army, in 1943. Back as a civilian, he rejoined Western Electric in June, 1946, where over the next five years he worked on Central Office switching systems. But the challenges of telephone switching system construction paled before the attraction of joining NBC in December 1951. After a year of audio maintenance work, he became a part of a newly-formed maintenance construction group and continued in that group until 1965. In 1965, Bill joined the Audio Video construction group, as it was then known. He retired in 1981 as Construction Supervisor with the Broadcast Systems Group within the Engineering Department.

Patents

Astro-Electronics

Bilsky, H.W. | Callen, P.J.
Battery charging system—4313078

Goldberg, E.A.
Frequency synthesizer incorporating digital frequency translator—4303893

Consumer Electronics

Bridgewater, T.A.
Continuous tuning arrangement for a multiband television receiver—4307467

Miller, M.E.
Stylus tracking aid using two bimorph elements longitudinally aligned—4310913

Willis, D.H.
Raster distortion corrected deflection circuit—4305023

Yost, T.D.
Keying signal generator with false output immunity—4313130

Government Communications Systems

Clanton, J.A.
Skylight cover—4307549

Nossen, E.J.
Symbols communication system—4306308

Laboratories

Avins, J.Y.
Incremental encoder for measuring positions of objects such as rotating shafts—4308500

Bartolini, R.A. | Burke, W.J. | Bloom, A.
Method of recording an ablative optical recording medium—4313188

Bloom, S. | Catanese, C.A.
CRT with dipolar deflection and quadrupolar-focusing color-selection structure—4311944

Boyer, L.A.
Magnetic variable capacitor—4312025

Carnes, J.E. | Woods, M.H.
Nonvolatile semiconductor memory device and method of its manufacture—4307411

Carroll, C.B. | Schneller, R.E.
Frontplate and shadow mask assemblies for a modular flat panel display device—4308484

Clark, J.F.
Self-heated solenoid—4306704

Dieterich, C.B.
Video disc system—4308557

Gange, R.A.
Line cathode structure having recessed geometry—4308486

Groeneweg, W.H.
Signal processor for beam-scan velocity modulation—4309725

Hinn, W.
Dual standard PAL-SECAM receiver circuitry—4309719

Hsu, S.T.
Method of manufacturing submicron channel transistors—4312680

Hsu, S.T.
Electrically programmable logic array—4313106

Johnson, H.C.
Ranging radar including a modulating reflector—4306236

Kleinknecht, H.P. | Bosenberg, W.A.
Optically testing the lateral dimensions of a pattern—4303341

Lang, F.B. | Gibson, J.J. | Ross, M.D.
Non-linear aperture correction circuit—4312013

Lock, B.E.
Method and apparatus for coating recorded discs with a lubricant—4309456

Matey, J.R. | Corson, C.R.
Video disc signal surface imaging apparatus—4307419

McGuffin, W.G.
Stylus position sensor for video disc player apparatus—4313189

Nelson, J.R.
Gas adsorption apparatus for determining the gaseous surface area of a material—4305291

Palmer, R.C.
Video disc player noise reduction circuit—4309722

Riddle, G.H.
Skipper-assisted active search—4310914

Roach, W.R. | Henderson, W.C.
Asymmetrical radiation exposure of spin coated photoresist to obtain uniform thickness coating used to replicate spiral grooves in plastic substrate—4306013

Roach, W.R. | Meyerhofer, D.
Uniform light exposure of positive photoresist for replicating spiral groove in plastic substrate—4308337

Sheng, P.
Optimal polarization for the optical readout of high density video recording—4310910

Spong, F.W.
Multilayer record blank for use in optical recording—4305081

Sterzer, F. | Paglione, R.W.
Nonsymmetrical bulb applicator for hyperthermic treatment of the body—4311154

Missile & Surface Radar

Bowman, D.F.
Transmission line hybrid junction—4310814

Thomson, D.N.
Envelope detector using balanced mixer—4307347

Picture Tube Division

Marett, T.A., Jr.
Television display system incorporating a coma corrected deflection yoke—4305055

McGlashan, K.W.
Permeable corrector for deflection yokes—4307363

RCA "SelectaVision" VideoDisc Operations

Christopher, T.J.
Preemphasis and clipping apparatus for reducing distortions—4306256

Christopher, T.J.
Error coding for video disc system—4309721

Hughes, L.M. | George, K.L.
Spindle retracting mechanism for disc record player—4305145

Hughes, L.M. | Stave, F.R.
Disc player having disc stabilizing apparatus—4305146

John, G.
Dual parallelogram cutterhead suspension apparatus—4310915

Mindel, M.J. | Rustman, J.C.
Video disc player system for correlating stylus position with information previously detected from disc—4307418

Prusak, J.J.
Cathode mask knob—4309265

Rustman, J.C. | Mindel, M.J.
Track error correction system as for video disc player—4313134

Stephens, J.W. | Yang, K.
Horizontal stability measurement apparatus—4303939

Weaver, C.A.
Method for the manufacture of stampers—4305795

Whitehurst, M.L.
Method for the manufacture of capacitive electronic discs—4305791

Wilber, J.A. | Christopher, T.J.
Bidirectional deflector driver for video disc—4313062

Solid State Division

Cardinal, R.E.
Coaxially mounted high frequency light detector housing—4309717

Faulkner, R.D. | McHose, R.E.
Focusing structure for photomultiplier tubes—4306171

Faulkner, R.D. | McHose, R.E.
Alkali antimonide layer on a beryllium-copper primary dynode—4311939

Gubitose, N.F. | Zelinka, M.J.
Method of and apparatus for outgassing raw material used to grow crystals—4305725

Ibaugh, J.L.
Photomultiplier tube having a photocurrent collector—4306188

Khajezadeh, H.
MNOS memory device and method of manufacture—4305086

Kucharewski, N.
IC clamping circuit—4307306

Leidich, A.J.
Amplifier circuit having controllable gain—4305044

Madajewski, J.A. | Mickowski, T.S.
Kelvin test fixture for electrically contacting miniature, two terminal, leadless, electrical components—4308498

McDonie, A.F.
Method for expeditiously processing a sodium-potassium-cesium-antimony photocathode—4305972

Pierfederici, A.J.
Plasma etching device and process—4304983

Schade, O.H., Jr.
Compensation for transistor output resistance—4311967

Wilson, R.E.
Low power switch closure sensing circuit—4303907

Pen and Podium

Recent RCA technical papers and presentations

To obtain copies of papers, check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint.

Advanced Technology Laboratories

G. Ammon | C. Reno
Optics for Multibeam Optical Disc Systems—Presented at International Technical Symposium of SPIE, San Diego, Calif., published in *Proceedings* (8/24-28/81)

G. Ammon | F. Kenville | M. Nigro | C. Reno
300 MBPS Optical Disc Recording System—Presented at 13th Annual Electro-Optics Laser '80 Conference, Anaheim, Calif., published in *Proceedings* (11/7-19/81)

F. Borgini | B.A. Suskind
CMOS/SOS Automated Universal Array—*IEEE Journal of Solid State Circuits* (10/1981)

W. Heagerty
A CMOS/SOS Successive Approximation A/D Converter for Radiation Environments—Presented at the SOS Workshop, Sun River, Oregon (10/6-8/81)

Helbig, W.
Four Well Chosen Bits—Presented at 1981 Naval Undersea Surveillance Symposium, Monterey, Calif., published in *Proceedings* (7/21-24/81)

R. Kenville
Digital Data Optical Disc Systems Video Disc Systems and Applications—Presented at IGC Conference on Optical Video Disc Systems and Applications, Carmel, Calif. (7/19-21/81)

H. Li
The Impact of Process Interconnection on the Global Bus Architecture—Presented at Realtime Symposium, Miami Beach, Fla., published in *Proceedings* (12/8-10/81)

H. Li (M. Mickle, UP/W. Vogt, UP)
Decentralized Load Flow Algorithm for Large Scale Power System—Presented at 19th Allerton Conference on Communication, Control & Computing, Urbana, Ill., published in *Proceedings* (9/30-10/2/81)

W. Schaming | G. Flachs
R. Skevington (NMSU)
Realtime Statistical Tracker for IR Focal Plane Array—Presented at International Symposium of SPIE, San Diego, Calif., published in *Proceedings* (8/24-28/81)

D.C. Smith | R. Noto
Automatic Layout Program for Hybrid Microcircuits (HYPAR)—Presented at ISHM '81, Chicago, Ill., published in *Proceedings* (12/8-10/81)

M. Stebnisky
Short Channel CMOS/SOS Technology—Presented at SOS Workshop, Sun River, Oregon (10/6-8/81)

Astro-Electronics

F.H. Chu
Transient Analysis of Structural Members Using a Continuous Space Continuous Time Method—*Computers and Structures*, Nov./Dec. Edition, Vol. 14 (1981)

K. Sabnani | Prof. M. Schwartz (Columbia University)
Performance Evaluation of Multidestination (Broadcast) Protocols for Satellite Trans-

mission—National Telecommunications Conference '81, New Orleans, La. (12/1/81)

Automated Systems

L.R. Armstrong
Non-Contact Sensors for Diesel Engine Test—AUTOTESTCON '81, Orlando, Fla. (10/81)

G.T. Burton | M.J. Cantella | H. Honickman
J.J. Klein | F.F. Martin | N.L. Roberts
Laboratories:
H. Elabd | H. Erhardt | W. Kosonocky
G. Meray | F. Shallcross | T. Villani
IR Imagery from Schottky Barrier Focal Plane Arrays—IRIS Specialty Group Meeting on Targets, Backgrounds, and Discrimination, Moffet Field, Calif. (12/81)

M.J. Cantella
IR Focal Plane Array System Performance Modeling—SPIE's Los Angeles Technical Symposium, Los Angeles, Calif. (1/82)

Automated Systems:
M.J. Cantella | J.J. Klein | N.L. Roberts
Laboratories:
H. Elabd | H. Erhardt | W. Kosonocky
G. Meray | JF. Shallcross | T. Villani
64 x 128-Element High-Performance PtSi IR-CCD Sensor—1981 IEEE International Electron Devices Meeting, Washington, D.C. (12//81)

R.E. Dehm | S.P. Patrakis
Early Life Cycle Cost Tradestudy by Parametric Analysis—SPIE's Los Angeles Technical Symposium, Los Angeles, Calif. (1/82)

J.E. Fay
A Distributed System Architecture for Modular ATE—AUTOTESTCON '81, Orlando, Fla. (10/81)

W.F. Fordyce | L.M. Springer
Calibration of Third Generation ATE Systems—AUTOTESTCON '81, Orlando, Fla. (10/81)

R.C. Guyer | W.C. Stenton
(Ernst Leitz, Canada Ltd.)
Optical Alignment Retention in the AN/GVS-5 Hand Held Laser Rangefinder—SPIE's Los Angeles Technical Symposium, Los Angeles, Calif. (1/82)

D.M. Kulig | R.C. Plaisted | W.K. Shubert
Microprocessor-Controlled Digital Test Subsystem Tailored to Automatic Test Program Generator Output—AUTOTESTCON '81, Orlando, Fla. (10/81)

N. Meliones | R.P. Percoski
Commercial ATE in a Field Environment—AUTOTESTCON '81, Orlando, Fla. (10/81)

P.M. Toscano
Some Management Views on Test Program Set (TPS) Salvageability—AUTOTESTCON '81, Orlando, Fla. (10/81)

Government Communications Systems

A.M. Earman
Optical Focus Servo for Optical Disc Mass Data Storage System Application—Presented at SPIE Technical Symposium, Los Angeles, Calif., published in *Proceedings* (1/25/82)

R.G. Erdmann | P. Basile
Solid State Antenna Switching—*RCA Review*, Vol. 42, No. 4 (12/81)

J. Rothweiler
Implementation of the In-Order Prime Factor Transform for Variable Sizes—Published in *IEEE Transaction Acoustics* (2/82)

Laboratories

D. Botez
Constricted Double-Heterojunction AlGaAs Diode Lasers: Structures and Electro-optical Characteristics—*IEEE Journal of Quantum Electronics*, Vol. QE-17, No. 12 (12/81)

G.W. Cullen | M.S. Abrahams
J.F. Corboy | M.T. Duffy | W.E. Ham*
L. Jastrzebski | R.T. Smith
M. Blumenfeld, RCA Solid State, Palm Beach Gardens
G. Harbeke, RCA Laboratories, Zurich
J. Lagowski, MIT, Cambridge, Mass. (Work carried out under a research contract with RCA Laboratories)
The Characterization of Heteroepitaxial Silicon, *Journal of Crystal Growth*, 56 (1982)
*currently with Wang Tech. Center

B.J. Curtis
Convective Effects in Open-Tube Chemical Vapour Deposition—*PCH: Physico-Chemical Hydrodynamics*, Vol. 2, No. 4 (1981)

S. Freeman
How to Generate a Small-Signal Test Program Set: An Information Theory—(Reprinted from AUTOTESTCON, (11/80)

J.M. Hammer | D. Botez
C.C. Neil | J.C. Connolly
High-Efficiency High-Power Butt Coupling of Single-Mode Diode Lasers to Indiffused $LiNbO_3$ Optical Waveguides—*Appl. Phys. Lett.*, Vol. 39, No. 15 (12/81)

M.L. Hitchman | A.E. Widmer
Semi-Insulating Polysilicon (SIPOS) Deposition in a Low Pressure CVD Reactor—*Journal of Crystal Growth*, 55 (1981)

J. Lagowski, MIT
L. Jastrzebski | G.W. Cullen
Electronic Characterization of Heteroepitaxial Silicon-on-Sapphire by Surface Photovoltage Spectroscopy—(Reprinted from *Journal of the Electrochemical Society*, Vol. 126, No. 12, (12/81))
J. Electrochem. Soc.: Solid-State Science and Technology (12/81)

C.W. Magee
Secondary Ion Mass Spectrometry and Its Relation to High-Energy Ion Beam Analysis Techniques—*Nuclear Instruments and Methods*, 191 (1981)

K. Miyatani
Anion Compression and Material Characterization on Spinel Compounds AB_2X_4 (X = O, S, Se, and Te)—*Proceedings* of the International Conference, Japan (9 & 10/80)

K. Miyatani | K. Minematsu | I. Sato
Cylindrical Parabolic Mirrors Made by Bending Thin Glass Sheets—*Applied Optics*, Vol. 20, No. 20 (10/81)

W. Rehwald
Absence of Dispersion in the Elastic Shear Stiffness c_{44} of Sodium Cyanide—*Physics Letters*, Vol. 87A, No. 5 (1/11/82)

A. Rosen | C.P. Wu
M. Caulton | A. Gombar | P. Stabile
Method of Fabricating High-Q Silicon Varactor Diodes—Reprinted from *Electronics Letters*, Vol. 17, No. 19 (9/17/81)

E.K. Sichel* | P. Sheng**
J.I. Gittleman | S. Bozowski
Observation of Fluctuation Modulation of Tunnel Junctions by Applied ac Stress in Carbon Polyvinylchloride Composites—*Physical Review*, Vol. 24, No. 10 (11/15/81)
*presently at GTE, Waltham, Mass.
**presently at Exxon Res. & Eng'g., Linden, N.J.

H.S. Sommers, Jr.
Threshold and Oscillation of Injection Lasers: A Critical Review of Laser Theory—*Solid State Electronics*, Vol. 25, No. 1 (1982)

H.S. Sommers, Jr.
Spectral Characteristics of Single-mode Injection Lasers: The Power-gain Curve from Weak Simulation to Full Output—*J. Appl. Phys.*, Vol. 53, No. 1, 1982 American Institute of Physics (1/82)

H.S. Sommers, Jr.
Spontaneous Emission Factor β for Injection Lasers—*J. Appl. Phys.*, Vol. 52, No. 2, 1981 American Institute of Physics (12/81)

G.A. Swartz
Computer Model of Amorphous Silicon Solar Cell—*J. Appl. Phys.*, Vol. 53, No. 1, 1982 American Institute of Physics (1/82)

M.L. Tarng
On-Resistance Characterization of VDMOS Power Transistors—Reprinted from International Electron Devices Meeting (12/81)

A.E. Widmer | R. Fehlmann | W. Rehwald
A Calibration System for Calorimetric Mass Flow Devices—*J. Phys. E: Sci. Instrum.*, Vol. 15 (1982)

Missile and Surface Radar

O.G. Allen
Control Charts Revisited—ASQC 25th Annual Symposium, King of Prussia Pa. (11/19/81)

F.J. Buckley
Application of Distributed Computers to a Real-time System—Sacramento State University, Sacramento, Calif. (10/13/81)

F.J. Buckley
Software Quality Assurance—Software Quality Assurance Seminar IEEE, Los Angeles, Calif. (2/22-24/82)

M.W. Buckley, Jr.
Introduction to Project Management—Instructor, IEEE short course via satellite transmission (1/12/82)

W.C. Grubb, Jr.
Electro-Optics for Non-Electrical Engineers—Drexel University, Phila., Pa. (2/82)
George Washington University, Washington, D.C. (2/82)

W.C. Grubb, Jr.
Solid State Electronics for Non-Electrical Engineers—George Washington University, Washington, D.C. (1/15/82)

A.G. Hopper
The RCA Laser Range Pole—An Inverted Plumb Bob—*COORDINATE* (Periodical of New Jersey Society of Professional Land Surveyors), (Winter 82)

W.T. Patton
Low Sidelobe Phased Array Antennas—IEEE Antennas and Propagation Microwave Theory and Techniques Atlanta Chapters Meeting, Norcross, Ga. (1/19/82)

Solid State Division

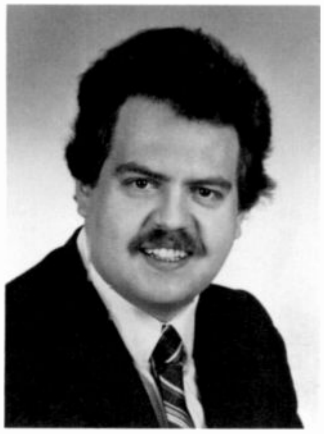
W.F. Allen, Jr. | R. Lydick | R. Glicksman
Radiation Hard CMOS/SOS LSI Circuits for Space Applications—Presented at First Annual Space Electronics Conference, Los Angeles, Calif. (1/28/82)

Engineering News and Highlights

Boose is MSR Ed Rep

Graham D. Boose was recently appointed Editorial Representative for the Missile and Surface Radar Naval Systems Department in Moorestown. She joined RCA in 1966 as a publications engineer in the Advanced Technology Laboratories in Camden. For the past five years, Graham has directed engineer-writer effort on the preparation and publication of AEGIS software and systems support documentation in Moorestown. Her current assignment is Unit Manager, Support Programs Project Engineering in the Computer Programs Development organization of Naval Systems Department. A member of IEEE, she holds a B.A. in mathematics from Randolph-Macon Woman's College and the B.S. in statistics from Villanova University.

Contact her at:
Missile and Surface Radar
Moorestown, N.J.
TACNET: 224-3680



Master named Ed Rep

Edward L. Master, Member of Engineering Staff, has been named Editorial Representative for the Advanced Technology Laboratories, Camden, New Jersey. Mr. Master joined RCA in 1979 and presently works as a Publications Engineer in the Engineering Communications Group. He previously worked as a training specialist/technical writer for the Planning Research Corporation, a Physics instructor in the apprentice training program at the Philadelphia Naval Shipyard, and a science teacher in the Kutztown, Pennsylvania school system. Mr. Master received a B.S. in Earth and Space Science (Secondary Education) in 1972 and is currently pursuing an M.S. in Communications from Clarion State College (Pennsylvania).

Contact him at:
Government Systems Division
Camden, N.J.
TACNET: 222-2731

Staff announcements

Commercial Communications Systems Division

Joseph B. Howe, Division Vice-President and General Manager, Commercial Communications Systems Division, announces the appointment of **Dennis J. Woywood,** Division Vice-President, Broadcast Video Systems.

Consumer Electronics Division

D. Joseph Donahue, Division Vice-President, Operations, announces the appointment of **James E. Carnes,** Vice-President, Engineering.

James E. Carnes, Division Vice-President, Engineering, announces the appointment of **Jack S. Fuhrer,** Director, New Products Laboratory.

Jack S. Fuhrer, Director, New Products Laboratory, announces his organization as follows: **Billy W. Beyers, Jr.,** Manager, Digital Products Development; **Dal F. Griepentrog,** Manager, Project Engineering; **Scott A. Keneman,** Manager, Television Digital Systems; **James L. Newsome,** Manager, Technology Applications; **Richard A. Sunshine,**

Manager, Engineering Systems; **Donald H. Willis,** Manager, Deflection Systems Development; **Craig S. Young,** Manager, Advanced Mechanical Engineering; and **Donald H. Willis,** Acting Manager, Signal Systems Development.

Larry A. Cochran, Director, Signal Systems and Components, announces the appointment of **William A. Lagoni,** Manager, Signal Processing.

Gary A. Gerhold, Manager, Cartridge Manufacturing Operations, announces his organization as follows: **Robert Goldberger,** Manager, High Vacuum Operations; **David W. Keller,** Manager, Quality and Material Control; **Dennis R. McCarthy,** Manager, Manufacturing Engineering; and **Lyndon T. Shearer,** Superintendent, Manufacturing and Test.

C. Wayne Hamilton, Plant Manager, Indianapolis Components Plant, announces the appointment of **Aldo R. Neyman,** Manager, Manufacturing, Indianapolis Components Plant.

Laboratories

Carmen A. Catanese, Director, Picture Tube Systems Research Laboratory, announces the appointment of **Curtis R. Carlson,** Head, Image Quality and Human Perception Research Group.

RCA Global Communications, Inc.

James H. Muller, Director, New York Operations and Engineering, announces his organization as follows: **James McDonald,** Director, New York Operations; **Solomon Nahum,** Manager, Construction and Installation; **Anthony Falco,** Manager, Central Office Engineering; **Alexander Avanessians,** Manager, Customer Engineering; **Robert Ruben,** Manager, Equipment Engineering; **James H. Muller,** Acting Manager, Engineering Administration; and **Joel Spanier,** Administrator, Project Control.

Richard H. Roth, Director, Program Management, announces his organization as follows: **Russell E. Blackwell,** Program Manager, Leased Systems; **Rudolph K. Lang,** Program Manager, Telex Systems; **Kenneth H. Wendt,** Program Manager, Message Switching Systems; and **Richard L. Chory,** Manager, Software Engineering.

Joe Terry Swaim, Vice-President, Switched Services Engineering and Operations, announces his organization as follows: **Richard H. Roth,** Director, Program Management; **William A. Klatt,** Director, Network Operations; **John P. Shields,** Manager, Network Engineering; **Leo A. Tita,** Manager, Administration; **Peter Theodore,** Manager, Safetran Operations; **Richard F. DiBitetto,** Manager, Safetran Maintenance; **Vernon E. Wellington,** Manager, Telex and Data Operations; and **Joe Terry Swaim,** Acting Manager, Service Assurance.

Solid State Division

James K. George, Director, LSI Operations, announces his organization as follows: **Richard W. Ahrons,** Manager, LSI Product Planning; **John A. DeStefano,** Administrator, LSI Administration; **Nicholas Kucharewski,** Manager, LSI Design Engineering; **H. Gene Patterson,** Manager, LSI Product Marketing and Applications Engineering; **Eugene M. Reiss,** Manager, LSI Product Engineering; and **Thomas M. Stavish,** Manager, LSI Manufacturing—Palm Beach Gardens Operations.

H. Gene Patterson, Manager, LSI Product Marketing and Applications Engineering, announces his organization as follows: **Julius S. Lempner,** Manager, Standard LSI Component—Product Marketing; **Joseph Paradise,** Leader Technical Staff, LSI Applications Engineering; and **Jack Yellin,** Manager, LSI Automotive—Product Marketing.

Ronald J. Costlow, Director, Solid State Offshore Manufacturing, announces his organization as follows: **Ralph M. Engler,** Manager, Solid State Operations, RCA Taiwan Limited; and **Russell L. Smith,** Managing Director, RCA Sendirian Berhad (Malaysia).

Obituaries

Edelman, business systems specialist, dies

Franz Edelman died suddenly on January 15, 1982. He learned about the capriciousness of life from his early experiences, fleeing to England from his native Germany at the age of sixteen, only to be interned as an alien and sent to Canada for an interlude of lumberjacking. He received his undergraduate education at McGill University, and he obtained a Ph.D in applied mathematics from Brown University.

Franz joined RCA Corporation as an engineer to apply his knowledge of rheology to the manufacture of phonograph records. In this way, he became involved with computational problems, and was attracted strongly to the use of computers in analysis. Initially, Franz solved physical problems. Rapidly, he came to envision the great value of computer systems in business. He became Director of Operations Research, always balancing analysis and systems to the benefit of both.

Franz always strove to achieve positive results. He would first develop the best interpretation of the facts that he could assemble before him. From that base, he would prepare an orderly and creative plan. Then he would charge into the fray. The result was usually rewarding. He wanted to be personally involved in whatever needed doing. That is why, for instance, he would sit down with a clerk and share the job until he really understood it.

Franz always responded to a legitimate request for help. As a result, he found himself cast in a leadership role over a broad spectrum of activities—community, professional, educational, and religious. That is also why so many people came to him for help and counsel.

A central focus of Franz's life work was computer systems. His reputation is assured by the imaginative way that he organized and used computer systems in the human environment—to permit all activities to be handled by a single system, from analytical to clerical to managerial.

Having become Staff Vice-President of Business Systems and Analysis, Franz retired a year ago after 30 years of service to RCA in order to organize Edelman Associates. In September, he was awarded the SMIS prize for his paper "Managers, Computers, and Productivity," which summarizes much of the experience at RCA in conceiving, designing, and using a live decision-support environment.

Franz actively participated in both ORSA and TIMS, serving TIMS as Vice-President of Finance.

—H. Newton Garber

Epstein, television pioneer, dies

David W. Epstein's entire professional career was devoted to the promotion of RCA's television interests, from 1930 when he joined RCA in Camden until he retired in 1973 at Lancaster. In the early days, he was closely associated with I.G. Maloff with whom he wrote the highly regarded and much-used book, *Electron Optics in Television,* published by McGraw-Hill in 1938. After being transferred to RCA's Princeton Laboratories in 1942, he took a leading role and published papers specifying details of photometry and colorimetry as related to television systems. His work on metal-backed luminescent screens resulted in the doubling of the light output of cathode-ray tubes, a very important consideration from the beginning of television.

Projection television was one of Dr. Epstein's major research projects during his early years with RCA. The problem was to provide larger viewing areas but with adequate brightness. Probably his most important contribution to projection television was his analysis and calculation of the proper correcting lens plates to be used in the Schmidt-type mirror systems, which then provided light-collection efficiencies 6 or 7 times that of an f/2 refractive system. A black-and-white projection system using a 15-ft. by 20-ft. screen and a cathode-ray tube operated at 70 kV was successfully demonstrated in 1941 at the New Yorker Theatre. Although color television projection systems are just now being introduced in various markets, a large-screen color system, developed by Epstein and his associates, was effectively demonstrated at the New Yorker Theatre in 1951. He also participated in the development of color television projectors for the home with demonstrations in 1955.

The accompanying picture shows Dr. Epstein with the "Emmy" award from the Academy of Television Arts and Sciences given to the David Sarnoff Research Center for the RCA color television picture tube as the best engineering technical achievements of 1955 in the field of television. Dr. Epstein had played a leading role in the development of the shadow-mask tube, which was demonstrated to the FCC in 1950, and he accepted the Emmy award on behalf of the many scientists and engineers who contributed to this achievement.

In 1958, Dr. Epstein was transferred to Lancaster, where he became manager of Conversion Tube Operations. He and the Lancaster engineering group were responsible for numerous developments including the vidicon tubes used in the Ranger 7 which provided close-up photographs of the lunar surface; vidicon tubes for the TIROS and NIMBUS weather satellites; high resolution return-beam vidicons for Air Force surveillance and earth resource satellites (ERT's); and photomultiplier tubes for the Gamma Camera used in most major hospitals.

Dr. Epstein was born January 11, 1908, in Russia. He emigrated to the United States after World War I, obtained a B.S. in Engineering Physics from Lehigh University and an M.S. and D.Sc. in E.E. from the University of Pennsylvania. He held memberships in the American Physical Society, the Optical Society of America and Sigma Xi. In 1952, he was made a Fellow in the Institute of Radio Engineers. He died January 28, 1982. Dr. Epstein was a brilliant scientist, a hard-driving manager, and a kindly and personable friend. We all miss him.

—Ralph W. Engstrom

Professional activities

Solid State Division author contributes to book

Kaare Karstad, Member of the Technical Staff, RCA Solid State Microsystems Products Group, Somerville, is a contributor to a recently published book by McGraw-Hill entitled, *Microprocessor Applications Handbook* (David F. Stout, Editor; price, $35.00). The book supplies information and guidance on the design, fabrication, debugging, and testing of a wide variety of microprocessor applications. The chapter authored by Mr. Karstad covers the use of a microprocessor in the control of a TV receiver. This chapter, like the others in the book, gives electronics designers the design concepts, hardware schematics, and software they need to apply a microprocessor to a specific task, including telephony, programmable games, voice recognition, microcomputer-based interfaces, digital filters, hamming code error correction for microcomputers, and some industry-specific applications such as lumber processing. Immediately useful applications data is stressed and theoretical discussion is minimized.

Redfield invited to conference

Dr. David Redfield, a scientist with RCA Laboratories in Princeton, used a grant from the National Science Foundation to participate in a conference, International Workshop on the Physics of Semiconductor Devices, in Delhi, India, held November 23-28, 1981. He was a Member of the International Advisory Committee, Session Chairman, and Invited Speaker at the Plenary Session.

IEEE broadcasts Buckley's course

An IEEE course given by **Merrill Buckley,** Administrator for Planning and Measurement, RCA Missile and Surface Radar, was broadcast to 38 sites across the U.S. on Jan. 12, 1982. More than 600 engineers and managers registered for the day-long course entitled *Introduction to Project Management.*

Buckley spoke to a live audience at the Columbia, S.C., Studios of the South Carolina Educational Television. Students at remote sites passed along questions during the session to a coordinator, who then phoned them to the studio. The course consisted of morning and afternoon 2-hour lectures, with a workshop session in between.

Labs scientists receive NASA awards

Robert V. D'Aiello and **Paul H. Robinson,** Energy Systems Research Laboratory, and **Robert D. Vibronek** and **Werner Kern,** Integrated Circuit Technology Research Laboratory, have been cited by NASA for "the reporting of a scientific or technical contribution approved for publication in a NASA Tech Brief Journal." Dr. D'Aiello and Mr. Robinson were honored for two inventions dealing with solar cells; and Messrs. Kern and Vibronek for development of a sprayable titanium composition.

R.J. Geehan, Jr., appointed Brigadier General, Reserve of the Air Force

Richard J. Geehan, Jr., Commander, Headquarters, Massachusetts Air National Guard, has been recently promoted to Brigadier General, Reserve of the Air Force.

Brigadier General Geehan has been an employee at RCA Automated Systems for about 25 years. He is currently Manager, Project Engineering, Command & Control Program Management Office responsible for integration and test of all Command and Control hardware.

He is one of three generals in the Massachusetts Air National Guard, and is the first non-rated officer in the Massachusetts Air National Guard to be federally recognized as a general. As Deputy Commander, he will be responsible for over 2,500 personnel located at four bases. Units within the state are equipped with the F-106 and the A-10 aircraft.

Fellows recognition dinner

Twenty-four Fellows of the Technical Staff were recently honored at a Fellow Recognition Dinner at the DSRC for their services to RCA Laboratories. **William C. Hittinger,** Executive Vice-President, and **William M. Webster,** Vice-President, RCA Laboratories, presented plaques and gold lapel pins to the Fellows. William H. Barkow, Electron-Optics and Deflection Research, was appointed to the position in 1981. The program included musical selections by the Westminster Singers, a choral ensemble group from the Westminster Choir College.

The rank of Fellow of the Technical Staff was established in 1959 to recognize individual staff members for their continued contributions to both RCA's business and the "state of the art." The designation of Fellow is comparable to the title used by universities and virtually all technical societies.

Annual Automated Systems dinner

On February 18, 1982, Automated Systems held its annual dinner to honor employees who have worked for RCA for 25 years. This year's dinner was held at Anthony's Pier 4 restaurant in Boston. Thirty-four new members were inducted into the 25-year club. Automated Systems now has over 100 employees with over 25 years of service. The gala night featured a brief address by **Paul Wright,** Division Vice-President and General Manager, Government Systems Division; and **Andrew Hospodor,** Division Vice-President and General Manager, Automated Systems, presented the service awards to this year's thirty-four new members.

Burris elected to education society post

Frank E. Burris, Manager, Engineering Education, Cherry Hill, was recently elected Chairman-Elect of the Continuing Professional Development (CPD) Division of the American Society for Engineering Education (ASEE). The CPD Division has a national membership of 900 individuals who share an interest in continuing engineering education. The Division co-sponsors the annual College-Industry Education Conference and supports an extensive publications program in the area of continuing professional development of technical personnel.

RCA Laboratories scientist named "Engineer of the Year"

RCA Laboratories scientist **Dorothy M. Hoffman,** has been named "Engineer of the Year" by the Central New Jersey Engineering Council. Mrs. Hoffman, a member of the technical staff at RCA's David Sarnoff Research Center in Princeton, New Jersey, has spent nearly all her 20-year RCA career in thin-film, high-vacuum-technology research. Currently, she is responsible for evaporated coatings in the newly enlarged thin-film technology group. Applications of evaporated coatings include solar cells, optical video discs, kinescope parts, optical wave guides, semiconductors, and optical elements.

The recipient of two RCA Laboratories outstanding achievement awards, Mrs. Hoffman has also been honored by several professional societies. She was the first woman elected to the Engineers Club in Philadelphia, the first woman officer of the Engineering and Technical Societies of Delaware Valley, and the first woman elected an honorary member of the American Vacuum Society. A member of the board of trustees of the Society of Women Engineers, she is active in student guidance activities.

Mrs. Hoffman received a B.S. degree from Rensselaer Polytechnic Institute and an M.S. degree from Bucknell University, both in chemical engineering. She has written 17 papers concerning thin-film and high-vacuum technology, and has had three U.S. patents issued to her.

Bartolini elected

Robert A. Bartolini, Solid State Devices Laboratory, RCA Laboratories, was recently elected President of the IEEE Quantum Electronics and Applications Society (QEAS). The QEAS publishes the *IEEE Journal of Quantum Electronics* and sponsors the Conference on Lasers and Electro-Optics, the Optical Fiber Conference, and the International Quantum Electronics Conference.

Technical excellence

Automated Systems Technical Excellence Team Award: Hellfire Test Program Generation Project

From left to right (back row), Andrew T. Hospodor, Division Vice-President and General Manager, **Edward Kramer, Richard Jameson, David M. Priestley,** Chief Engineer, **Sam Mason.** From left to right (back row), **Julian Loui, Robert Dunham, Russell Baldwin, Mark Lacasse, John Haggis. Randy LaRoque** is not pictured.

The pictured RCA personnel who worked on the HELLFIRE ATE Project have been selected for a Technical Excellence Team Award for their combined efforts in developing and successfully demonstrating test program sets for the Hellfire Launcher.

The team from Automated Systems, Burlington, Massachusetts, designed test programs for the Launcher, Electronic Command Signals Programmer and Upper/Lower Harness Assemblies. In addition, they and two sets of breadboard interface accessories and were able to integrate and validate the test program sets in record time. The design of the Launcher test program alone required generations of over 2,100 tests and 39,000 lines of ATLAS code. This is a new record for a single ATLAS program.

Some of the more difficult problems the team was required to solve included:

- Development of a Test philosophy that made use of the Serial Digital Interface of the AAH-64 ATE as a real-time remote terminal to simulate the wing pylon MRTU of the AAH-64 Helicopter.
- Development of test sequences that used, for the first time, the AAH real-time measurement in conjunction with the Serial Digital commands to measure the duration of non-repetitive waveforms.
- Since probing was not allowed for fault isolation, a design requirement for the diagnostic tests was the ability to analyze measured data to deduce which component was faulty. The design resulted in isolation to a single component circuit card for greater than 90 percent of the inserted failures.

The programs performed to the complete satisfaction of both Rockwell International and the military personnel involved and both parties sent letters of commendation to RCA.

Lionel E. Choiniere named MSR 1981 annual Technical Excellence award winner

Left to right: B.J. Matulis, Chief Engineer; W.V. Goodwin, Division Vice-President and General Manager; and Lionel Choiniere.

This year marks a first in annual Technical Excellence awards—the first to a member of our staff working at Lincoln Laboratory. In fact, **Lionel Choiniere** has been with us for more than six years and has never been in the Moorestown plant.

I'm especially pleased with his award, partly because I know something of the struggle our people at Lincoln have in maintaining their identity with Moorestown and feeling part of the Moorestown engineering community. I'm pleased also because Lionel's achievement is clearly outstanding and clearly important—regarded by the Air Force as a major contribution to the science of Space Object Identification. The award citation is as follows:

> For outstanding contributions to the field of Space Object Identification through his development of Doppler Resolved Phase Imaging. With his work as a basis, it is now possible to extract information pertaining to a target configuration and internal mass distribution with far greater accuracy than could be obtained in the past using standard SOI data analysis procedures.

One result of his radar measurement analysis work was an award to the Air Force Foreign Technology Division (FTD) for the most significant analysis performed during 1981. In its letter of appreciation to RCA, the FTD cited the "exceptional expertise of Mr. Choiniere" in fully satisfying all of the requirements of "an extraordinarily complex problem" of ICBM analysis.

—B.J. Matulis
Chief Engineer
Missile and Surface Radar

Consumer Electronics TEC Annual Awards

William Lehmann—for expeditious multiband tuner design in response to late-breaking extended cable-channel tuning requirements. Bill is to be congratulated on his achievement in the face of a substantially shortened schedule, which was essential to maintain marketplace competitiveness.

Bob Lancaster—for the upgrading of RCA's mechanical design evaluation procedures with a quantitative, computer-aided approach leading to improved quality and product reliability.

Randy Clayburn—for development of a new ferrite material and production process to enable advances to be made in television regulated power supplies.

Voldemers Rage—for the successful design and implementation of a new cost-reduced concept of clamping ferrite cores for 110° yoke manufacture.

Bobby Rooks—for providing technical leadership in the analysis of soldering problems in Juarez on the CTC-107/108/110 chassis and being instrumental in the implementation of controls to improve the overall process.

Jim Keeth/Bob Gries—for the development and implementation of a high speed spectrum analyzer for use with the VideoDisc player ATE System—a major task that resulted in a significant reduction in alignment and test time.

MSR's second-quarter 1981 Technical Excellence award winners announced


Azzolina


Choiniere


Sikos

C.M. Azzolina—for his technical contributions in planning, developing, programming, and implementing an automated microwave phase-shifter test station for AEGIS SPY-1A production. The result of his efforts is a highly cost-effective test station with double the test throughput of previous stations and significantly reduced test-labor requirements.

L.E. Choiniere—for outstanding contributions to Space Object Identification (SOI) technology through his development of Doppler-Resolved Phase Imaging. His technique allows extraction of target configuration and internal mass-distribution data with far greater accuracy than possible with standard SOI analysis procedures. The Air Force Foreign Technology Division cited his work as a basis of the most significant analysis achievement of the year.

T.J. Sikos—for his leadership and technical performance in the development of the shipboard AEGIS Post-Training Analyzer system. This new, experimental system—which involved a new compiler, large amounts of new software, and new I/O control interfaces—has fully met all technical objectives. The result is a successful new product and significant enhancement of MSR software system expertise.

MSR's third-quarter 1981 Technical Excellence award winner announced


Lewis

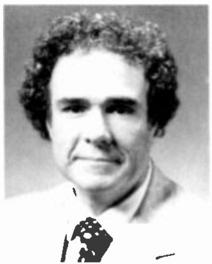
H.D. Lewis has been cited by Missile and Surface Radar for outstanding accomplishments in planning, integrating and directing the highly successful tests of the AEGIS S-band Data Link. Largely as a result of his test program design and subsequent direction, the AN/SPY-1A Radar System clearly demonstrated its ability to control air interceptors effectively in dense ECM, thereby significantly enhancing the potential role of the AEGIS Combat System in battle-group antiair-warfare coordination.

The Mountaintop Technical Excellence Award


Don Burton (left) and John Nelson (right) are recipients of the Mountaintop Technical Excellence Award for February, 1982.

MSR's fourth quarter 1981 Technical Excellence award winners announced


Buder


Campbell


Douglas


Henderson


Johnson

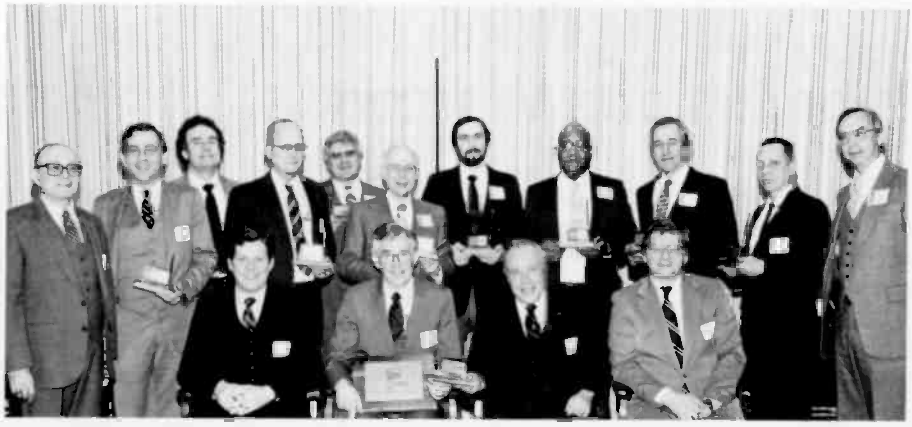
S.H. Buder—for development of a mathematical model for precise, accurate simulation of radar multipath propagation phenomena in a diffuse sea surface environment. His model, developed for evaluation of AN/SPY-1A target tracking algorithms, is also a valid evaluation tool for predicting multipath performance of any monopulse tracking radar over sea surfaces.

J.J. Campbell—for deriving a highly accurate mathematical model for analysis of the electromagnetic circuit resulting from excitation of the new, short-waveguide horn radiator for the EDM-4 antenna. His model was vital to the optimization of radiating element design, evaluation of environmental coatings, and prediction of array performance for all scan angles within the required solid triangle.

J.W. Douglas—for his development of a "rats nest" generator computer program, called RATS, for interactive placement of components on printed wiring boards. His extraordinarily efficient design and use of memory resulted in an average program run of 1 second instead of the typical 20 *minutes* required for the next best alternative. This innovative program is a key element in the success of automated printed wiring board design in MSR.

E.L. Henderson—for design of a precision ferrite phase-shifter driver circuit that meets new performance standards required for AN/SPY-1B antenna operation. In particular, his design of a custom monolithic-control integrated circuit reduced both cost and space, while increasing circuit reliability and producibility.

R.S. Johnson—for formulating and validating a sequence of seven computer programs to provide numerical solutions to the impedance of the new, short-waveguide horn radiator for the EDM-4 antenna. A major contribution to the project was his derivation of roots for extremely unusual waveguide modes that have complex propagation constants.



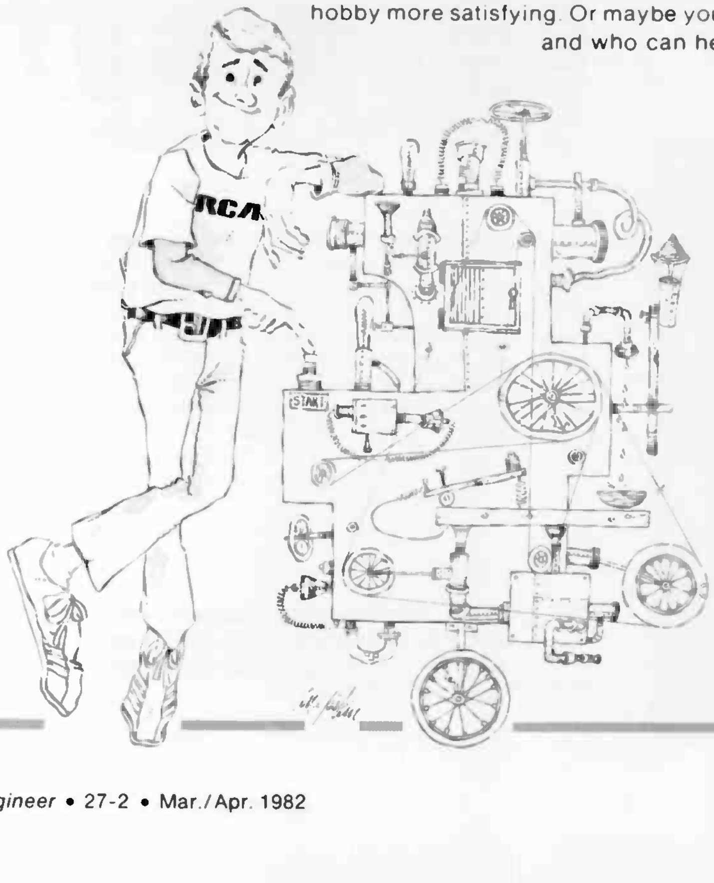
MSR 1981 Technical Excellence Awards Winners. Seated (left to right): **J.J. O'Brien,** Chairman, Chief Engineer's Technical Excellence Committee; **L.E. Choiniere,** 1981 annual Technical Excellence award winner; **W.V. Goodwin,** Division Vice-President and General Manager; **B.J. Matulis,** Chief Engineer. Standing (left to right): **G.R. Field,** Manager, Technical Operations; award winners **H.D. Lewis, J.J. Campbell, S.H. Buder, B.A. Wiegand, J.W. Douglas, T.J. Sikos, E.L. Henderson, E.B. Smith,** and **R.S. Johnson; W.S. Hahn,** Manager, Data Analysis Programs. (Absent award winners: **C.M. Azzolina, J.S. Spencer**).

Proud of your hobby?

Why not share your hobby with others? Perhaps their interest will make your hobby more satisfying. Or maybe you'll find others who already share your hobby and who can help make your own efforts more rewarding.

The *RCA Engineer* likes to give credit to engineers who use their technical knowledge away from the job. We've published articles about subjects as diverse as a satellite weather station, model aircraft and railroading, solar heating, and an electronic fish finder.

For more information on how you can participate in this feature of the *RCA Engineer*, call your local EdRep (listed on the inside back cover of the *Engineer*) or contact Frank Strobl (222-4220).



Engineering Form and Function: Submissions Wanted

Deadline:
May 10, 1982

Do you work with visually interesting materials and outputs? We want to show your technical photographs, unusual line art, and even small and interesting objects in the July/August 1982 Anniversary Issue of the *RCA Engineer.*

This is not a contest. Your contribution will help us present visual correlates to the engineering overviews to be published in the issue. Be sure to attach a 50- to 75-word legend that explains what we are seeing and summarizes the technology and application involved. This legend allows you to give a by-lined technical description (or technical note) on an aspect of RCA technology that otherwise might not merit a full article in the *RCA Engineer.*

Art fluorishes wherever man or his machines create new forms, and in the twentieth century that includes engineering even more than it did in Leonardo da Vinci's time. For example, technology has put powerful visual tools—computer-aided designs, scanning electron micrographs, finite-element models, and so on—at the engineer's disposal. These tools often provide elegant solutions to engineering problems that also approach aesthetic perfection.

Please package your contributions carefully. For example, put flat art and photographs between two pieces of cardboard. Put objects in a box. Then send them to:

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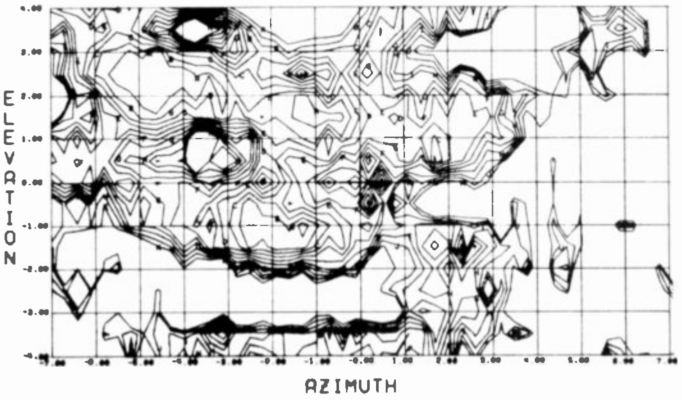
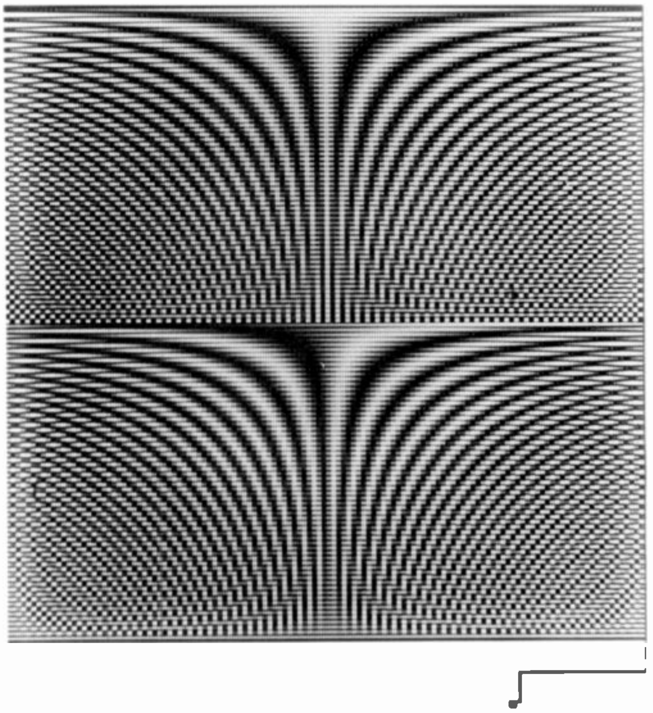


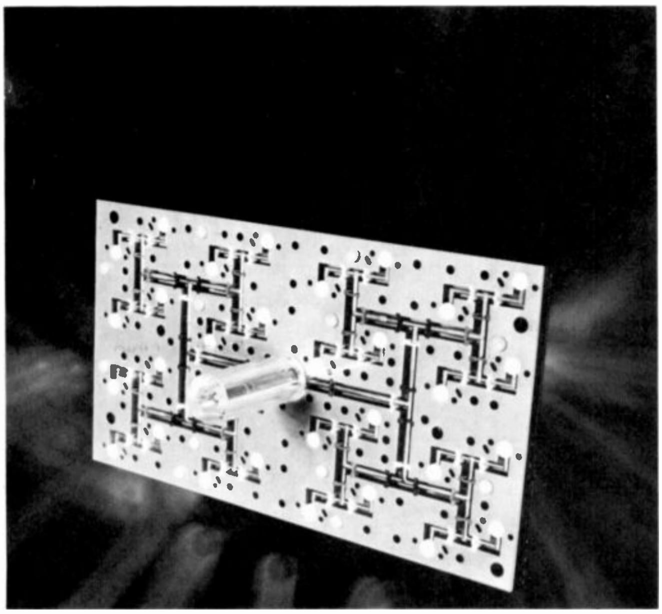
An antenna gain contour plot. This plot represents a Satcom F horizontal cross-polarization gain contour, measured on the engineering test model. Each contour line represents amplitude level relative to an antenna beam peak (0dB). Data acquisition and contour plot was performed on a Scientific Atlanta Antenna Analyzer, Model 2021C.

—*C. Renton*
Astro-Electronics



The Discrete Fourier Transform optical memory mask formed on the surface of the Gated-Output CCD Imager (TC1253). This device and the technology for aligning the pattern of apertures with the sensing portion of the CCD pixels was developed at RCA Laboratories under contract from the Naval Ocean Systems Center for use in an Electro-Optical Signal Processor. This integral mask consists of an evaporated layer of chromium in which the apertures are defined using conventional photo-lithographic technology.

—*A.D. Cope*
RCA Laboratories



Power divider. This 32:1 power divider accepts a single RF input from the radar transmitter and distributes the power into 32 phase shifters and thence to a 32-horn waveguide assembly that is part of the AN/SPY-1A antenna.

R. DiFelice
Missile and Surface Radar

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